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# 2019 Ocean Surface Topography Science Team Meeting

**Monday, October 21 2019 - Friday, October 25 2019**

The 2019 Ocean Surface Topography Meeting will occur 21-25 October 2019 and will include a variety of science and technical splinters. These will include a special splinter on the Future of Altimetry (chaired by the Project Scientists), a splinter on Coastal Altimetry, and a splinter on the recently launched CFOSAT. In anticipation of the launch of Jason-CS/Sentinel-6A approximately 1 year after this meeting, abstracts that support this upcoming mission are highly encouraged.

[Abstracts Book](#)

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## Abstract list

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## Keynote/invited

### OSTST Opening Plenary Session

Mon, Oct 21 2019, 09:00 - 12:30 - The Forum

12:00 - 12:20: [How accurate is accurate enough?](#): Benoit Meyssignac

### Science Keynotes Session

Mon, Oct 21 2019, 14:00 - 15:45 - The Forum

14:00 - 14:25: [Does the large-scale ocean circulation drive coastal sea level changes in the North Atlantic?](#): Denis Volkov et al.

14:25 - 14:50: [Marine heat waves in eastern boundary upwelling systems: the roles of oceanic advection, wind, and air-sea heat fluxes in the Benguela system, and contrasts to other systems](#): Melanie R. Fewings et al.

14:50 - 15:15: [Surface Films: Is it possible to detect them using Ku/C band sigmaO relationship](#): Jean Tournadre et al.

15:15 - 15:40: [Sea Level Anomaly from a multi-altimeter combination in the ice covered Southern Ocean](#): Matthis Auger et al.

## Oral

### Application development for Operations

Wed, Oct 23 2019, 09:00 - 10:30 - The Monroe Hub

09:00 - 09:15: [The Copernicus marine service wave reanalysis : WAVERYS](#): Lotfi Aouf et al.

09:15 - 09:30: [Water-Watch: a New Phase of the Operational Monitoring of Lakes, Wetlands, and River Reaches for Natural Hazards and Regional Security](#): Charon Birkett et al.

09:30 - 09:45: [Utilization of Satellite Altimetry Data in Monitoring Intraseasonal Oscillations in the Indian Ocean](#): Subrahmanyam Bulusu et al.

09:45 - 10:00: [Toward Higher resolution Level3 altimeter products for Assimilation Systems](#): Marie Isabelle Pujol et al.

10:00 - 10:15: [Collaborative Design of Real-Time Displays of Forecast Fields for Targeted End-Users](#): Ted Strub

### CFOSAT

Thu, Oct 24 2019, 11:00 - 12:30 - The Monroe Hub

11:00 - 11:15: [CFOSAT: New wind and wave observations from the nadir and near-nadir SWIM Ku-Band instrument](#): Daniele HAUSER et al.

11:15 - 11:30: [Performance analysis of the SWIM ground-segment solution for retracking nadir echos](#): Annabelle Ollivier et al.

11:30 - 11:45: [Validation of CFOSAT data in the German Bight and Baltic Sea](#): Luciana Fenoglio et al.

11:45 - 12:00: [Rain flags for SWIM on-board CFOSAT: methods and assessment](#): Bruno PICARD et al.

12:00 - 12:15: [The assimilation of CFOSAT wave data in the wave model MFWAM : Ready for operational use ?](#): Lotfi Aouf et al.

### Coastal Altimetry

Wed, Oct 23 2019, 11:00 - 12:30 - The Monroe Hub

- 11:00 - 11:15:** [Coastal sea level trends and extremes from Delay-Doppler altimetry](#): Luciana Fenoglio et al.
- 11:15 - 11:30:** [Assessment of Sentinel-3A and Sentinel-3B altimeter data in the Coastal Zone](#): Nadim Dayoub et al.
- 11:30 - 11:45:** [Baltic+ SEAL: Building a Sea Level Product for Climate Research in a Region Featuring Jagged Coastline and Sea-ice Coverage](#): Felix L. Müller et al.
- 11:45 - 12:00:** [Volume Transport from In-situ and Altimetry Data Over a Wide Continental Shelf.](#): Loreley Lago et al.
- 12:00 - 12:15:** [Combining coastal altimetry and in situ observations to improve Meridional Overturning Circulation estimates: focus on the Southwestern Atlantic](#): Matthieu Le Henaff et al.

## **Instrument Processing: Measurement and Retracking**

**Tue, Oct 22 2019, 09:00 - 12:30 - The Forum**

- 09:00 - 09:15:** [TOPEX Data Reprocessing using a Numerical Retracking Approach](#): Jean-Damien DESJONQUERES et al.
- 09:15 - 09:30:** [Sentinel-3A, Jason-3 and AltiKa instrumental drifts and their impacts on geophysical estimates](#): Jean-Christophe Poisson et al.
- 09:30 - 09:45:** [On the Effect of Surface Motion in SAR Altimeter Observations of the Open Ocean](#): Alejandro Egido et al.
- 09:45 - 10:00:** [An Investigation of the Impact of Vertical Water Particle Motions on Fully-Focused SAR Altimetry](#): Christopher Buchhaupt et al.
- 10:00 - 10:15:** [Impact of the ocean waves motion on the Delay/Doppler altimeters measurements](#): Laïba Amarouche et al.
- 10:15 - 10:30:** [Reducing the high-frequency noise in Jason-3 and Sentinel-3A SWH data](#): Ngan Tran et al.
- 11:00 - 11:15:** [Sentinel-3A and Sentinel-3B Tandem Phase Evaluation of the Surface Topography Mission Sea State Products](#): Chris Banks et al.
- 11:15 - 11:30:** [First SAR altimeter tandem phase: a unique opportunity to better characterize open ocean SAR altimetry signals with unfocused and focused processing](#): Pierre Rieu et al.
- 11:30 - 11:45:** [Sea-ice freeboard and sea level from altimetry using fast and robust 2 dimensional retracker](#): Sara Fleury et al.
- 11:45 - 12:00:** [Improved Retrieval Methods for Sentinel-3 SAR Altimetry over Coastal and Open Ocean and recommendations for implementation: ESA SCOOP Project Results](#): David Cotton et al.

## **Instrument Processing: Propagation, Wind Speed and Sea State Bias**

**Tue, Oct 22 2019, 14:00 - 15:45 - The Forum**

- 14:00 - 14:15:** [Inspecting Jason-3 and Sentinel-3 WPD over their first 3 years of mission](#): M. Joana Fernandes et al.
- 14:15 - 14:30:** [Altimeter 1D-Var Tropospheric Correction for Sentinel-3](#): Ralf Bennartz et al.
- 14:30 - 14:45:** [Modelling the vertical dependence of the Wet Path Delay: application in satellite altimetry over coastal and inland waters](#): Telmo Vieira et al.
- 14:45 - 15:00:** [Performances and stability assessment of Sentinel3 Microwave radiometers](#): Marie-Laure Frery et al.
- 15:00 - 15:15:** [High Resolution Microwave Radiometer \(HRMR\) on Sentinel-6](#): Shannon Brown et al.

**15:15 - 15:30:** [Next-generation radiometer instruments, algorithms, and uncertainties due to 24 GHz 5G interference](#): Tanvir Islam et al.

## **Outreach, Education and Altimetric Data Services**

**Tue, Oct 22 2019, 14:00 - 15:45 - The Monroe Hub**

**14:00 - 14:15:** [The Latest Updates at PO.DAAC](#): Jessica Hausman

**14:15 - 14:30:** [The ESA CCI Knowledge Exchange: explaining climate from space with altimetry and other EO data](#): Stephen Plummer et al.

**14:30 - 14:45:** [Ocean and Climate Change Education Using Fiction](#): LuAnne Thompson et al.

**14:45 - 15:00:** [Citizen science and volunteers in floateco project](#): Nikolai Maximenko et al.

**15:00 - 15:15:** [Argonautica, altimetry from kindergarten to engineering school](#): Danielle De Staerke et al.

**15:15 - 15:30:** [Outreach & data services showcases](#): All All

## **Precision Orbit Determination**

**Tue, Oct 22 2019, 09:00 - 12:30 - The Monroe Hub**

**09:00 - 09:15:** [CNES POE-F precise orbit performances for the current altimeter missions](#): John Moyard et al.

**09:15 - 09:30:** [Improved orbit time series for the TOPEX and Jason missions from 1992-2019.](#): Frank Lemoine et al.

**09:30 - 09:45:** [Performance of the Jason-2 and Jason-3 GPS Receivers and Resulting GPS-Based Precise Orbit Determination Solutions](#): Shailen Desai et al.

**09:45 - 10:00:** [Copernicus POD Service - Model updates and validation of Sentinel-3 orbit determination](#): Heike Peter et al.

**10:00 - 10:15:** [Precise Orbit Determination of DORIS satellites by CNES/CLS IDS Analysis Center in the frame of the next ITRF](#): Hugues Capdeville

**11:00 - 11:15:** [Performance of dynamic and ambiguity-fixed LEO orbits in SLR validation and network calibration](#): Daniel Arnold et al.

**11:15 - 11:30:** [Analysis of Altimetry satellites SLR residuals](#): Flavien Mercier et al.

**11:30 - 11:45:** [An analytical method to propagate errors in the Altimeter system; from space to Earth \(orbit, reference frame and mean sea level\)](#): Pierre EXERTIER et al.

**11:45 - 12:00:** [Impact of satellite yaw attitude regime on in-flight calibration of low-Earth orbiter GPS antenna phase center](#): Aurore E. Sibois et al.

**12:00 - 12:15:** [Impact of nominal and measured satellite attitude on SLR- and DORIS-derived orbits of Jason satellites and altimetry results](#): Sergei Rudenko et al.

## **Quantifying Errors and Uncertainties in Altimetry data**

**Wed, Oct 23 2019, 14:00 - 15:45 - The Monroe Hub**

**14:00 - 14:18:** [Uncertainties in sea ice thickness products from altimetry. Towards new methods](#): garnier florent et al.

**14:18 - 14:36:** [A new way to assess and represent the error budget for any altimeter mission](#): Pierre Thibaut et al.

**14:36 - 14:54:** [Harmonizing the Jason-1, Jason-2, Jason-3 Time Series of Altimeter Rain Flags](#): Matthieu Talpe et al.

- 14:54 - 15:12: [Lessons learned from Sentinel SARM missions in preparation of Jason-CS](#): Matthias Raynal et al.
- 15:12 - 15:30: [Improving the DAC de-aliasing model by combining with sub-monthly GRACE gravity data](#): Jennifer Bonin et al.

## **Regional and Global CAL/VAL for Assembling a Climate Data Record**

**Wed, Oct 23 2019, 09:00 - 12:30 - The Forum**

- 09:00 - 09:15: [Corsica: A 20+ Years Multi-Mission Absolute Altimeter Calibration Site](#): Pascal Bonnefond et al.
- 09:15 - 09:30: [The Harvest Experiment: New Results From the Platform and Moored GPS Buoys](#): Bruce Haines et al.
- 09:30 - 09:45: [Updated absolute altimeter bias results from Bass Strait, Australia](#): Christopher Watson et al.
- 09:45 - 10:00: [Current Results from Multi-mission Calibrations at the Permanent Facility for Altimetry Calibration in west Crete, Greece attaining Fiducial Reference Measurement Standards](#): Stelios Mertikas et al.
- 10:00 - 10:15: [Comparisons of Jason-3 and Sentinel-3A and tide gauges](#): Eric Leuliette et al.
- 11:00 - 11:15: [Global Calibration and Validation of Reprocessed TOPEX Data](#): Matthieu Talpe et al.
- 11:15 - 11:30: [The first three years of Sentinel-3 altimetry – Reprocessing 2019](#): Remko Scharroo et al.
- 11:30 - 11:45: [Performance of the altimetry constellation: contribution of HY2B mission](#): Sylvie Labroue et al.
- 11:45 - 12:00: [Global Quality Assessment of SARAL/AltiKa's reprocessed GDR-F dataset](#): GHITA JETTOU et al.
- 12:00 - 12:15: [Evaluation and exploitation of CryoSat ocean products for oceanographic studies](#): Chris Banks et al.

## **Science I: Climate data records for understanding the causes of global and regional sea level variability and change**

**Mon, Oct 21 2019, 16:15 - 18:00 - The Forum**

- 16:15 - 16:30: [Estimation and impact of Sentinel-3a GMSL drift on climate-driven studies](#): Michael Ablain et al.
- 16:30 - 16:45: [Uncertainty in Satellite estimate of Regional Mean Sea Level trends](#): Pierre Prandi et al.
- 16:45 - 17:00: [Contributions of atmospheric forcing and chaotic ocean variability to global and regional sea level changes over 1993-2015](#): William Llovel et al.
- 17:00 - 17:15: [Why sea-level swings in the Pacific](#): Y. Tony Song
- 17:15 - 17:30: [Validating Arctic Sea Level Change in the GRACE-era](#): Carsten Ludwigsen
- 17:30 - 17:45: [Extrapolating Satellite Data Records for Short-Term Sea Level Projections](#): Robert Steven Nerem et al.

## **Science II: Large Scale Ocean Circulation Variability and Change**

**Wed, Oct 23 2019, 14:00 - 15:45 - The Forum**

- 14:00 - 14:15: [Surface and Upper Ocean Circulation from the combined use of in situ and space borne observations](#): Sandrine Mulet et al.
- 14:15 - 14:30: [Volume transport and modes of variations of the Malvinas Current at 44.7°S from satellite altimetry and current-meter velocities](#): Martin Saraceno et al.
- 14:30 - 14:45: [The Malvinas Current at the Confluence with the Brazil Current: inferences from 25 years of Mercator Ocean reanalysis](#): Camila Artana et al.

**14:45 - 15:00:** [Causes for the intense interannual upwelling events in the tropical Indian Ocean](#)  
: Weiqing Han

**15:00 - 15:15:** [Remote Forcing of the Benguela Current System](#): Ted Strub et al.

**15:15 - 15:30:** [Attenuating the ocean chaotic variability in altimetric observations: from band-pass filtering to machine learning](#): Thierry Penduff et al.

### **Science III: Mesoscale and sub-mesoscale oceanography**

**Wed, Oct 23 2019, 16:15 - 18:00 - The Forum**

**16:15 - 16:30:** [High-wavenumber variability in the California Current: Evaluating sub-100-km scales with high-resolution altimetry, ADCP, and model output](#): Teresa Chereskin et al.

**16:30 - 16:45:** [Constrained scales in ocean forecasting](#): Gregg Jacobs et al.

**16:45 - 17:00:** [The ocean mesoscale regime of the reduced-gravity quasi-geostrophic model](#): Roger Samelson et al.

**17:00 - 17:15:** [SWOT-ACC, Satellite and ship-based investigation of mesoscale-submesoscale interactions in the Antarctic Circumpolar Current](#): Benoit LEGRESY et al.

**17:15 - 17:30:** [Nonlinear short-term SSH evolution during the 2015/16 El Nino event in the tropical western Pacific](#): Bo Qiu et al.

**17:30 - 17:45:** [Synergetic use of altimetry and surface drifters to increase resolution and accuracy of sea level anomaly and geostrophic current maps in the Gulf of Mexico](#): Sandrine Mulet et al.

### **Science IV: Altimetry for Cryosphere and Hydrology**

**Thu, Oct 24 2019, 16:15 - 18:00 - The Forum**

**16:15 - 16:30:** [Assessment of ICESat-2 Performance over the Arctic Ocean During its First Year in Orbit](#) : Sinead Farrell et al.

**16:30 - 16:45:** [Sentinel-3 LAND Altimetry products and intended evolutions](#): Pierre Femenias et al.

**16:45 - 17:00:** [River levels from multi-mission satellite altimetry, a statistical approach](#): Karina Nielsen et al.

**17:00 - 17:15:** [Status and evolutions of ESA CryoSat data products](#): Jerome Bouffard et al.

**17:15 - 17:30:** [Snow depth on sea ice from altimetry for 2013-2018 Arctic and Austral winters](#): Sara Fleury et al.

**17:30 - 17:45:** [Delivering the Lake Essential Climate Variables - an update from ESA CCI Lakes](#): Jean-François Crétaux et al.

### **The Future of Altimetry**

**Thu, Oct 24 2019, 11:00 - 12:30 - The Forum**

**11:00 - 11:15:** [The altimeter product suite for Sentinel-6/Jason-CS mission](#): Remko Scharroo et al.

**11:15 - 11:30:** [Overview and Status of the Copernicus Polar Ice and Snow Topography Altimeter \(CRISTAL\) Mission](#): Michael Kern et al.

**11:30 - 11:45:** [Observing the Ocean Surface Topography at High Resolution by the Surface Water and Ocean Topography \(SWOT\) Mission](#): Lee-Lueng Fu et al.

**11:45 - 12:00:** [Perspectives for Surface Current reconstruction combining future high-resolution Altimetry and Doppler current data](#): Clement Ubelmann et al.

**12:00 - 12:15:** [First Results of Grazing Angle GNSS-R Altimetry from Sea Ice and Ocean Surfaces Using the Spire CubeSat Constellation](#): Dallas Masters et al.

## The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

Thu, Oct 24 2019, 09:00 - 10:30 - The Monroe Hub

09:00 - 09:15: [Marine Gravity from the first two cycles of the Jason-2 LRO extension of Life mission](#) : Ole Baltazar Andersen et al.

09:15 - 09:30: [ESA's new satellite-only gravity field model via the direct approach \(DIR-R6\)](#): Sean Bruinsma

09:30 - 09:45: [New CNES-CLS18 Mean Dynamic Topography of the global ocean from altimetry, gravity and in-situ data](#): Sandrine Mulet et al.

09:45 - 10:00: [A new combined mean dynamic topography model – DTUHH19MDT](#): Per Knudsen et al.

10:00 - 10:15: [Improvements and limitations of recent mean sea surface models: importance for Sentinel-3](#): Marie Isabelle Pujol et al.

## Tides, internal tides and high-frequency processes

Thu, Oct 24 2019, 09:00 - 10:30 - The Forum

09:00 - 09:15: [Impact of internal tide correction on the DUACS maps accuracy](#): Yannice Faugere et al.

09:15 - 09:30: [Progress towards GOT5: high latitudes and minor constituents](#): Richard Ray

09:30 - 09:45: [Internal tides fate and energy budget off the Amazonian shelf](#): Florent Lyard et al.

09:45 - 10:00: [Decomposition of the multimodal multidirectional M2 internal tide field](#): Zhongxiang Zhao et al.

10:00 - 10:15: [Comparison of global and regional internal tide and gravity wave models with observations](#): Brian Arbic

## Poster

### Application development for Operations

Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery

Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery

APOP\_001: [Multi-Scale Assimilation of Simulated SWOT Observations](#): Joseph D'Addezio et al.

APOP\_002: [Wave Model Confidence Index: A metocean decision support tool](#): Chafih Skandrani et al.

APOP\_003: [CMEMS Level-3 Near-Real-Time Significant Wave Height and Spectral Parameters derived from altimetry and SAR measurements](#): Elodie Charles et al.

APOP\_004: [Assimilation of high frequency altimeter wave data in regional wave model for the french coastal areas](#): Alice Dalphinnet et al.

APOP\_005: [Maximizing the impact of altimetry measurements in data assimilation with a high resolution model](#): Zhijin Li et al.

APOP\_006: [Impact of altimetry observations in the Mercator Ocean real time monitoring and forecasting systems](#): Elisabeth Remy et al.

APOP\_007: [Improving DUACS Sea Level products with CFOSAT and HY2B](#): Yannice Faugere et al.

APOP\_008: [NOAA's Jason Products](#): David Donahue et al.

APOP\_009: [Jason-2 and Jason-3 Near-Real Time Products Latency over the Past Year](#): Donald Richardson et al.



**APOP\_010:** [Satellite altimeter observations of extreme winds and waves, and special editing required for Jason-2 Geodetic Mission data](#): Walter Smith et al.

**APOP\_011:** [New Developments for NOAA's operational upper Ocean Heat Content product suite](#): Deirdre Byrne et al.

**APOP\_012:** [A REAL-TIME PRODUCT TO HELP OCEAN CLEANUP OPERATIONS](#): Nikolai Maximenko et al.

## **CFOSAT**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**CFOSAT\_001:** [Initial Analysis of CFOSAT SCAT and SWIM Data using Relative and Cross Calibration Technique](#): Suchandra Bhowmick et al.

**CFOSAT\_002:** [First results of multi-incidence radar at Ku-band analysis over land surfaces](#): Frédéric Frappart et al.

**CFOSAT\_003:** [Combined wave and wind products based on CFOSAT multi-instrument observations](#): Alexey Mironov et al.

## **Coastal Altimetry**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**COAST\_001:** [A RIP-based SAR Retracker and its application in North East Atlantic with Sentinel-3](#): Salvatore Dinardo et al.

**COAST\_002:** [The new generation of high-resolution X-TRACK/ALES regional altimetry product](#): Fabien LEGER et al.

**COAST\_003:** [Spaceborne coastal altimetry for monitoring slope current intrusion events into the Gulf of Lion](#): Daniele Casella et al.

**COAST\_004:** [Sea level anomalies using altimetry, model and tide gauge along the African coasts in the Eastern Tropical Atlantic Ocean: inter-comparison and temporal variability](#): Habib Boubacar Dieng et al.

**COAST\_005:** [Variability of Coastal circulation in the Gulf of Guinea using altimetry data](#): Kouacou BOSSON et al.

**COAST\_006:** [A new coastal tidal model for Australia](#): Madeleine Cahill et al.

**COAST\_007:** [Improvements in the Validation Techniques Applied to Tide Gauge and Altimetry Observations of Coastal Sea Level Rates](#): Andrew Shaw et al.

## **Instrument Processing: Measurement and Retracking**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**IPM\_001:** [Applying the pulse-pair processing to high PRF nadir altimeter data: sensitivities to geophysical parameters and possible applications](#): Pierre Rieu et al.

**IPM\_002:** [Exploring the potential of Sentinel-3 fully-focused SAR altimeter range data for enhanced detection of coastal currents along the Northwestern Atlantic Shelf](#): Hui Feng et al.

**IPM\_003:** [Evaluation of FF-SAR Altimetry Observations over the Open Ocean](#): Alejandro Egido et al.

**IPM\_004:** [Impact of the Sentinel-3A SRAL PTR Evolution on the L2 Marine Measurements](#): Salvatore Dinardo et al.

**IPM\_005:** [ICESat-2 Altimetry of the Open Ocean](#): James Morison et al.

## **Instrument Processing: Propagation, Wind Speed and Sea State Bias**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**IPC\_001:** [Analysis of surface wind speed from Jason-3 and Sentinel-3A in the Peru-Chile EBUS](#): Orlando Astudillo et al.

**IPC\_002:** [Sea state bias for retracked TOPEX altimeter data](#): Hui Feng et al.

**IPC\_003:** [Understanding the level of error within sea state bias models](#): Alexa Putnam et al.

**IPC\_004:** [A new side-lobe correction for Sentinel-3A Microwave Radiometer: definition and assessment](#): Mathilde Siméon et al.

**IPC\_005:** [From ERA-Interim to ERA5: impact of the latest ECMWF reanalysis in the computation of radar altimeter Wet Path Delays](#): Telmo Vieira et al.

**IPC\_006:** [Small scales variability of the wet tropospheric correction](#): Marie-Laure Frery et al.

**IPC\_007:** [Side-by-side evaluation of Ku- and Ka-band sea state bias variability using Jason-3 and AltiKa data](#): Doug Vandemark et al.

## **Others (poster only)**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**OTH\_001:** [ALTIS: a new tool for processing along-track altimetry data](#): Fabien Blarel et al.

**OTH\_002:** [Monitoring marine litter with ocean current products in the North Atlantic Ocean](#): Muriel Lux et al.

**OTH\_003:** [Operational ocean data assimilation/prediction system for the western North Pacific at JMA](#): Kotaro Mine et al.

**OTH\_004:** [Fundamental Data Records For Altimetry: a reprocessing of ERS-1, ERS-2 and ENVISAT altimeter and radiometer dataset oriented towards dedicated Level 1 and Level 2+ products](#): Pierre Thibaut et al.

## **Outreach, Education and Altimetric Data Services**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**ODS\_001:** [Outreaching hydrology from space & SWOT \(updates\)](#): Vinca Rosmorduc et al.

**ODS\_002:** [RUS: Research and User Support for Sentinel Products](#): Simon Boitard et al.

**ODS\_003:** [Exploring ocean eddy characteristics through the DynEd atlas](#): Yannice Faugere et al.

**ODS\_004:** [TUDaBo: a G-POD service for SAR and RDSAR Products](#): Luciana Fenoglio et al.

**ODS\_005:** [PO.DAAC's Redesigned Web Portal](#): Jessica Hausman et al.

**ODS\_006:** [PO.DAAC in the Cloud: Data Services and Access](#): Jessica Hausman et al.

**ODS\_007:** [Some cool things we do with ERDDAP](#): John Wilkin

**ODS\_008:** [Aviso+ products & services: what's new?](#): Laurent Soudarin et al.

**ODS\_009:** [Feedback loops in product development for Sentinel-3 and Sentinel-6 altimeter missions](#): Remko Scharroo et al.

**ODS\_010:** [Altimetry Applications Program Status](#): Margaret Srinivasan et al.

**ODS\_011:** [SAR and SARin Altimetry Processing on Demand for Cryosat-2 and Sentinel-3 at ESA G-POD:](#) Jérôme Benveniste et al.

**ODS\_012:** [The BRAT and GUT Couple: Broadview Radar Altimetry and GOCE User Toolboxes:](#) Jérôme Benveniste et al.

**ODS\_013:** [NOAA CoastWatch/OceanWatch Altimetry Products:](#) Jessica Burns et al.

**ODS\_014:** [Homogeneous along-track sea level anomalies \(Level-2+\) data set for all altimetry missions :](#) Sabine Philipps et al.

**ODS\_015:** [CTOH altimetry products for ocean, ice and continental surfaces applications:](#) Sara Fleury et al.

## **Precision Orbit Determination**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**POD\_001:** [Single-receiver ambiguity resolution for Sentinel-3 Precise Orbit Determination at the Copernicus POD Service:](#) Emilio Calero et al.

**POD\_002:** [Status of precise orbit determination of altimetry satellites at DGFI-TUM:](#) Sergei Rudenko et al.

**POD\_003:** [Performance of the Sentinel-3 A and B GPS Receivers and associated GPS-Based Orbit Solutions :](#) Aurore Sibois et al.

## **Quantifying Errors and Uncertainties in Altimetry data**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**ERR\_001:** [On denoising satellite altimeter measurements for high-resolution geophysical signal analysis:](#) Yves Quilfen et al.

**ERR\_002:** [Daily harmonics of ionospheric Total Electron Content and implications for single-frequency altimeters:](#) Richard Ray

## **Regional and Global CAL/VAL for Assembling a Climate Data Record**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**CVL\_001:** [Regional in situ CalVal of Sentinel-3 altimeter range at non-dedicated sites:](#) Mathilde Cancet et al.

**CVL\_002:** [CWPIES, a shallow water current, waves and pressure inverted echo sounder for higher resolution satellite altimetry calibration and validation.:](#) Benoit LEGRESY et al.

**CVL\_003:** [In Situ Measurements for Satellite Altimeter Calibration and Validation using LiDAR Systems:](#) Adam Dodge et al.

**CVL\_004:** [Round robin assessment of radar altimeter LRM and SAR retracking algorithms for significant wave height. :](#) Florian Schlembach et al.

**CVL\_005:** [Improving Conventional Altimetry SSH observability: Global assessment of SSH datasets derived from innovative LRM retrackers:](#) Matthias Raynal et al.

**CVL\_006:** [Assessment of Sentinel-3A/B ocean data sets: Recent results of DGFI-TUM's multi-mission cross-calibration:](#) Denise Dettmering et al.

**CVL\_007:** [Results from Independent and Inter-Satellite Calibration and Validation of Jason-3 and Jason-2:](#) Matthieu Talpe et al.

**CVL\_008:** [Jason-2 mission performance:](#) Hélène Roinard et al.

**CVL\_009:** [Jason-3 mission performance towards GDR-F](#): H  l  ne Roinard et al.

**CVL\_010:** [Assessment of the last TOPEX SideB reprocessing](#): H  l  ne Roinard et al.

**CVL\_011:** [CryoSat-2 Long-term Ocean Data Analysis and validation](#): Marc Naeije et al.

**CVL\_012:** [The Altimeter Sea Level Climate Data Record in the Copernicus Climate Service \(C3S\)](#): Jean-Francois Legeais et al.

## **Science I: Climate data records for understanding the causes of global and regional sea level variability and change**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**SC1\_001:** [Relationship between Sea Level and Sea Surface Salinity in the Maritime Continent](#): Severine Fournier et al.

**SC1\_002:** [Impact of 2014-2016 El Ni  o on the South Indian Ocean heat content: local versus remote forcing](#): Denis Volkov et al.

**SC1\_003:** [Investigating vertical land motion and potential systematic errors in altimetry using a filter-based estimation approach](#): Mohammad-Hadi Rezvani et al.

**SC1\_004:** [Investigating sea state trends and variability with new climate-quality satellite altimeter products](#): Ben Timmermans et al.

**SC1\_005:** [Observational constraint on greenhouse gas and aerosol contributions to global ocean heat content changes](#): Benoit Meysignac et al.

**SC1\_006:** [Investigating Regional Sea Level Budget Closure During the Altimeter Era](#): Thomas Harvey et al.

**SC1\_007:** [Extended Global Mean Sea Level Budget Study](#): Hamlington Benjamin et al.

## **Science II: Large Scale Ocean Circulation Variability and Change**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**SC2\_001:** [Using observations of SSH, SST and air-sea turbulent flux of heat to find the depth of the ocean that interact with the atmosphere](#): LuAnne Thompson et al.

**SC2\_002:** [Twenty-five years of Mercator ocean reanalysis GLORYS12 at Drake Passage: performance and volume transport](#): Camila Artana et al.

**SC2\_003:** [Salinity advection and Rossby waves in northern Indian Ocean](#): Xiaosu Xie et al.

**SC2\_004:** [Observations of the Antarctic Circumpolar Current over the Udintsev Fracture Zone, the narrowest choke point in the Southern Ocean](#): Young-Hyang Park et al.

**SC2\_005:** [Forcings of the west African coastal upwelling by ocean and atmosphere intraseasonal waves](#): alban lazar et al.

**SC2\_006:** [A western tropical Atlantic dynamics analysis using statistics and satellite data](#): Sabine Arnault et al.

**SC2\_007:** [Effect of regional water cycle on meridional sea level gradient along the Makassar Strait](#): Tong Lee et al.

## **Science III: Mesoscale and sub-mesoscale oceanography**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

- SC3\_001:** [Nonlocal effects of an unstable ocean current](#): Tom Farrar et al.
- SC3\_002:** [On the Agulhas Bank Circulation](#): Ricardo Matano et al.
- SC3\_003:** [Forced vs Intrinsic variability of the Agulhas Bank circulation](#): vincent combes et al.
- SC3\_004:** [Understanding Regional Trends in Southern Ocean Eddy Kinetic Energy](#): Don Chambers et al.
- SC3\_005:** [PRELIMINARY RESULTS OF FLOATECO: EXPERIMENTAL STUDY OF PHYSICAL AND BIOLOGICAL PROCESSES MAINTAINING THE FLOATING PELAGIC ECOSYSTEM](#): Nikolai Maximenko et al.
- SC3\_006:** [Particle dispersion in a multiple migrating quasi-zonal jet regime: A case study in the eastern North Pacific](#): Oleg Melnichenko
- SC3\_007:** [High-wavenumber variability in the eastern tropical Pacific from ADCP, altimetry, and a high-resolution numerical model](#): Saulo Soares et al.
- SC3\_008:** [Monitoring open sea and coastal ocean dynamics in the Baltic Sea and North East Atlantic](#): Luciana Fenoglio et al.
- SC3\_009:** [Analysis of Second-Order Transverse Structure Functions of Velocity in the Southern Ocean](#): Don Chambers et al.
- SC3\_010:** [A New NRT Mesoscale Eddy Trajectory Atlas on AVISO](#): Antoine Delepoulle et al.
- SC3\_011:** [Improvements of Sentinel-3A altimetry data in the retrieval of sea level variability in the coastal region of the European Seas](#): Antonio Sánchez Román et al.
- SC3\_012:** [Meso to sub-mesoscale variability observed by Sentinel-3A](#): Oscar Vergara et al.
- SC3\_013:** [Spectral content of nadir altimetry at regional scales: a case study in the Bay of Biscay and New Caledonia region](#): Mei-Ling Dabat et al.
- SC3\_014:** [High-Resolution Maps of Sea Surface Height: A new method applied to the California Current system](#): Matthew Archer et al.
- SC3\_015:** [Multiscale Data Assimilation for SWOT Ocean Application](#): Jinbo Wang et al.
- SC3\_016:** [Nested data assimilative modeling of submesoscale variability at the Mid Atlantic Bight Pioneer Coastal Array](#): John Wilkin et al.

## Science IV: Altimetry for Cryosphere and Hydrology

Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery

Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery

- SC4\_001:** [Quality Assessment of the new CryoSat Ice Baseline-D over the Cryosphere](#): Marco Meloni et al.
- SC4\_002:** [An interactive website for enhancing the Open-Loop Tracking Command \(OLTC\) of conventional altimeters for inland waters observation](#): Sophie Le Gac et al.
- SC4\_003:** [Performance of the Sentinel-3 STM constellation over Inland Waters](#): Nicolas TABURET et al.
- SC4\_004:** [Sea ice thickness estimates impact temperature and heat flux estimates in the Arctic Ocean](#): James Carton et al.
- SC4\_005:** [Validation of Lake Water Level from altimetry with in-situ measurements.](#): Beatriz CALMETTES et al.
- SC4\_006:** [Validation of the database of hydrology targets for DEM onboard altimeters \(Jason3, Sentinel-3A and Sentinel-3B\)](#): Léa Lasson et al.

- SC4\_007:** [A remotely-sensed/modeling approach to monitor the the hydro-climatology of the Ogooué River Basin](#): Sakaros Bogning et al.
- SC4\_008:** [Assimilating SWOT virtual discharge and water levels into a large scale hydrological model](#): Vanessa Pedinotti et al.
- SC4\_009:** [Parabola and horizontal line detection in inland water radargrams](#): Léa Lasson et al.
- SC4\_010:** [Enhancing the Sea Ice Thickness and Freeboard Record With Combined Sentinel-3A, Sentinel-3B and CryoSat Observations.](#): Isobel Lawrence et al.
- SC4\_011:** [Towards homogeneous multi-mission altimeter processing in sea ice regions for retrieving SLA and sea ice parameters](#): Jean-Christophe Poisson et al.
- SC4\_012:** [Water level retrieval from Delay Doppler altimetry](#): Luciana Fenoglio et al.
- SC4\_013:** [Are global models correctly estimating water storage in major river basins? A comparison of remote sensed river channel storage and global model data](#) : Steve Coss et al.
- SC4\_014:** [The ICESat-2 Mission: Global Geolocated Photons, and Surface-Specific Data Products](#): Thomas Neumann et al.
- SC4\_015:** [NRT, open-licensed and high-frequency hydrological variables time series in Tropical Basins from operational satellite altimetry](#): Adrien Paris et al.
- SC4\_016:** [CryoSat-2 for enhanced sea-ice thickness and ocean observations in Antarctica CryoSat+ Antarctica](#): Michel Tsamados et al.
- SC4\_017:** [Arctic Altimetric Sea Level Cross-Validation of IceSat-2, SARAL/AltiKa, Sentinel-3 and CryoSat-2](#): Carsten Ludwigsen
- SC4\_018:** [G-REALM: Investigating the Jason-3 and Sentinel-3A Data Sets for the Next Phase of Operational Lake and Reservoir Monitoring](#): Martina Ricko et al.
- SC4\_019:** [A Robust Error Characterization Method for SAR Altimetry over the Inland Water Domain](#): Martina Wenzl et al.
- SC4\_020:** [SPICE: Sentinel-3 Performance Improvement for Ice Sheets](#): McMillan Malcolm et al.
- SC4\_021:** [Sentinel-3 Hydrologic Altimetry Processor prototypE \(SHAPE\): Project achievements](#): Nicolas Bercher et al.
- SC4\_022:** [Quality Status of the CryoSat Data Products](#): Erica Webb et al.

## **The Future of Altimetry**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

- FOA\_001:** [Standardization for Time and Coordinates in Satellite Altimetry](#) : Stelios Mertikas et al.
- FOA\_002:** [Effect of spatio-temporal sampling of altimeter observations in the north Indian Ocean: A synthetic study using ocean model and SWOT simulator](#): Neeraj Agarwal et al.
- FOA\_003:** [MISSION REQUIREMENTS FOR KU/KA-BAND SIGNALS OF OPPORTUNITY ALTIMETRY](#): James Garrison
- FOA\_004:** [WiSA : a Wide Swath Altimetry Mission for Operational Oceanography and Hydrology - A good candidate for of Copernicus-NG Sentinel 3-Top Program](#): Cecile CHEYMOL et al.
- FOA\_005:** [SMASH: a Constellation of Small Altimetry Satellites Dedicated to Hydrology](#): Denis BLUMSTEIN et al.

**FOA\_006:** [Altimetry over inland waters: current achievements thanks to the Open-Loop Tracking Command \(OLTC\) and perspectives for future missions](#): Sophie Le Gac et al.

**FOA\_007:** [Combining Fully Focused and Swath Processing for Glacier applications](#): Albert Garcia-Mondejar et al.

## **The Geoid, Mean Sea Surfaces and Mean Dynamic Topography**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**GEO\_001:** [GOCE User Toolbox and Tutorial](#): Per Knudsen et al.

**GEO\_002:** [NEW CNES CLS 2019 MEAN SEA SURFACE: FIRST VALIDATION](#): Philippe Schaeffer et al.

**GEO\_003:** [THE NEW CNES-CLS 2019 MARINE GRAVITY ANOMALY MODEL: FIRST VALIDATION IN THE MEDITERRANEAN](#): Philippe Schaeffer et al.

**GEO\_004:** [Geomed2: High-Resolution Geoid Models of the Mediterranean](#): Sean Bruinsma

## **Tides, internal tides and high-frequency processes**

**Tue, Oct 22 2019, 16:15 - 18:00 - The Gallery**

**Thu, Oct 24 2019, 14:00 - 15:45 - The Gallery**

**TID\_001:** [Bathymetry improvement and tidal modeling in the North East Atlantic Ocean and in the Mediterranean Sea](#): Mathilde Cancet et al.

**TID\_002:** [Coastal tides and sea level variations at high latitudes from GNSS-R and satellite altimetry](#): Ole Baltazar Andersen et al.

**TID\_003:** [The effect of horizontal resolution and wave drag on tidal baroclinic mode waves in realistic global ocean simulations](#): Maarten Buijsman et al.

**TID\_004:** [Using Complex-Demodulation to Identify Non-Phase-Locked Tides from Reference-Mission Altimetry](#): Edward Zaron

**TID\_005:** [De-aliasing of tidal signals using wide-swath sun synchronous orbits](#): Loren Carrere et al.

**TID\_006:** [Last TUGO model simulations and perspectives of evolution of the Dynamic Atmospheric Correction for altimetry](#): Loren Carrere et al.

**TID\_007:** [Mapping Internal Tides from Satellite Altimetry without Blind Spots](#): Zhongxiang Zhao

**TID\_008:** [Temporal variability of the mode-1 M2 internal tide](#): Zhongxiang Zhao et al.

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## **Abstract details**

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# How accurate is accurate enough?

**Benoit Meyssignac (CNES/LEGOS, France)**

**Session:** OSTST Opening Plenary Session

**Presentation type:** Keynote/invited

## **Abstract:**

After 26 years of research and development, the sea level estimates derived from satellite altimetry measurements have reached a level of maturity that is unprecedented. Among the ECVs measured from space, sea level is arguably one of the most advanced with a quasi global coverage, a very low ratio of missing or corrupted data, an advanced estimate of the uncertainties which accounts for the time-correlation in errors, a robust validation (through both the comparison with tide gauge records and the closure of the sea level budget) and a very high accuracy which exceeds the altimetry missions' requirements. This level of maturity make wonder about the real need of further research to improve the sea level record and in particular the sea level estimates' accuracy. Simply put the question gets down to: How accurate is accurate enough? This question is important for the ocean surface and topography science team as a significant amount of resources is currently used to keep on improving the sea level record accuracy.

In this presentation I explore the question of the accuracy that should be targeted in satellite altimetry. I review the literature and summarize the current scientific questions associated to the sea level science. For each scientific question I analyse the litterature and derive from recent papers the level of accuracy in sea level estimates that is needed to tackle the question. I focus on climate science questions as climate science is arguably the field that needs the highest level of accuracy in sea level estimates. I find that four major science questions need an accuracy in sea level or in its contributions that is close or higher than the current available accuracy. These questions are the closure of the sea level budget, the estimate of the Earth energy imbalance, the observational constraint on projections of future sea level and the estimate of sea level rise in coastal zones. With this list of science questions and the level of accuracy they require from sea level observations, I am able to propose to the OST science team and the satellite program managers a simple answer to the question "How accurate is accurate enough?". This answer is: Tell me which scientific question you want to tackle in the list and I will tell you how accurate is accurate enough?

## **Corresponding author:**

**Benoit Meyssignac (CNES/LEGOS, France)**, benoit.meyssignac@legos.obs-mip.fr

# Does the large-scale ocean circulation drive coastal sea level changes in the North Atlantic?

**Denis Volkov (NOAA-AOML/University of Miami, United States); Sang-Ki Lee (NOAA-AOML, USA); Ricardo Domingues (NOAA-AOML / University of Miami, USA); Marlos Goes (NOAA-AOML / University of Miami, USA)**

**Session:** Science Keynotes Session

**Presentation type:** Keynote/invited

## **Abstract:**

While the global mean sea level is rising, ocean and atmosphere dynamics make sea level change spatially and temporally nonuniform. On interannual and longer time scales, the ocean exhibits certain patterns of sea level change with alternating signs over different time periods. These patterns are relatively small amplitude, however, they can extend to coastal regions and provide background conditions favorable for the occurrence of extreme sea levels that represent a threat for coastal communities, especially in low-lying and flood-vulnerable regions. In this study, we show that the gyre-scale circulation in the North Atlantic, associated with the Atlantic Meridional Overturning Circulation (AMOC) and meridional redistribution of heat, is related to a tripole mode of sea surface height (SSH) variability, with the subtropical band varying out-of-phase with the tropical and subpolar bands (see figure enclosed). Observations of the AMOC at 26.5N are representative for heat exchange between the tropical and subtropical bands of the tripole. We demonstrate that a reduction/strengthening of the AMOC transport at this latitude leads to heat divergence/convergence in the subtropical/tropical band. On one hand, the associated anomalies in the thermosteric sea level in the tropical band extend along the northwest coast of Africa towards the Strait of Gibraltar and, thus, can impact sea level in the Mediterranean. On the other hand, the thermosteric sea level anomalies in the subtropical band of the tripole are largely responsible for interannual to decadal changes of coastal sea level south of Cape Hatteras and in the Gulf of Mexico. The SSH tripole appears to explain 60-80% of the coastal sea level variance in these regions. Using an ocean data synthesis product, we further demonstrate that the temporal evolution of the SSH tripole mode in 1993-2018 is largely driven by the large-scale heat divergence related to the AMOC and linked to the low-frequency North Atlantic Oscillation.

## **Corresponding author:**

**Denis Volkov (NOAA-AOML/University of Miami, United States)**, [denis.volkov@noaa.gov](mailto:denis.volkov@noaa.gov)

# Marine heat waves in eastern boundary upwelling systems: the roles of oceanic advection, wind, and air-sea heat fluxes in the Benguela system, and contrasts to other systems

**Melanie R. Fewings (Oregon State University - College of Earth, Ocean, and Atmospheric Sciences, United States);** P. Ted Strub (Oregon State University - College of Earth, Ocean, and Atmospheric Sciences, United States); Craig Risien (Oregon State University - College of Earth, Ocean, and Atmospheric Sciences, United States); Corinne James (Oregon State University - College of Earth, Ocean, and Atmospheric Sciences, United States); Carlos Moffat (University of Delaware - School of Marine Science and Policy, United States); Kevin S. Brown (Oregon State University - Department of Pharmaceutical Sciences and School of Chemical, Biological, and Environmental Engineering, United States)

**Session:** Science Keynotes Session

**Presentation type:** Keynote/invited

## **Abstract:**

The coastal ocean off southwest Africa experiences interannual warming events known as Benguela Niños (Shannon et al. 1986). These events have important ecological effects on the Benguela coastal upwelling system. However, a qualitatively different type of warm water anomaly occurred during the 2016 January-March upwelling season (Lübbecke et al., 2018). This warm event ended earlier in the year than typical Benguela Niños. Sea-surface temperature (SST) anomalies exceeded 3°C. Here, we examine the sea-surface height (SSH) anomalies and atmospheric forcing during this and other warm water anomaly, or marine heat wave (MHW), events during 2000–present in the Benguela upwelling region. We compare the Benguela MHWs to MHW events observed in the California and Chile-Peru upwelling systems over the past 20 years.

Strong regional spatial variability is observed in MHWs in coastal areas worldwide, but is largely unexplained. Therefore, the scientific community presently has little to no ability to predict the timing or location of future MHWs that could have major economic and ecological impacts. Our previous work in the California Current upwelling system indicates that coastline shape, via its influence on the wind stress field, explains regional variability within MHWs in summer and could give predictability for the spatial pattern of future MHWs in that upwelling system. A direct relationship between wind stress and SST anomalies existed during a MHW off California in July 2015 because the net air-sea heat flux anomalies were small in the region of warm water anomaly. In a new project, we are working to determine whether the above relationships hold during other MHW events in the California and Chile-Peru upwelling systems. Here, we extend this analysis to the Benguela upwelling region, and also examine the role of along-coast advection of warm water during MHWs.

We include an overview of the statistics of MHW occurrences in the Benguela region during 2000–present. We present climatologies and anomalies of SST, satellite ocean vector wind stress from QuikSCAT and ASCAT, objectively analyzed air-sea fluxes from OAFlux, radiative fluxes from CERES, and sea level anomalies from satellite altimetry offshore of the Benguela upwelling region. Examining MHW and wind events on shorter time scales than the monthly anomalies used in most previous studies allows diagnosis of the relative importance of changes in ocean advective heat fluxes, air-sea fluxes, and wind stress in structuring MHW in the Benguela region during the summer upwelling season.

## **Corresponding author:**

**Melanie R. Fewings (Oregon State University - College of Earth, Ocean, and Atmospheric Sciences, United States),** melanie.fewings@oregonstate.edu

# Surface Films: Is it possible to detect them using Ku/C band $\sigma_0$ relationship

Jean Tournadre (IFREMER, France); Douglas Vandemark (University New Hampshire, USA)

**Session:** Science Keynotes Session

**Presentation type:** Keynote/invited

## Abstract:

Most altimeters operate at dual frequencies, Ku (13.5GHz) and C (5.3GHz) bands. The relationship between the two backscatters has been used to detect altimeter samples affected by rain using the differential attenuation of the signal by liquid water. The KU-C band relationship contains much more information than the rain attenuation. The analysis of Jason1 and 2 and Envisat data during the Deep Water Horizon oil spill and the comparison with oil spill thickness and extent data showed that the presence of oil spills on the sea surface can distort the altimeter waveforms and cause 'blooms' in the radar backscatter cross-section signal, but compresses the surface capillary wave and reduce the  $\sigma_0$  in SAR imagery.

The comparison of high resolution surface  $\sigma_0$  obtained by waveform inversion method and ERMA oil cover fields showed that locally the Jason-1/2 Ku band  $\sigma_0$  increased up to 10 dB in low wind speed. At low wind speed ( $<3 \text{ m.s}^{-1}$ ), the mean  $\sigma_0$  in Ku and C bands increased by 1.0 to 3.5 dB for thick oil and 0.9 to 2.9 dB for thin oil while the waveforms are strongly distorted. At medium winds (up to  $6 \text{ m.s}^{-1}$ ) the mean  $\sigma_0$  bloom and waveform distortion in both Ku and C bands weakened for both thick and thin oil. For larger winds ( $> 6 \text{ m.s}^{-1}$ ) only does the Ku band  $\sigma_0$  slightly increase by 0.2-0.5 dB for thick oil.

A further analysis reveals that surface films have a differential impact at Ku and C band depending on the existing surface roughness (due to wind) and film thickness. This differential impact reflects in the Ku-C band relationship by modifying the departure from the "normal" Ku-C band relation. The presence of a film tend to increase the Ku band backscatter more than the C band one, i.e. the Ku band roughness (2cm) is more suppressed than the C (6cm) band one. The difference (dS) between the measured Ku band  $\sigma_0$  and the Ku  $\sigma_0$  estimated from the C band using the mean KU/C band relationship becomes significantly larger than that without film. In general it can exceed 1.8 rms of the relationship. At low wind speed, the Ku/C band relation, i.e. dS above 1.8 rms, could then allow to discriminate between normal low wind conditions and the presence of surface film either biogenic or anthropogenic. Such occurrences are called high dS in the following.

We use the whole Jason2 archive to test the possibility of the detection of surface films on a global scale using Ku/C band relationship. The departure dS at 1Hz has thus been analyzed over the global ocean. Six special regions corresponding to different environmental conditions and number of high dS events have been selected for which the 20 Hz data are analyzed. The distributions of the events are estimated and analyzed in terms of wind speed (from ECMWF), off-nadir angles (to estimate the waveform distortion), Chlorophyll (using coincident daily CHL estimates), SWH ..

In some regions such as the Argentinian basin, there is a clear indication that high dS are associated to high CHL content while other regions like the China Sea high dS can be associated to very low CHL content. As these zone are close to main shipping lanes they might result from anthropogenic film.

The global and regional analysis of the distribution of the relationship departure dS as a function of CHL reveals a clear impact of the presence of biomass on the the dS pdf confirming that the KU/C band can be used to detect surface films at least at low winds.

The global spatio-temporal distribution of high dS on a global will be presented showing the regions of high biomass productivity as well as the impact of human activities in some specific regions.

## Corresponding author:

Jean Tournadre (IFREMER, France), jean.tournadre@ifremer.fr

# Sea Level Anomaly from a multi-altimeter combination in the ice covered Southern Ocean

**Matthis Auger (CLS, France);** Pierre Prandi (CLS, France); Jean-Baptiste Sallée (LOCEAN, France); Amandine Guillot (CNES, France); Gerald Dibarboure (CNES, France); Yannice Faugère (CLS, France)

**Session:** Science Keynotes Session

**Presentation type:** Keynote/invited

## **Abstract:**

For the first time, we construct a gridded Sea Level Anomaly (SLA) product for the open and ice-covered Southern Ocean, based on the combination of high rate measurements from different satellite altimeters.

We benefit from the current constellation using both LRM and SAR data to improve the resolution of SLA fields in ice-covered areas of the ocean. The processing starts from L1b waveforms which are classified using a neural network algorithm to select open ocean and sea-ice leads returns. When possible a dedicated retracking algorithm is used to estimate geophysical parameters, ensuring a processing continuity from the open ocean to ice covered areas. Standard geophysical corrections and a rigorous editing allow to derive valid SLA measurements.

These measurements are mapped on an EASE-2 grid using an objective analysis method. While the mapping is derived from current CMEMS operational processing, its parameters were tuned to match the regional ocean variability.

Daily maps are estimated from 2002 to present, combining measurements from Envisat, Jason-2, Cryosat-2, SARAL/AltiKa, Jason-3 and Sentinel-3A when available. First results suggest that we are able to map ocean features with unprecedented resolution for the region. Comparisons between these maps, the current CMEMS product, GLORYS12 model and previous regional studies are shown. Validation techniques are also discussed.

## **Corresponding author:**

**Matthis Auger (CLS, France),** [mauger@groupcls.com](mailto:mauger@groupcls.com)

# Estimation and impact of Sentinel-3a GMSL drift on climate-driven studies

**Michael Ablain (Magellium, France); Rémi Jugier (Magellium, France); Meysignac Benoit (CNES/LEGOS, France); Matthias Raynal (CLS, France); Sylvie Labroue (CLS, France)**

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Oral

## **Abstract:**

The uncertainty level of the Global Mean Sea Level (GMSL) record is of crucial importance for climate studies such as estimating precisely the current rate and acceleration of sea level, analyzing the closure of the sea level budget, understanding the causes of sea level rise, detecting and attributing the response of sea level to anthropogenic activity, or estimating the Earth energy imbalance.

To date, satellite altimetry missions provide a more than 25 years record of continuous measurements of sea level with a very good accuracy. All GMSL groups report very similar results with GMSL trend estimates close to 3.3-3.4 mm/yr over the 1993-2018 period, with an uncertainty of 0.4 mm/yr within a 90% confidence interval (CL). A significant GMSL acceleration over the 25-year period at  $0.12 \pm 0.07$  mm/yr<sup>2</sup> (90% CL) has also been highlighted. Thanks to the good accuracy of altimeter data records, closure budget analyses have been carried out over the past years allowing a better understanding of sea level rise causes.

In order to continue to conduct and enhance these climate-driven studies, altimeter errors should be regularly checked, analyzed and corrected. One of the classical way to do it, it's to cross compare altimeter missions together in order to detect any jump or drift.

In this study, we are precisely interested in the Sentinel-3a (S3-a) mission launched in February 2016. Indeed, an instrumental drift has recently been detected on S3-a data that have an impact on SWH and range estimates. Although the causes of this drift are still being investigated, preliminary analyses tend to reveal a drift in the width of the System Aperture Radar (SAR) point target response.

This study aims to characterize this S3-a instrumental drift on the evolution of Global Mean Sea Level (GMSL) by comparing with other altimeter missions on the same period (SARAL/Altika, Jason-3 and Jason-2), but also with independent measurements derived from the global tide gauge network. As the S3-a period is short (~3 years), the statistics relevance of the results obtained is analyzed by estimating the uncertainty trend estimates for GMSL altimeter time series separately, but also between two GMSL time series. We also evaluate the impact of different altimeter corrections on S3-a (e.g. empirical corrections, new retracking...).

Finally, through all these analyses, recommendations for improving the S3-a data are made identifying the risks on the different climate-driven studies that need to use these data, especially in the event of Jason-3 failure and also with the perspective of the future Sentinel-6a (Jason-CS) mission. In order to support discussions, we provide an updated altimeter GMSL error budget using Sentinel-3a data instead of Jason-3.

## **Corresponding author:**

**Michael Ablain (Magellium, France)**, michael.ablain@magellium.fr



# Uncertainty in Satellite estimate of Regional Mean Sea Level trends

**Pierre Prandi (CLS, France)**; Benoît Meyssignac (CNES/LEGOS, France); Jean-François Legeais (CLS, France); Yannice Faugère (CLS, France); Michael Ablain (Magellium, France); Jérôme Benveniste (ESA, Italy)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Oral

## **Abstract:**

Satellite altimetry missions now provide more than 25 years of accurate, continuous and quasi-global measurements of sea level along the reference ground track of TOPEX/Poseidon. These measurements are used by different groups to build the Global Mean Sea Level (GMSL) record, an essential climate change indicator. Recently Ablain et al. (2019) derived uncertainty levels for the GMSL record, its trend and acceleration.

The quasi-synoptic view of the global ocean provided by satellite altimetry also provides information about the regional sea level rise distribution. In some regions the altimetry record shows a local sea level rise up to 5 times greater than the global mean rise (i.e  $>12$  mm/yr) since 1993. This very fast sea level rise increases significantly the exposure of the local coastal communities to flooding. Estimating a realistic uncertainty of the regional sea level records is of crucial importance for impact studies.

In this study we use the SL-CCI monthly sea level dataset over 1993-2014 and downscale the approach of Ablain et al. (2019) to build local error variance covariance matrices with a yearly resolution. The error prescription relies on an empirical estimate of the different contributions to the sea level measurement error budget: long term drifts in the orbit solution, long period oscillations in geophysical corrections and the local level of the altimeter noise. We use a least square approach and the error variance-covariance matrix to estimate the local MSL trend uncertainties. Results suggest that local uncertainty levels range between 1.9 and 2.2 mm/yr (at the 90% confidence level). Such uncertainty values imply that the majority (about 60%) of global ocean is rising at a statistically significant rate. A sensitivity analysis shows that the regional uncertainty pattern is robust to changes in the empirical error estimates. Further work aims at providing a description of the spatial structure of the altimetry error covariance and building a full space/time description of the altimeter measurement error at climate scales.

## **Corresponding author:**

**Pierre Prandi (CLS, France)**, pprandi@groupcls.com



# Contributions of atmospheric forcing and chaotic ocean variability to global and regional sea level changes over 1993-2015

**William Llovel (LEGOS (CNRS/CNES/IRD/UPS), France)**; Benoit Meyssignac (LEGOS, France); Nicolas Kolodziejczyk (LOPS, France); Thierry Penduff (IGE, France); Jean-Marc Molines (IGE, France)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Oral

## **Abstract:**

Sea level rise is one of the most important consequences of the actual global warming. Since the early 1990s, satellite altimetry has become the main observing system for continuously measuring the sea level variations. Satellite altimetry data have revealed a global mean sea level rise of 3.1 mm/yr since 1993. This rise is not uniform and presents large deviation around its global average. Since 2005 and because of the high accuracy of the complementary observing systems, we are now able to close the sea level budget within the uncertainties by combining satellite altimetry data, ocean mass change from GRACE and in situ measurements of temperature and salinity (T/S) based on Argo floats. Ocean model simulations, in particular in the eddying regime, revealed the existence of chaotic imprints in regional sea level trends. These chaotic fluctuations may leave random imprints on decadal regional sea level trends. A global  $\frac{1}{4}^\circ$  ocean/sea-ice 50-member ensemble simulation is analyzed to disentangle the imprints of the atmospheric forcing and the chaotic ocean variability on sea level change and its causes over the satellite altimetry period. We first present the respective contributions of atmospherically-forced and chaotic variability to sea level change and its causes as resolved by the ensemble model simulations. We refine our analysis by investigating these variability imprints as resolved by the different observing systems. Thus, we subsample the ensemble model outputs to the observations, we interpolate the synthetic data set on a regular grid to quantify the chaotic imprints of sea level change and its causes at global and regional scales over 1993-2015.

## **Corresponding author:**

**William Llovel (LEGOS (CNRS/CNES/IRD/UPS), France)**, [william.llovel@legos.obs-mip.fr](mailto:william.llovel@legos.obs-mip.fr)

# Why sea-level swings in the Pacific

Y. Tony Song (JPL/NASA, United States)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Oral

## Abstract:

Over the past decades, the sea level in the western Pacific rose up to three times faster than the global mean, while its counterpart in the eastern Pacific including U.S. west coast was nearly stationary or decreasing [Moon and Song, 2013; Moon et al, 2013]. In fact, the regional sea-level trends have undergone two shifts, during the mid-1970s and in the early 1990s, with an east-west dipole pattern in the tropical Pacific. In each of these phases, the regional sea levels accelerated on one side of the Pacific, but decelerated on the other side. It is puzzling how long this pattern of regional sea level changes has been gone, what is the dynamic cause, and how these can affect deep ocean. These regional sea level changes, when superimposed on the global trend of sea level rise, could have profound implications for coastal communities and the health of marine and estuarial habitats. In this study, we have examined recently reconstructed long-term sea level data products, upper-ocean measurements, satellite data, and a mass-conserving OGCM results [e.g., Song and Colberg 2011] to gain insight into the puzzling swings of the Pacific sea levels. We will show that (1) the multi-decadal sea-level swings are the consequence of upper-ocean heat changes, closely related to the Pacific Decadal Oscillation (PDO)-induced ocean circulations [Moon et al., 2015]; (2) the dueling climate cycles, PDO and ENSO, may have intensified the sea level swings in the tropical Pacific since 1980s [Cha et al. 2018]; and (3) the relative roles played by the local/Pacific atmospheric forcing and the global ocean circulation are examined to explain the underlying dynamic mechanisms.

## Reference:

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## Corresponding author:

Y. Tony Song (JPL/NASA, United States), [Tony.Song@jpl.nasa.gov](mailto:Tony.Song@jpl.nasa.gov)

# Validating Arctic Sea Level Change in the GRACE-era

Carsten Ludwigsen (DTU, Denmark)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Oral

## **Abstract:**

As one of the most remote and inaccessible regions in the world, the sea level in the Arctic is still today in large parts uncertain. Altimetry measurements by satellites have been available in the Arctic for more than 25 years. However, retracers vary in how they treat sea surface height data contaminated by sea-ice and the merging of Low-Resolution Mode (LRM) data with SAR data and until the launch of CryoSat-2 in 2011, altimetric satellites only covered up to 81.5N.

OBP measurements from GRACE can be used to indicate the 'truth', but mass leakage from land ice makes it necessary to apply large corrections to divide land and ocean gravity signals from GRACE. Furthermore have recent studies (Morison et al 2012, Peralta-Ferriz et al 2014 & 2016 and Armitage 2016 & 2018) shown that especially the halosteric sea level is a larger contribution to both temporal and spatial arctic sea level variations than the actual ocean mass change seen by GRACE.

At DTU, we have collected all available hydrographic data north of the 60th latitude by adding recent data from 2016-2017 to the UDASH-database (Behrendt et al, 2017). All in-situ profiles are quality checked and finally extrapolated into a 4D-hydrographic grid covering the Arctic region for the altimetry era.

The hydrographic dataset (DTUSteric) is compared with different available datasets from GRACE and altimetry, exploiting the budget equation  $SSH = Mass + Steric$ . The best agreement ( $R=0.76$ ) is reached between the combination of DTUSteric and the JPL Mascon (RL06) solution and the altimetry product from Centre of Polar Observation and Modelling (CPOM). A large residual signal is found in the East Siberian Sea, an area with no in-situ observations and in general uncertain satellite observations. The spatial correlation coefficients range from 0.32-0.76 indicating that satellite observations should be used carefully in the Arctic, as large parts of the observed sea level trend from satellite altimetry cannot be validated with in-situ data.

## **Corresponding author:**

**Carsten Ludwigsen (DTU, Denmark)**, caanlu@space.dtu.dk

# Extrapolating Satellite Data Records for Short-Term Sea Level Projections

**Robert Steven Nerem (University of Colorado, United States);** John Fasullo (NCAR, United States); Benjamin Hamlington (Jet Propulsion Laboratory, United States); Thomas Harvey (University of Colorado, United States); Surendra Adhikari (Jet Propulsion Laboratory, United States)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Oral

## **Abstract:**

The satellite altimeter record has provided an unprecedented climate data record for understanding sea level rise and has recently reached a major milestone at 26 years in length. This record of sea level change is becoming sufficiently long that we can begin to infer how sea level will change in the future. Observations of the rate and acceleration of global mean sea level change from satellite altimetry have become sufficiently well determined that we can do simple extrapolations under the (big) assumption that the rate and acceleration remain constant over the time period of the extrapolation. Also, there is evidence that the observed pattern of regional sea level change is being driven by the forced climate response and that these trends will continue into the future. Therefore, the observed regional trends from satellite altimetry can be used to inform the patterns of future regional variations. Finally, the GRACE mass change record, while comparatively short, can be used to extrapolate future mass loss from the ice sheets, which can also be used to compute the gravitational fingerprints and get the regional sea level variations. Taken together, we can put this into a framework to extrapolate regional sea level change 20-30 years into the future. We will discuss this framework and show some initial results. Considerable uncertainties exist and these will be addressed.

## **Corresponding author:**

**Robert Steven Nerem (University of Colorado, United States),** [nerem@colorado.edu](mailto:nerem@colorado.edu)

# TOPEX Data Reprocessing using a Numerical Retracking Approach

**Jean-Damien DESJONQUERES (NASA Jet Propulsion Laboratory, United States);** Matthieu TALPE (NASA Jet Propulsion Laboratory, United States); Philip CALLAHAN (NASA Jet Propulsion Laboratory, United States); Shailen DESAI (NASA Jet Propulsion Laboratory, United States); Joshua WILLIS (NASA Jet Propulsion Laboratory, United States)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Oral

## **Abstract:**

The historical TOPEX data products contain well-documented drifts which are particularly obvious in the time series of Significant Wave Height (SWH) from the side-A altimeter. As this degradation became severe, the redundant side-B chain was activated in February 1999.

We have developed a numerical approach to process - or "retrack" - the altimeter echoes from the TOPEX side-A and B altimeters using instrument calibrations, as measured in-flight, to mitigate the altimeters' evolution.

We present results from our investigation of a numerical approach where the echoes are corrected from the instrument equivalent filter and then the Point Target Responses (PTR) are used to generate models of the echoes [Thibaut et al., 2012]. The two echoes are then compared to compute estimates of the range, the significant wave height (SWH) and the backscatter coefficient ( $\sigma_0$ ) of the ocean surface.

The TOPEX altimeter was calibrated in-flight measuring the PTR and the instrument equivalent filter, respectively, from cal-1 and cal-2 modes. The PTRs as measured daily in routine cal-1 mode are not oversampled. As the side-A altimeter degradation became obvious, new onboard software was developed and uploaded to allow the measurement of more accurate oversampled PTRs using the so-called sweep calibration mode. Due to the late patch of the onboard software, only a few sweep calibrations are available at the end of side-A, while for side-B, these calibrations have been performed more regularly throughout its lifetime.

We have extracted the cal-1, cal-2 and sweep calibration data from the TOPEX Science Data Record (SDR) products and have reprocessed those data. Our retracking algorithm is based on the numerical convolution of a theoretical echo model (derived from Brown's echo model) with an oversampled PTR. For side-B, we used the sweep calibrations. For side-A, there are only a limited number of available sweep calibrations. We have therefore developed a technique to generate a homogenous time series of oversampled PTRs using both measured sweep and routine PTRs.

In addition, we have found the root cause of the hemispheric bias that has been observed in all the altimeter geophysical parameters provided on the TOPEX GDR products, and have applied an approach to significantly mitigate those errors. We present evidence to support our explanation and results from our approach to correct for these errors.

[Thibaut et al., 2012]: P. Thibaut, J.C.Poisson, F. Boy And N. Picot, "Numerical Solution For the Retracking Algorithm: Performances On Conventional Altimeter Waveforms", Presented at the 2012 OSTST Meeting, Venice.

**Corresponding author:**

**Jean-Damien DESJONQUERES (NASA Jet Propulsion Laboratory, United States)**, jean-damien.m.desjonqueres@jpl.nasa.gov

# Sentinel-3A, Jason-3 and AltiKa instrumental drifts and their impacts on geophysical estimates

**Jean-Christophe Poisson (CLS, France);** Fanny Piras (CLS, France); Matthias Raynal (CLS, France); Emeline Cadier (CLS, France); Pierre Thibaut (CLS, France); François Boy (CNES, France); Nicolas Picot (CNES, France); Franck Borde (ESA, Netherlands)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Oral

## **Abstract:**

Measuring sea surface height from space is a challenging exercise. Even if the measurement principle is simple in theory (a difference between the satellite altitude and the measured altimeter range), a large set of corrections must be applied to satellite measurements so as to manage all potential errors. Instrumental corrections are one of the most important and essential correction set to be accounted for. Radar altimeters are designed and calibrated on ground before the satellite launch but then, are not perfectly stable over time. Once in flight, the altimeter is subjected to extreme conditions impacting its electronics components that are monitored via the instrumental impulse response. The evolutions of the instrument behavior must then be accounted for in order to ensure the measurement quality and stability, in particular for climate application purpose.

In all altimeter missions, instrumental calibrations are regularly performed (several times per day) in order to monitor the instrument PTR (and also the low pass filter of the RX chain). In each altimeter ground segment, the PTR monitoring is exploited to derive instrumental corrections that are applied on the altimeter range (the internal path delay correction) and the backscatter coefficient (PTR total power). These two instrumental corrections allow to correct altimeter measurements from any instrumental drift if and only if the altimeter PTR is symmetric (the PTR has a squared sinc shape). From previous studies conducted in the frame of the Sentinel-3 Mission Performance Center, it has been shown that the PTR symmetry of the Sentinel-3A radar altimeter (SRAL) is changing, impacting geophysical measurements, sigma naught, sea level but also significant wave height measurements.

In this study we propose to compare Sentinel-3A, Jason-3 and AltiKa PTR drifts/evolutions and to assess how geophysical estimates are impacted by the instrumental ageing.

This analysis is of particular importance to be certain that the Sentinel-6 ground processing chains are well designed to guaranty an accurate measurement of the global mean sea level trend. This is a major requirement of the Sentinel-6 mission.

## **Corresponding author:**

**Jean-Christophe Poisson (CLS, France),** [jpoisson@cls.fr](mailto:jpoisson@cls.fr)

# On the Effect of Surface Motion in SAR Altimeter Observations of the Open Ocean

Alejandro Egido (NOAA / GST Inc., United States); Chris Ray (St Mary, USA)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Oral

## **Abstract:**

The effects of surface waves motion on synthetic aperture radar (SAR) images of the ocean has been an intense topic of study for a number of decades, [Hasselmann, et al., 1985], [Alpers and Bruening, 1986]. As the SAR locates targets on the azimuth dimension based on their Doppler history, the main effect of the surface motion is a misplacement of targets within the image. In the case of a distributed target as the ocean surface, this displacement originates a degradation of the image. One of these effects is a loss of azimuth resolution, induced by a) the vertical acceleration of surface scatterers, and b) the loss of coherence due to the vertical motion of the different scatterers within the resolution cell. At all effects, this can be interpreted as a widening of the azimuth point target response (PTR) of the instrument. Despite the fact that the azimuth smearing can be very significant, i.e. in some cases more than 50% of the azimuth resolution, this effect has been largely overlooked in SAR altimetry.

For SAR systems with a moderate resolution, as is the case of delay/Doppler altimetry, [Raney, 1998], waves of intermediate wavelengths are the ones that play a more significant role, and in this case, it is the finite surface coherence that induces the degradation of azimuth resolution, [Alpers and Bruening, 1986].

This can be readily observed in the delay/Doppler data, when computing the autocorrelation function of the speckle noise for adjacent Doppler beams. The consequence of this is a decrease of the multilooking efficiency, which results in an increase in the measurement error of geophysical parameters. In addition, the widening of the along-track point target response impacts the estimation of geophysical parameters, particularly significant wave height (SWH). We believe this effect could be the root cause of the previously observed discrepancies in SWH between the delay/Doppler and the pseudo-low resolution mode data, [Raynal, et al, 2018].

Through the processing and analysis of Sentinel-3 SAR data and simulations of realistic ocean surfaces, we evaluate the surface motion effects on the final delay/Doppler multilooked waveforms and develop the theory to update the SAR waveform model to better account for the sea state dependent surface wave's motion.

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[Alpers and Bruening, 1986] W. R. Alpers and C. Bruening, "On the Relative Importance of Motion-Related Contributions to the SAR Imaging Mechanism of Ocean Surface Waves," in IEEE Transactions on Geoscience and Remote Sensing, vol. GE-24, no. 6, pp. 873-885, Nov. 1986.



[Raney, 1998] R. K. Raney, "The delay/Doppler radar altimeter," in IEEE Transactions on Geoscience and Remote Sensing, vol. 36, no. 5, pp. 1578-1588, Sep 1998.

[Raynal, et al, 2018] M. Raynal, T. Moreau, N. Tran, S. LabroueF. Boy, P. Féménias, F. Borde, Assessment of the SARM processing sensitivity to swell, 2018 Ocean Surface Topography Science team meeting, Ponta Delgada, PT

**Corresponding author:**

**Alejandro Egido (NOAA / GST Inc., United States), [alejandro.egido@noaa.gov](mailto:alejandro.egido@noaa.gov)**

# An Investigation of the Impact of Vertical Water Particle Motions on Fully-Focused SAR Altimetry

Christopher Buchhaupt (Uni Bonn, Germany); Luciana Fenoglio (Uni Bonn, Germany); Jürgen Kusche (Uni Bonn, Germany)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Oral

## **Abstract:**

SAR altimeter processing became possible with the Synthetic Aperture Radar (SAR) Interferometric Radar Altimeter (SIRAL), which was launched on board of CryoSat-2 in April 2010. SAR altimetry, also known as Delay-Doppler altimetry (DDA), is pulse-limited in cross-track direction, just like conventional altimetry (CA), and beam-limited in along-track direction. It has therefore the potential to provide a better along-track resolution and a higher Signal-to-Noise ratio (SNR). It has been suggested that these could be further improved by applying additional phase terms; the so-called Fully-Focused-SAR (FF-SAR) processing has a theoretical along track resolution limit of half the antenna length.

However, it has been also shown that the vertical velocity of the sea surface reduces the achievable resolution in along track direction (Buchhaupt, 2019). Here we focus on deriving the second order wave spectral moment (which is the variance of the vertical velocities in a wave field) also for small sea states from CryoSat-2 full bit rate (FBR).

In the 20 Hz FF-SAR processing scheme four bursts are used here instead of the usual 160 bursts (integration time of 0.05 sec and 2 sec respectively), as this gives a similar resolution in the open ocean even for small vertical velocities of 10 cm/s (Fig. 1, right). The 20 Hz FF-SAR Delay-Doppler-Maps are retracked with a FF-SAR extension of SINCS-OV ZSK. Processed FF-SAR data are cross-compared to a reduced SAR (RDSAR) product having the same surface locations as SAR. The geophysical parameters that we compare are sea surface height, significant wave height, second order wave spectral moment and backscatter coefficient. The area of interest is the region from 30°N to 60°N and from 16°W to 10°E (North East Atlantic Box) over the year 2013.

## **Corresponding author:**

**Christopher Buchhaupt (Uni Bonn, Germany)**, buchhaupt@geod.uni-bonn.de

# Impact of the ocean waves motion on the Delay/Doppler altimeters measurements

**Laïba Amarouche (CLS, France);** Ngan Tran (CLS, France); Damien Herrera (CLS, FRANCE); Charles-Antoine Guerin (MIO, France); Pierre Dubois (CLS, France); Jérémie Aublanc (CLS, France); François Boy (CNES, France)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Oral

## **Abstract:**

Since the launch of Sentinel-3 A in February 2016, the data acquired in SAR mode over ocean have opened up a very wide field of investigations. Indeed, the improvement of the along-track resolution and the reduction of the noise of the measurements have led the scientific community wondering if ocean phenomena with smaller scales are observable. Nevertheless, before we can fully interpret the observed small scales phenomena, it is important to fully understand the content of the altimeter signal in SAR mode.

Among the phenomena likely to alter the performance of the measurements, as long as they are not considered in the processing, we can mention the surface motion. Indeed, Doppler altimeters, which use the motion of the platform to improve the measurement resolution, assume that the surface is stationary. In the event that the surface movements are not negligible, the processing assumptions are no longer valid and the final performance is likely to be impacted.

A first analysis has been performed in the context of a CNES/CLS/MIO PhD and resulted in a scientific paper published in IEEE TGRS (O. Boisot et al. 2017). In this work statistical solutions have been developed to estimate the means and standard deviations of the Doppler shift induced by the surface motion. Considering the average values and associated standard deviations, we were able to highlight the possibility of encountering situations where the performance is significantly impaired.

To complement this work, a new analysis has been performed to accurately assess the impact of these Doppler shifts on the altimetry performance. This analysis is based on a theoretical development allowing to describe the long and short waves time evolution and then on the use of simulation tools to assess the impact on the performance. Finally, real Sentinel-3 SAR mode data are used to validate the theoretical conclusions.

The results showed that the high positive biases observed on the SAR mode significant wave height (SWH) estimations of real Sentinel-3 data, in comparison to the low-resolution mode, are explained by the waves orbital velocities that affect the Doppler signal. The waves orbital velocity is the higher for high significant slopes. This phenomenon is not linked to swell and doesn't depend on the wave propagation direction. At the same time, SWH is underestimated in the case of swell with high wavelengths propagating in the same direction as the satellite. In this case very high noise is observed on SWH and range estimates.

This talk will give an overview of the analysis performed on the time evolution of the short and long wave scales and how this analysis has been used to assess the impact on the delay/Doppler altimeters performances. The results using real SAR mode data will be also presented.

## **Corresponding author:**

**Laïba Amarouche (CLS, France)**, [lamarouche@groupcls.com](mailto:lamarouche@groupcls.com)

# Reducing the high-frequency noise in Jason-3 and Sentinel-3A SWH data

**Ngan Tran (CLS, France);** Pierre Thibaut (CLS, France); Gérald Dibarbouré (CNES, France); François Boy (CNES, France); Nicolas Picot (CNES, France); Doug Vandemark (UNH, USA)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Oral

## **Abstract:**

Lately, several studies have focused on the high-frequency content of the SSH and its dependence to SWH signal at wavelengths shorter than 100 km [Zaron and DeCarvalho, 2016; Smith et al, 2017; Quartly et al, 2019]. The empirical approaches developed for reducing the high-frequency errors in SSH can also be applied to SWH, with benefits to several applications. We can think about the improved consistency across satellite missions, the provision of smoother wind speed estimation from 2D empirical models or for the potential re-design of the SSB approach [Tran et al, 2016]. This could be also an asset for wave model data assimilation as well as ocean gravity wave dynamics and wave-current interaction studies. This work is one of several related investigations being pursued within the framework of the ESA Sea State CCI project [Passaro et al, 2018].

This presentation will show our results on reducing the high-frequency noise in Jason-3 and Sentinel-3A SWH data. For Jason-3, we evaluate the impact for 2 retrackers (MLE4 and ADAPTIVE). For Sentinel-3A, we show results for both SAR and LR-RMC processings.

## **Corresponding author:**

**Ngan Tran (CLS, France),** ntran@groupcls.com

# Sentinel-3A and Sentinel-3B Tandem Phase Evaluation of the Surface Topography Mission Sea State Products

**Chris Banks (National Oceanography Centre, United Kingdom)**; Christine Gommenginger (National Oceanography Centre, UK); Francisco Mir Calafat (National Oceanography Centre, United Kingdom); Helen Snaith (British Oceanographic Data Centre, UK); Nadim Dayoub (National Oceanography Centre, United Kingdom); Matthew Hammond (National Oceanography Centre, United Kingdom)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Oral

## **Abstract:**

Sentinel-3A (S3A) has been in orbit since February 2016 and routinely provides data on ocean wind and waves (significant wave height/SWH, Sigma0 and wind speed). S3A was joined in orbit by Sentinel-3B (S3B) in April 2018 with a requirement to establish the consistency of the instruments on the two satellites, through inter-comparisons with each other and also comparisons with independent data. The operation of S3B in tandem with S3A during the early phase provides a unique opportunity to obtain data close in space and time to quantify instrument-related sources of discrepancies. During the tandem phase, S3B flies as little as 30 seconds ahead of S3A, which for most purposes can essentially be considered to be instantaneous. In the case of the Sentinel-3 Surface Topography Mission (STM) altimeter payload, the operation of the altimeter instruments on the two Sentinel satellites in different operating modes (Low Resolution Mode/LRM and Synthetic Aperture Radar Mode/SARM) brings additional benefits by providing the opportunity to directly compare the performance and dependencies of the retrieved measurements in the two operating modes. Evaluation of the inter-satellite consistency incorporates independent data such as in situ data, model output and other satellite data all of which, like the S3 data, include uncertainties.

In this study, we present ongoing work concerned with the calibration and validation of sea state data from the two Sentinel-3 STM instruments. Using independent data, we examine the geographical distribution and uncertainty characteristics of SWH and wind speed from the S3A and 3B satellites, as well as any global and regional offsets and discrepancies. Statistical methods are explored to formally quantify the errors of the STM sea state measurements, as well as the dependence of errors in SWH and wind speed on various sea state parameters in LRM and SARM operating modes.

## **Corresponding author:**

**Chris Banks (National Oceanography Centre, United Kingdom)**, [chris.banks@noc.ac.uk](mailto:chris.banks@noc.ac.uk)

# First SAR altimeter tandem phase: a unique opportunity to better characterize open ocean SAR altimetry signals with unfocused and focused processing

**Pierre Rieu (CLS, France)**; Thomas Moreau (CLS, France); Matthias Raynal (CLS, France); Pierre Thibaut (CLS, France); Craig Donlon (ESA, The Netherlands); Franck Borde (ESA, The Netherlands); François Boy (CNES, France); Nicolas Picot (CNES, France); Sébastien Clerc (ACRI-ST, France)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Oral

## **Abstract:**

The Sentinel-3 mission is a two-satellite operational system designed to provide wide coverage and high-quality data for the Copernicus environmental monitoring programme. Sentinel-3B, the second satellite of this system, has been successfully launched in April 2018, and before being inserted into its final orbit (at  $\pm 140^\circ$  to its twin, Sentinel-3A), has been positioned in a four-month-long close formation with S3A, during which the two satellites were observing the same scene a mere 30 seconds apart. Such flight configuration was designed to perform very accurate cross-calibration of the Sentinel-3 constellation instruments, in order to produce homogeneous and unbiased time-series observations for climate record as requested by the user community.

Being the first SAR-mode tandem phase, the Sentinel-3 tandem phase offers an unprecedented opportunity to go further into the characterization of SAR-mode signals over ocean. By exploiting the time lag between the datasets, the signals related to rapidly evolving phenomena, like propagating swells, surface heterogeneities and surface motion, can be identified in a more efficient way than with a mono-satellite dataset. The spectral signature of these signals is discussed. Both operational unfocused data and high-precision fully-focused data have been processed and analyzed at both local and global scale.

This presentation reports the most significant findings emerging from this study based on joint use of S3A and S3B satellites in tandem phase configuration, and on the exploitation of the unfocused and focused SAR processing.

## **Corresponding author:**

**Pierre Rieu (CLS, France)**, [prieu@groupcls.com](mailto:prieu@groupcls.com)

# Sea-ice freeboard and sea level from altimetry using fast and robust 2 dimensional retracker

**Sara Fleury (LEGOS, France)**; Antoine Laforge (LEGOS, France); Florent Garnier (LEGOS, France); Salvatore Dinardo (He Space, Germany); Giovanni Sabatino (ESA, Italy); Jérôme Benveniste (jerome.Benveniste@esa.int, Italy)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Oral

## **Abstract:**

The Arctic sea-ice is a fundamental actor and witness to the on-going climate changes. The SIRAL instrument aboard the polar mission CryoSat-2, endowed with the delay-Doppler mode, has enabled to produce several truthful estimations of the ice freeboard and consequently the Arctic ice volume. However, the ice thickness estimation using altimetry still holds several sources of uncertainties.

One major source of errors is the result of the misinterpretation of complex multi-return echoes by the retracker. These parasitic peaks occur when high backscatter surfaces adjoin low backscatter surfaces because of two well-known effects in SAR altimetry: the side-lobe effect and the off-nadir effect. This configuration is very frequently encountered over sea-ice where high backscatter fractures travel through the ice pack.

Even if the Hamming filtering attenuates the side-lobe effect, these phenomenon induce several centimeters of error. For instance about 15% of the measurements obtained with SAMOSA+ (Dinardo) are impacted.

The solution presented here allows identifying the peak of the waveform that corresponds to the nadir, even in very complex configurations. It relies on the flatness characteristic of the sea-ice (+-50cm) to detect and extract the ground line from the whole echogram one satellite track.

Several options can be considered to exploit the output of this 2D retracker: it can be used as a post-processing to remove the outliers find out by the retracker or it can be used as a first guess for a heuristic or a physical retracker.

We will show the positive impacts of this 2D retracker to retrieve the sea ice freeboard and the sea level anomaly among the ice in conjunction with heuristic retracker and with the physical retracker SAMOSA+.

## **Corresponding author:**

**Sara Fleury (LEGOS, France)**, sara.fleury@legos.obs-mip.fr

# Improved Retrieval Methods for Sentinel-3 SAR Altimetry over Coastal and Open Ocean and recommendations for implementation: ESA SCOOP Project Results

**David Cotton (Satellite Oceanographic Consultants Ltd, United Kingdom);** Thomas Moreau (CLS, France); Eduard Makhoul (isardSAT, Spain); Christine Gommenginger (National Oceanography Centre, UK); Mathilde Cancet (Noveltis, France); Luciana Fenoglio-Marc (University of Bonn, Germany); Marc Naeije (TU Delft, Netherlands); M Joana Fernandes (University of Porto, Portugal); Andrew Shaw (SKYMAT, UK); Marco Restano (SERCO / ESRIN, Italy); Américo Ambrózio (DEIMOS / ESRIN, Italy); Jérôme Benveniste (ESA-ESRIN, Italy)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Oral

## **Abstract:**

SCOOP (SAR Altimetry Coastal & Open Ocean Performance) is a project funded under the ESA SEOM (Scientific Exploitation of Operational Missions) Programme Element, to characterise the expected performance of Sentinel-3 SRAL SAR mode altimeter products, and then to develop and evaluate enhancements to the baseline processing scheme in terms of improvements to ocean measurements. Another objective was to develop and evaluate an improved Wet Troposphere correction for Sentinel-3.

We report the development and testing of new processing approaches designed to improve performance, including:

- Application of zero-padding
- Application of intra-burst Hamming windowing
- Exact beam forming in the azimuthal direction
- Restriction of stack processing to within a specified range of look angles.
- Along-track antenna compensation

Based on the results of this assessment, a second test data set was generated, processed with zero-adding and hamming windowing, and we present an assessment of the performance of this second Test Data Set, for the open ocean and in the coastal zone, and compare it to that of the original Test Data Set.

Based on the outcomes of this study we provide recommendations for further developments and improvements to existing processing chains.

## **Corresponding author:**

**David Cotton (Satellite Oceanographic Consultants Ltd, United Kingdom),** [pd.cotton@me.com](mailto:pd.cotton@me.com)



# CNES POE-F precise orbit performances for the current altimeter missions

**John Moyard (CNES, France)**; Alexandre Couhert (CNES, France); Flavien Mercier (CNES, France); Sabine Houry (CNES, France); Hanane Ait Lakbir (CSSI, France); Clément Masson (CSSI, France)

**Session:** Precision Orbit Determination

**Presentation type:** Oral

## **Abstract:**

Since last year's OSTST meeting, several altimeter missions started switching from CNES GDR-E to CNES POE-F orbit standard: NASA/CNES Jason-3 in November 2018, the EU Copernicus twin satellites Sentinel-3A and Sentinel-3B in December 2018, ISRO/CNES Saral/AltiKa in January 2019, and ESA CryoSat-2 in May 2019.

Additionally, their past orbit solutions were reprocessed and made available in February, March, April, and June 2019, respectively, as well as those of the historical TOPEX/Poseidon spacecraft in March 2019.

This paper gives a status of the performances of these updated DORIS+GPS orbits for Jason-3 and Sentinel-3A/B, and DORIS-only orbits for Saral/AltiKa and CryoSat-2, all of them bordering on 5 mm RMS radial orbit accuracies, as seen by independent SLR observations.

Comparisons of these orbit solutions with available external solutions will be shown, as a complement to the SLR validations.

A short overview of the activities led by the CNES POD Group, current advances in POD modeling, anticipated future works, as well as the preliminary performances of the NSOAS HY-2B GPS-only orbits will be presented.

## **Corresponding author:**

**John Moyard (CNES, France)**, [john.moyard@cnes.fr](mailto:john.moyard@cnes.fr)

# Improved orbit time series for the TOPEX and Jason missions from 1992-2019.

**Frank Lemoine (NASA GSFC, United States);** Nikita Zelensky (ESSIC, University of Maryland, USA); Alexandre Belli (Universities Space Research Association (USRA) @ NASA GSFC, USA); Brian Beckley (SGT Inc., U.S.A.); Douglas Chinn (SGT Inc., USA); Despina Pavlis (ESSIC, University of Maryland, USA)

**Session:** Precision Orbit Determination

**Presentation type:** Oral

## **Abstract:**

Orbit error remains a major component in the overall error budget of all altimeter satellite missions. Error sources include terrestrial reference frame and station positions, systematic and unaccounted-for errors in the satellite tracking measurements, mismodeling of non-conservative forces, and incomplete modeling of time-variable gravity. The agreement between the SLR/DORIS and GPS-reduced-dynamic orbits is at the level of 6-9 mm radial RMS, however we continue to observe systematic signatures in the orbits and in the tracking data. This paper presents a status report on the development of a consistent set of new orbit standards that can be applied for the entire orbit time series, from 1992 to 2019. We have addressed three important issues: (1) adapting a new static and time-variable geopotential model to apply over the altimetry time period; (2) further improvements to the non-conservative force modeling, (3) Mitigation of the SAA effect in the Jason-2 & Jason-3 DORIS data, and the impact on the orbits and the coordinates for the DORIS stations. For the time-variable gravity modeling, the approach we have taken is to adjust a low-degree harmonic field from a large set of SLR & DORIS satellites on top of the new GRACE+GOCE a priori gravity field. Other improvements include adoption of the IERS2014 mean pole, use of the new 3-hrly AOD product developed by the GFZ for the GRACE RL06 processing. With these new set of geophysical standards, we find that RMS of fit to other altimeter satellite missions (e.g. Envisat, SARAL, HY-2A) is frequently at or below the cm level. Making an assessment of radial orbit accuracy for these non-reference mission satellites is more challenging.

We present the altimeter measurement calibration with tide gauges for the new sets of orbits for TOPEX & Jasons1-3, as well as comparisons of the GSFC orbits with those produced by other analysis centers, including the CNES, JPL, ESA, and other centers.

## **Corresponding author:**

**Frank Lemoine (NASA GSFC, United States),** Frank.G.Lemoine@nasa.gov

# Performance of the Jason-2 and Jason-3 GPS Receivers and Resulting GPS-Based Precise Orbit Determination Solutions

**Shailen Desai (Jet Propulsion Laboratory, United States);** Willy Bertiger (Jet Propulsion Laboratory, United States); Bruce Haines (Jet Propulsion Laboratory, United States); Da Kuang (Jet Propulsion Laboratory, United States); Aurore Sibois (Jet Propulsion Laboratory, United States)

**Session:** Precision Orbit Determination

**Presentation type:** Oral

## **Abstract:**

We present updated results of the in-flight tracking performance of the Jason-2 and Jason-3 GPS receivers, with particular consideration of the Jason-2 receiver before and after the early-2019 long-duration safehold event. As part of that performance evaluation we also present results from our most recent GPS-only precise orbit determination solutions for Jason-2 and Jason-3. We consider the usual suite of internal (post-fit residuals, day-to-day consistency as measured by overlaps of daily solutions) and external (sea surface height crossover variance, and withheld satellite laser ranging residuals) metrics, as well as comparisons to independent precise orbit determination solutions from GSFC and CNES. In this presentation we also provide results from studies that we have performed on the sensitivity and impact of various strategies for handling geocenter motion. We considered three approaches: 1) ignoring geocenter motion and using JPL's standard IGS14-based orbit and clock products; 2) use of so-called no-net-rotation orbit and clock products for the GPS constellation; 3) using models to account for geocenter motion while generating orbit and clock products for the GPS constellation.

## **Corresponding author:**

**Shailen Desai (Jet Propulsion Laboratory, United States),** [shailen.desai@jpl.nasa.gov](mailto:shailen.desai@jpl.nasa.gov)

# Copernicus POD Service - Model updates and validation of Sentinel-3 orbit determination

**Heike Peter (PosiTim, Germany);** Emilio J. Calero (GMV AD, Spain); Jaime Fernández (GMV AD, Spain);  
Pierre Féménias (ESA/ESRIN, Italy)

**Session:** Precision Orbit Determination

**Presentation type:** Oral

## **Abstract:**

The Copernicus POD (Precise Orbit Determination) Service operationally generates precise orbital products for the Copernicus Sentinel-1, -2, and -3 missions. Model updates are necessary from time to time to follow up latest model developments. Validation of such updates is important to continuously guarantee the quality of the orbit products. Model updates do also have an impact on the long-term stability of the products, which has to be monitored as well.

The impact of the switch to EIGEN-GRGS RL04 gravity field model, GFZ AOD1B product, and FES2014 ocean tide model is investigated for the orbit products of the altimeter satellites Sentinel-3A and -3B. Comparisons to operational Sentinel-3 orbits from CNES, CPOD, and to post-processed orbits from other groups as well as SLR measurements are used for validation. For the long-term validation a reprocessed time series based on the new models is generated as well.

## **Corresponding author:**

**Heike Peter (PosiTim, Germany),** [heike.peter@positim.com](mailto:heike.peter@positim.com)

# Precise Orbit Determination of DORIS satellites by CNES/CLS IDS Analysis Center in the frame of the next ITRF

Hugues Capdeville (CLS, France)

**Session:** Precision Orbit Determination

**Presentation type:** Oral

**Abstract:**

We are currently preparing the processing configuration for our IDS contribution to the next ITRF realization (ITRF2020). We will adopt the last standards and models recommended by IERS and IDS. We now use body and solar array quaternions for Jason-2 and Jason-3 satellites.

A Precise Orbit Determination (POD) status for DORIS satellites by taking into account all these improvements will be presented. We will give statistical results such as one per revolution empirical acceleration amplitudes and orbit residuals. We will also give some comparisons to the CNES precise orbit used for altimetry and to GPS-only orbits contributing to the Copernicus POD Quality Working Group of Sentinel. Some external validations of our orbits will be done, such as with independent SLR measurements processing as well as through the use of altimeter crossovers. We will also look at the impact on the DORIS station position estimation.

**Corresponding author:**

**Hugues Capdeville (CLS, France)**, [hcapdeville@groupcls.com](mailto:hcapdeville@groupcls.com)

# Performance of dynamic and ambiguity-fixed LEO orbits in SLR validation and network calibration

**Daniel Arnold (Astronomical Institute of the University of Bern, Switzerland);** Adrian Jäggi (Astronomical Institute of the University of Bern, Switzerland); Stefan Schaer (Astronomical Institute of the University of Bern, Switzerland); Ulrich Meyer (Astronomical Institute of the University of Bern, Switzerland); Linda Geisser (Astronomical Institute of the University of Bern, Switzerland)

**Session:** Precision Orbit Determination

**Presentation type:** Oral

## **Abstract:**

For Low Earth Orbiters (LEOs), Satellite Laser Ranging (SLR) is a tool widely applied for the independent and external validation of orbit solutions derived from Global Navigation Satellite System (GNSS) or other radiometric measurements. For various satellite missions over the last decade SLR residuals, i.e., differences between observed and computed ranges, have been at the 1-3 cm RMS level when selecting only measurements from high-performing SLR stations. Refining orbit or observation modeling techniques, e.g., by making use of advanced non-gravitational force modeling or single-receiver ambiguity resolution, allows on the one hand to further reduce SLR residuals. On the other hand, up-to-date orbit solutions reach such a high accuracy and precision that in fact uncertainties in SLR station coordinates and/or range biases start to constitute limiting factors for the achieved levels of SLR residuals.

Especially for LEOs, SLR measurements are not only sensitive to radial, but also to lateral directions. Because different errors induce different systematic patterns in SLR residuals, the analysis of the latter allows for the estimation of offset corrections for orbits, or, if high-quality orbits are introduced for the SLR residual computation, for the estimation of station coordinate and range bias corrections for the stations in a least-squares adjustment.

We show the performance of reduced-dynamic and kinematic orbit solutions for the ESA Sentinel and Swarm missions, using state-of-the-art non-gravitational force modeling and undifferenced ambiguity resolution techniques. Ambiguity resolution is enabled by using the high-quality phase bias products and high-rate ambiguity fixed GNSS clock corrections of the Center for Orbit Determination in Europe (CODE). Both the reduction of SLR residuals, and the better separability of orbit and station errors is demonstrated when using these orbits.

## **Corresponding author:**

**Daniel Arnold (Astronomical Institute of the University of Bern, Switzerland),** [daniel.arnold@aiub.unibe.ch](mailto:daniel.arnold@aiub.unibe.ch)

# Analysis of Altimetry satellites SLR residuals

Flavien Mercier (CNES, France); Alexandre Couhert (CNES, France); John Moyard (CNES, France)

**Session:** Precision Orbit Determination

**Presentation type:** Oral

## **Abstract:**

The analysis of the SLR residuals is an important external validation for the precise orbits. For altimetry satellites the high elevation residuals are used to analyse the radial quality of the orbits.

However, due to the actual performances to verify (better than 1 cm rms in the radial direction), it is now necessary to improve the SLR measurements knowledge : the observed measurement noise can be as good as 2 mm rms, and the limitation is the value of the systematic biases. These biases can be directly observed on many stations.

The current practice is to choose a reduced set of stations (core network) assumed with negligible biases to check the radial performance. The number of used stations can be reduced to 5 stations only.

The objective of this study is to enlarge the core network by estimating the biases for different satellites (Jason 3, Sentinel 3a, Cryosat, Saral), and try to remove the possible geographically correlated errors that can be present in the orbits. This has been checked on sentinel 3a and b, and it was possible to extend the core network from 6 to 12 stations without degrading the initial observations. This will be extended on the other orbits, using a set of common biases for the added stations.

## **Corresponding author:**

**Flavien Mercier (CNES, France)**, [flavien.mercier@cnes.fr](mailto:flavien.mercier@cnes.fr)

# An analytical method to propagate errors in the Altimeter system; from space to Earth (orbit, reference frame and mean sea level)

**Pierre EXERTIER (CNRS-GRGS, France);** Pascal BONNEFOND (Observatoire de paris, SYRTE - GRGS, France); Ngoc Dung LUONG (University of Civil Engineering, Ha Noi, Viet Nam)

**Session:** Precision Orbit Determination

**Presentation type:** Oral

## **Abstract:**

Simulation studies involving new space geodesy scenarii are strictly necessary today to improve the Earth system, especially on a global scale in view of new challenges related to climate change. From these studies, the propagation of errors (measurements and models) and/or the space and time characterization of their impact in some final geodetic

products is of great interest for Earth sciences, in particular oceanography.

Actually, most studies take the advantage of numerical methods ; they form the background of current error analyses by using the comparison of existing geodetic products (gravity field, mean sea surface, reference frame and orbit) including the variance/covariance information when available.

On the contrary here, the study of the propagation of errors from the satellite orbit to the Earth (reference frame and

mean sea level) is based on some analytical development in which all system of equations are developed at order one.

The first result is to directly provide the wellkown Geographically Correlated Error coming from the orbit (gravity field notably);

the second interest of this approach is to provide also an explicit formulation of these errors, in addition to some measurement

error models (Doppler and range tracking), on a given geodetic site.

The result of such a combination of errors of dynamics and geometrical natures, thus allows us to better identifying their

source. Applications to some altimeter satellite missions, like Jason and Sentinel, are described and errors in the reference

frame serving as a basis for the mean sea level determination are quantified.

## **Corresponding author:**

**Pierre EXERTIER (CNRS-GRGS, France),** pierre.exertier@get.omp.eu



# Impact of satellite yaw attitude regime on in-flight calibration of low-Earth orbiter GPS antenna phase center

**Aurore E. Sibois (Jet Propulsion Laboratory, California Institute of Technology, United States); Shailen D. Desai (Jet Propulsion Laboratory, California Institute of Technology, United States)**

**Session:** Precision Orbit Determination

**Presentation type:** Oral

## **Abstract:**

We investigate the sensitivity of the in-flight calibration of the Global Positioning System (GPS) antenna phase center onboard low-Earth orbiters (LEOs) to the spacecraft's yaw attitude regime. The precise determination of the phase center offset (PCO) and variations (PCV) of the GPS antenna onboard LEOs is critical to achieve high-precision GPS-based orbit determination (POD) of these satellites. Changes in the geometry between the GPS transmitter and LEO receiver antennas are beneficial to the receiver antenna calibration by increasing the observability of its PCO. Knowledge of the LEO attitude is therefore essential and can be used to tune the estimation strategy of the LEO PCO/PCV.

We study the case of two LEOs with different yaw attitude behaviors: Jason-3 and Sentinel-3A. Jason-3 transitions between a yaw-steering mode characterized by large (e.g., +/- 120 degrees) sinusoidal yaw angle variations and a yaw-fixed mode, as well as yaw-flips where the satellite transitions from flying 'forward' to flying 'backward'. The transitions between those attitude regimes are dictated by the variation of the satellite's beta prime angle. The Sentinel-3 satellites on the other hand are designed to always fly in yaw-steering mode with variations of very low (e.g., +/- 6 degrees) amplitude. For both spacecraft, we evaluate the impact of each attitude mode on the estimated values of the Along-track, Cross-track and Radial coordinates of the PCO and their associated formal errors. We show that yaw flip transitions dramatically decrease the uncertainties on all 3 coordinates and that the amplitude of change in the yaw angle in yaw-steering mode is highly correlated with the observability of the Cross-track-offset but has little influence on the determination of the Along-track and Radial offsets. We also analyze the impact of using PCO/PCV estimates derived from in-flight tracking data covering different time spans characterized by the attitude regime of the satellite of interest on the quality of the orbit determination. Based on these results, we conclude on the potential advantages of large and rapid changes in yaw attitude for in-orbit calibration and validation post-launch, with potential application to Sentinel-6 and SWOT.

## **Corresponding author:**

**Aurore E. Sibois (Jet Propulsion Laboratory, California Institute of Technology, United States),**  
aurore.e.sibois@jpl.nasa.gov

# Impact of nominal and measured satellite attitude on SLR- and DORIS-derived orbits of Jason satellites and altimetry results

**Sergei Rudenko (Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM), Germany); Julian Zeithöfler (DGFI-TUM, Germany); Mathis Bloßfeld (DGFI-TUM, Germany); Denise Dettmering (DGFI-TUM, Germany)**

**Session:** Precision Orbit Determination

**Presentation type:** Oral

## **Abstract:**

For non-spherical satellites, the precise knowledge on satellite attitude is important for precise modeling of non-gravitational forces acting on a satellite. Moreover, the satellite attitude is necessary for the correct definition of the phase centers of the mounted SLR, DORIS and GPS measurement devices in space. The phase center corrections are important, since they influence the modeled observables, e.g., the range from a tracking station to the satellite, the Doppler shift, as well as the GPS pseudo-range and carrier phase. For altimetry satellites Jason-1/-2/-3, the satellite attitude can be modeled as nominal attitude (yaw steering mode) or as measured one in quaternion form.

In this presentation, we investigate the impact of using the measured satellite attitude, as compared to using the nominal one, on the SLR and DORIS RMS and mean observation residuals, orbit differences, RMS and mean of altimetry crossover differences and geographically correlated mean errors. Our analysis covers the time intervals from January 13, 2002 to June 29, 2013 for Jason-1, from July 20, 2008 to January 9, 2019 for Jason-2, and from February 17, 2016 to January 9, 2019 for Jason-3. We use SLR-only and DORIS-only orbits derived using "DGFI Orbit and Geodetic parameter estimation Software".

## **Corresponding author:**

**Sergei Rudenko (Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM), Germany), [sergei.rudenko@tum.de](mailto:sergei.rudenko@tum.de)**

# Inspecting Jason-3 and Sentinel-3 WPD over their first 3 years of mission

**M. Joana Fernandes (Universidade do Porto, Faculdade de Ciências; CIIMAR, Portugal);** Clara Lázaro (Universidade do Porto, Faculdade de Ciências; CIIMAR, Portugal); Telmo Vieira (Universidade do Porto, Faculdade de Ciências; CIIMAR, Portugal); Nelson Pires (Universidade do Porto, Faculdade de Ciências; CIIMAR, Portugal); Eliana Vieira (Universidade do Porto, Faculdade de Ciências, Portugal)

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Oral

## **Abstract:**

Since 1992, satellite altimetry observations from two complementary missions have been playing a crucial role in studies such as climate change. Launched in January 2016, Jason3 (J3) is the fourth of the series of the so-called reference missions, flying in 10-day repeat orbits. Launched in February 2016, Sentinel-3A (S3A) is the first of the Sentinel-3 constellation, in a new 27-day repeat orbit, followed by Sentinel-3B (S3B) in April 2018, flying on the same orbit, 140° apart. The 27-day orbit replaced the 35-day configuration of the ERS/Envisat and SARAL series.

The importance of having range and geophysical corrections with the same level of accuracy of the altimeter range retrievals has long been recognised. Amongst these corrections, the wet tropospheric correction (WTC), accounting for the path delay induced by the presence of water vapour and cloud liquid water in the atmosphere, has particular relevance due to its high 4D variation. The most accurate method to retrieve the WTC is by means of collocated observations made by microwave radiometers (MWR) placed aboard the main altimetric missions. However, these instruments and respective retrieval algorithms have been designed for open ocean. Moreover, they are prone to instabilities such as drifts or external interferences.

The aim of this study is to inspect the MWR on board Jason-3 and Sentinel-3 and corresponding wet path delays (WPD) derived from these instruments, in terms of their accuracy and stability. The absolute and relative calibrations of these MWR are crucial tasks to ensure the retrieval of sea level climate data records from the respective altimeters.

An in-depth study of J3, S3A and S3B MWR performance has been carried out by means of i) validation against other MWR such as the Special Sensor Microwave Imager Sounders (SSMIS) aboard F16, F17 and F18 and the Global Precipitation Measurement (GPM) Microwave Imager (GMI), with GNSS observations, with a GPD+ WTC using only third-party data and with the ERA5 reanalysis model; ii) inter-comparison of the 3 instruments, namely S3A/S3B during the S3 mission tandem phase. In what concerns the analysed parameters, both the brightness temperature (TB) of the various MWR channels and the WTC were analysed. The two retrieval algorithms present on S3A products (from 3 and 5 parameters) have also been assessed.

Results reveal an RMS difference between SSM/IS and J3 of 1.2 and 0.9 cm before and after adjustment of the two datasets, solving for two parameters: offset (0.95 cm) and scale factor (0.99). On average, J3 measures dryer than SSM/IS by 1 cm.

After the last reprocessing, the differences between S3A and S3B are very small ( $\Delta TB_{23} = -0.2 \pm 0.4$  K;  $\Delta TB_{36} = -0.1 \pm 0.8$  K;  $\Delta WTC = 0.2 \pm 0.2$  cm), evidencing the good agreements between the two sensors.

Concerning S3A data for the first 3 years of mission, the MWR-derived WTC agrees well with that from the GMI and J3 MWR, with RMS differences of 0.9 and 1.1 cm, respectively. Scale factors and offsets of S3A with respect to other sensors are 1.0 and 0.2 cm (w.r.t. GMI) and 1.0 and 0.1 cm (w.r.t. J3, previously adjusted to SSM/IS), respectively. This illustrates that, once J3 is aligned with the SSM/IS sensors, both J3, S3A and S3B sensors seem to be aligned.

Strong ice and land contamination can be observed in both S3A and S3B instruments, the latter one being mainly up to 25 km, as shown by comparisons with GNSS. The corresponding results for J3, reveal a much reduced land effect, still up to about 25 km from the coast. No significant difference has been found between the two WPD retrieval algorithms adopted in Sentinel-3.

By comparison with SSM/IS, GMI, GNSS and the GPD+ WTC solely derived with third-party data, the long-term evolution of J3 and S3A radiometers for the first 3 years of their missions has been analysed. Considering this time span, too short to infer any possible drift in any of these instruments, the respective WPD seem to be relatively stable.

In spite of the good overall performance of J3 and S3A/B radiometers over open-ocean, in view to get accurate WTC, valid everywhere, in particular in coastal and polar regions, updated GPD+ WTC have been derived and the gain obtained by these datasets in these regions will also be presented.

**Corresponding author:**

**M. Joana Fernandes (Universidade do Porto, Faculdade de Ciências; CIIMAR, Portugal), [mjfernan@fc.up.pt](mailto:mjfernan@fc.up.pt)**

# Altimeter 1D-Var Tropospheric Correction for Sentinel-3

**Ralf Bennartz (Vanderbilt University, United States);** Bruno Picard (Fluctus SAS, France); Frank Fell (Informus GmbH, Deutschland); Estelle Obligis (Eumetsat, Deutschland)

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias  
**Presentation type:** Oral

## **Abstract:**

A major source of uncertainty for SSH estimates from radar altimetry is the wet tropospheric correction (WTC). The spatial and temporal variability of water vapour is such that an instantaneous estimation of its impact is needed.

Since February 2016, these observations are being provided by the SRAL / MWR pair of instruments flown on-board the Sentinel-3A (S3-A) satellite, which in April 2018 has been complimented by the identically equipped Sentinel-3B (S3-B) satellite. S3-A, S3-B (and, in the future S3-C) thus provide critical continuing radar altimeter and MWR coverage at a 10:00 local time sun-synchronous high inclination orbit for the next ten or more years.

The ESA GMES Sentinel-3 System Requirements Document has defined the requirements for the topography mission over ocean. The overall objective is a measurement of the altimeter range with an error below 3 cm. Apart from the sea state bias which absorbs the remaining errors on the altimeter measurements, the WTC is indeed the major source of error, associated with a requirement on retrieval accuracy of 1.4 cm.

The current retrieval approach for Sentinel-3 is based on a “mixed” approach successfully applied since ERS-1, the adjective “mixed” referring to the joint use of statistical and physical methods. These operationally applied algorithms provide WTC estimates with a good accuracy over the open ocean. However, systematic errors may occur at regional scales, where atmospheric characteristics are not well represented in the learning database.

These errors are propagated into the final sea level maps, leading to local biases. Land contamination in radiometer observation near coasts is another source of degradation of WTC retrievals, caused by the sharp gradient between land and sea brightness temperatures (land surface emissivity is about 2-3 times higher than sea surface emissivity).

Previous studies have already shown the potential of variational methods such as one-dimensional variational approaches (1D-Var) to retrieve temperature, humidity and cloud vertical profiles. Over ocean, SSMIS measurements were assimilated under clear and cloudy non-precipitating conditions by Deblonde and English [2003] to retrieve temperature and humidity profiles as well as liquid water content. Hewison [2007] assimilated ground-based microwave observations as well as other IR and surface sensor measurements in a 1D-Var scheme to retrieve temperature, humidity and cloud profiles using a specific cloud classification scheme.

Finally, the study conducted by Bennartz et al. [2017] aims at retrieving TCWV and WTC over ocean using measurements from the Microwave Radiometers (MWR) onboard the ERS-1/-2 and Envisat platforms.

The mentioned studies demonstrate the potential of the 1D-Var approach as a relevant global method to retrieve WTC and its particular value for creating inter-calibrated long-term datasets from multiple satellites that are

essential to climate studies. In addition to the retrieval, this method also provides a-posteriori retrieval uncertainties with all retrieved parameters, which are not available from the current empirical algorithms.

Herein, we propose to apply an existing 1D-Var solution originally developed by the authors for the MWRs onboard ERS-1, ERS-2, and Envisat [Bennartz et al., 2017] also to Sentinel-3 MWR observations to retrieve TCWV and WTC over the open ocean. The performance will be validated against GNSS observations and using the usual altimetry metrics, such as the difference of SSH variance at cross-overs.

**Corresponding author:**

**Ralf Bennartz (Vanderbilt University, United States), [bennartz@me.com](mailto:bennartz@me.com)**

# Modelling the vertical dependence of the Wet Path Delay: application in satellite altimetry over coastal and inland waters

**Telmo Vieira (Universidade do Porto, Faculdade de Ciências; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR), Portugal); M. Joana Fernandes (Universidade do Porto, Faculdade de Ciências; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR), Portugal); Clara Lázaro (Universidade do Porto, Faculdade de Ciências; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR), Portugal); Nelson Pires (Universidade do Porto, Faculdade de Ciências; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR), Portugal)**

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Oral

## **Abstract:**

The accuracy of water surface height measurements from satellite radar altimetry, depends on the accuracy of all terms involved in its computation, namely the effect due to the Wet Path Delay (WPD). With a high spatial-temporal variation, the most accurate way to measure the WPD over open-ocean is from on-board Microwave Radiometers (MWR) measurements. Satellite altimetry has been used over coastal and inland waters, however the WPD retrievals from MWR become invalid and cannot be used over these regions of interest. Alternative WPD sources for these zones can be Global Navigation Satellite Systems (GNSS) and Numerical Weather Models (NWM), e.g. those from the European Centre for Medium-Range Weather Forecasts (ECMWF).

Designed for applications over the ocean, altimetric missions are mainly focused on the sea surface and, for this reason, all corrections such as MWR-derived WPD must refer to the sea level. On the contrary, WPD derived from an NWM are computed at the level of its orography and the corresponding path delays from GNSS are available at each station height. Due to these different vertical references, the modelling of the altitude dependence of the WPD is a crucial step to better combine these different WPD sources, particularly important for altimetry application over coastal and inland waters. Therefore, expressions to reduce the various WPD to sea level (over coastal zones) and to water body height (over continental waters) are required. The most commonly used expression for the WPD altitude reduction has been developed by Kouba (2008), however it has some limitations, since it considers the same altitude reduction, irrespective of the WPD spatial-temporal variation.

The focus of this study is the modelling of the altitude dependence of the WPD, aiming at developing improved expressions to account for its complex 4-D variability. For this purpose, the latest ERA5 reanalysis from ECMWF is used. It provides hourly atmospheric parameters at  $0.25^\circ \times 0.25^\circ$  spatial sampling on 137 vertical levels. To be used in this modelling, global WPD vertical profiles have been computed for a time span of 4 years.

This study is performed in three main steps. First, the errors introduced when using the Kouba expression are quantified in terms of their spatial distribution. For this purpose, two WPD are derived from ERA5 at pressure levels: i) from single level (orography) parameters and then reduced to the upper pressure levels using the Kouba expression (the so-called 2-D approach); ii) from numerical integration of 3-D parameters (temperature and specific humidity), from the top of the atmosphere down to the orography, at each pressure level (the so-called 3-D approach). The comparison between these two WPD profiles reveals differences with RMS values up to 3.2 cm, with larger differences at low latitudes, mainly attributed to errors in the height reduction performed using the Kouba formula.

Secondly, improved expressions have been developed in this study (so-called UP expressions), considering spatial and temporal dependent coefficients. As performed for the Kouba expression, the same assessment using ERA5 data (for a period not used in this modelling) has been performed for the UP expressions. Considering only regional-dependent coefficients in the UP modelling, for the region where Kouba reduction has an RMS error of 3.2 cm, when using the UP reduction this value is 1.2 cm, corresponding to an RMS error decrease of 2 cm. These results also show that the inclusion of temporal-dependent coefficients in this modelling can lead to an RMS error decrease larger than 1 cm in some regions.

Finally, the last step of this study concerns the validation of the various expressions using in-situ data: radiosondes (RS) and GNSS. At each RS site two WPD vertical profiles are considered: the first one computed from 3-D RS data and the other one considering only the WPD at the lowest RS vertical level, further reduced to the upper levels using the different altitude reductions (Kouba and UP). A similar validation is performed at GNSS sites by comparing GNSS-derived WPD at station height and those derived from ERA5 using the 2-D approach further reduced to the same station height. Results with RS and GNSS data show that the RMS of the WPD differences decrease by more than 1 cm, when UP modelling is used instead of Kouba, thus quantifying the impact of the new expressions in the derivation of accurate absolute water levels in these regions.

**Corresponding author:**

**Telmo Vieira (Universidade do Porto, Faculdade de Ciências; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR), Portugal), [telmo.vieira@fc.up.pt](mailto:telmo.vieira@fc.up.pt)**



# Performances and stability assessment of Sentinel3 Microwave radiometers

Marie-Laure Frery (CLS, France); Mathilde Siméon (CLS, France); Pierre Féménias (ESA, Italy)

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Oral

## **Abstract:**

Sentinel-3B was launched the 25 April 2018, two years after Sentinel-3A. The two radiometers are identical in design. The pair of satellite will increase coverage and data delivery for Copernicus service. For routine operation, Sentinel-3 configuration is such that both satellites will fly with a 140° separation.

The two-channels microwave radiometer (23.8 and 36.5 GHz) on board the two missions is similar to the Envisat and ERS MWR sensors. It is combined to the altimeter in order to correct the altimeter range for the excess path delay (WTC for wet tropospheric correction) resulting from the presence of water vapor in the troposphere.

The wet tropospheric correction (WTC) is a major source of uncertainty in altimetry budget error, due to its large spatial and temporal variability. It also contributes significantly to the uncertainty in the long term mean sea level trend.

In order to better quantify the WTC trend, it is important to focus on the detection of potential instrumental drifts. The long-term stability of each radiometer will be assessed using different methods.

First, vicarious calibrations are statistical selections of coldest and hottest temperatures over the ocean and the Amazon forest respectively. They are commonly used for the in-flight calibration during commissioning phase, but also for long-term monitoring.

Second, the double difference accounts for frequency, Earth Incidence Angle, and orbital differences between platforms. To calculate the double difference, the single differences for each radiometer are first computed. The single difference is found by taking the difference between a reference statistic of the observed radiometer brightness temperatures (TBs) and a reference statistic from simulated TBs. The double difference is then the difference between the single differences of the two radiometers. Single differences suffer from the discontinuities introduced by evolutions of the Numerical Weather Prediction model due to improvements in the operational version or modification of the assimilation scheme. By construction, double differences cancel out the impact of these evolutions.

Third, comparison to Fundamental Climate Data Record will be performed for overlapping periods. FCDR are homogenized and intercalibrated brightness temperatures to ensure long term stability suitable for climate related applications.

Finally, conclusions can be drawn on the stability of the WTC.

## **Corresponding author:**

Marie-Laure Frery (CLS, France), [mdenneulin@groupcls.com](mailto:mdenneulin@groupcls.com)

# High Resolution Microwave Radiometer (HRMR) on Sentinel-6

**Shannon Brown (JPL, United States);** Tanvir Islam (JPL, United States); Pekka Kangaslahti (JPL, United States); Isaac Ramos (JPL, United States); Sharmila Padmanabhan (JPL, United States)

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Oral

## **Abstract:**

Sentinel-6 will carry the latest edition of the Advance Microwave Radiometer, termed AMR-C. This radiometer includes external stable calibration sources to stabilize the data for climate studies and an experimental high-frequency radiometer called the High Resolution Microwave Radiometer (HRMR). The HRMR has channels at 90, 130 and 166 GHz. We will describe the HRMR instrument design and highlight results from the pre-launch performance characterization. The HRMR data will be used to provide path delay measurements up to about 5km from land with 1cm accuracy. We will describe the pre-launch algorithm and plans for distributing the HRMR PD product after the Sentinel-6 A launch. We will show performance estimates for the algorithm as applied to data from the GPM Microwave Imager, which has similar channels as the HRMR.

## **Corresponding author:**

**Shannon Brown (JPL, United States),** shannon.t.brown@jpl.nasa.gov

# Next-generation radiometer instruments, algorithms, and uncertainties due to 24 GHz 5G interference

**Tanvir Islam (NASA JPL, United States);** Shannon Brown (NASA JPL, United States); Sidharth Misra (NASA JPL, United States)

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Oral

## **Abstract:**

This presentation summarizes the recent advancements in radiometer instruments and algorithms development at the NASA's Jet Propulsion Laboratory for the next-generation path delay correction in the Sentinel-6/SWOT-era. Particularly, the Sentinel-6 mission will provide continuity to ocean surface topography measurements started by the Topex/Poseidon mission launched in 1992, followed by Jason-1 in 2001 and Jason-2 in 2008. The Advanced Microwave Radiometer (AMR) is one of the primary instruments on-board the current altimetry missions (Jason-2/Jason-3) that determines radar travel time delay, also known as path delay (PD), caused by atmospheric water vapor and liquid water content in the atmosphere using three frequency channels (23.8, 18.7 and 34.0 GHz). The AMR-C (Climate Quality) receiver for the Sentinel-6 is an improvement from the previous AMR, designed and developed to meet the level 3 payload requirement of long-term radiometric stability through Supplemental Calibration System (SCS). In this presentation, we will report preliminary pre-launch radiometric performances from the Sentinel-6 AMR-C instrument.

Besides, a next-generation Combined Active Passive Retrieval System (CAPRS) is developed at JPL that uses all information available in both active/passive radar and radiometer instruments. The next-generation CAPRS system is based on variational inversion technique, where, path delay and other atmospheric parameters, including wind speed and cloud liquid water are derived simultaneously using both the information available from the radiometer brightness temperature and altimeter backscatter measurements. The status and results from the CAPRS system will be presented. Our final part of the presentation will cover the simulation studies performed at JPL to understand the impact of 24 GHz 5G interferences on AMR radiometers. The uncertainties on path delay measurements due to the interferences, and possible mitigations will be discussed.

## **Corresponding author:**

**Tanvir Islam (NASA JPL, United States),** [tanvir.islam@jpl.nasa.gov](mailto:tanvir.islam@jpl.nasa.gov)

# The Latest Updates at PO.DAAC

Jessica Hausman (JPL, United States)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Oral

**Abstract:**

The Physical Oceanography Distributed Active Archive Center (PO.DAAC) is NASA's data center responsible for data management and distribution of satellite oceanographic data, as well as providing support for its scientific user base. Part of this support comes as providing data and expanding its data holding and services for those data to accommodate the various user communities. This year PO.DAAC has new versions of gridded sea surface heights and terrestrial water height time series. There are also new missions, GRACE-FO and Oceans Melting Greenland (OMG), at PO.DAAC. To help users know if these data are being used, along with the rest of PO.DAAC's data holdings, data metrics, based on citations, are now provided on the dataset landing pages. The whole web portal has been redesigned and modernized so information is easier to discover by simplifying the design and improving search results.

**Corresponding author:**

Jessica Hausman (JPL, United States), [jessica.k.hausman@jpl.nasa.gov](mailto:jessica.k.hausman@jpl.nasa.gov)

# The ESA CCI Knowledge Exchange: explaining climate from space with altimetry and other EO data

**Stephen Plummer (ESA Climate Office, United Kingdom);** Ed Pechorro (ESA Climate Office, United Kingdom); Paul Fisher (ESA Climate Office, United Kingdom); Paolo Cipollini (ESA Climate Office, United Kingdom)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Oral

## **Abstract:**

The ESA Climate Change Initiative (CCI) is a research programme which aims to realise the full potential of the global Earth Observation archive to generate long-term satellite-derived Essential Climate Variables (ECVs) in support of the UNFCCC and IPCC.

Comprising 23 projects focussed on developing ECV data products across atmospheric, oceanic and terrestrial domains, two budget closure projects and a Climate Modelling User Group for product assessment, the CCI programme has advanced understanding of climate science through a large portfolio of results, documentation and scientific publications. The primary aim is to support IPCC assessment reports and make tangible impacts on decision making.

Following the success of the initial phase of the CCI programme (2010-2017), a subsequent phase (2018-2024) is now underway and places a stronger emphasis on knowledge exchange beyond science and policy circles, to increase young people's awareness of ESA EO in particular by utilising ECV data in example applications of science, in school and university curricula.

Here we present the two existing CCI engagement and outreach tools – the Climate from Space tablet app and the CCI Toolbox – that help to visualise, manipulate and analyse climate observation data; we show examples of their application where the altimetry-derived ECVs (Sea Level and Sea State) are combined with other ECVs (which is facilitated by the adoption of a common data standard within the CCI) to allow the investigation of climate processes.

We then discuss the lessons learned, which are shaping the evolution of knowledge exchange work in the current phase of the CCI; and finally we present our plans to engage the next generation of EO specialists and scientists on the topic of monitoring Climate from Space.

## **Corresponding author:**

**Stephen Plummer (ESA Climate Office, United Kingdom),** [stephen.plummer@esa.int](mailto:stephen.plummer@esa.int)

# Ocean and Climate Change Education Using Fiction

LuAnne Thompson (University of Washington, United States); Kathie Kelly (Self, United States)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Oral

## **Abstract:**

In an era where the opinions of experts are derided and facts themselves are questioned, alternative ways are needed to reach the public about the threats to the ocean environment and the role of the ocean in climate change. Fictional narratives can hold the attention of an audience and increase retention of information more than fact-based presentations. We are producing a climate-fiction ("cli-fi") web series about scientists' response to interference in sea level observations using a thriller format. "An Unlikely Insurgency" integrates accurate climate and ocean science into a story about the sabotage of a sea level satellite, the consequences for hurricane prediction and the actions taken by an outraged public. Scientists form a secret organization (the Insurgency) to counter and expose political meddling by climate deniers. The characters include a climate scientist and her daughter (a network security engineer), her graduate student and a coastal biologist. Their personal interactions, as well as their dedication to their mission, carry the narrative through political intrigue, generational conflict and romance, combined with discussions of sea level and its measurement. The goal is to illustrate the possible disastrous consequences of interference in climate research and loss of our measurement systems. We will show one (of five) eleven-minute episodes.

## **Corresponding author:**

LuAnne Thompson (University of Washington, United States), [luanne@uw.edu](mailto:luanne@uw.edu)

# Citizen science and volunteers in floateco project

**Nikolai Maximenko (IPRC/SOEST, University of Hawaii, United States);** Linsey Haram (Smithsonian Environmental Research Center, United States); Mary Crowley (Ocean Voyages Institute, United States); Jan Hafner (IPRC/SOEST, University of Hawaii, United States); Gregory Ruiz (Smithsonian Environmental Research Center, United States); James Carlton (Williams College, United States); Luca Centurioni (Scripps Institution of Oceanography, United States); Andrey Shcherbina (Applied Physics Laboratory, University of Washington, United States); Cathryn C Murray (Fisheries and Oceans Canada, Canada)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Oral

## **Abstract:**

Artificial floating marine debris generated by disasters and everyday operations can carry some species over long distances and provide a substrate for a new type of pelagic ecosystem, in which coastal species can survive and establish signifying another global change caused by people.

FloatEco is a multi-institutional, interdisciplinary project, co-sponsored by the NASA Physical Oceanography and NASA Biodiversity and Ecological Forecasting, studying physical and biological processes maintaining such floating ecosystem.

FloatEco heavily relies on help of dozens of companies and individuals to:

- deploy, inspect and recover scientific instruments;
- collect biological samples;
- search floating debris and tag it with satellite trackers;
- survey large debris to validate satellite and model data;
- publicize outcomes of the project and raise awareness.

In this presentation we overview our experience and achievements in collaboration with citizen scientists and volunteers during the first year of the project.

Figure Caption. Collage of photographs from citizen scientists and volunteers, who contributed to FloatEco project.

## **Corresponding author:**

**Nikolai Maximenko (IPRC/SOEST, University of Hawaii, United States),** maximenk@hawaii.edu

# Argonautica, altimetry from kindergarten to engineering school

Danielle De Staerke (CNES, France); Vinca Rosmorduc (CLS, France)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Oral

## **Abstract:**

Since Fall 2000, the French Space Agency, Cnes, has proposed to teachers and their classes, mostly at primary and secondary school levels (but not only), to monitor marine animals and buoys using Argos location system. This STEM educational project is called "Argonautica", joining both Argos and Jason (and his Argonauts) in its name. It aims to help pupils understand the ocean, its relation to environmental change and the effects on the living world. It also shows them what roles satellites can have in monitoring and understanding these resources. Students and teachers can thus undertake a real scientific investigation with hypothesis, ways to check on them, and analysis of results, with help from scientific partners. It has three different sub-projects, with joint resources for the first two.

With "ArgOcean", students can compare the buoys' tracks with ocean data – from satellites such as the Jason altimeters and others, or from an ocean circulation model. Moreover, classes can build their own buoy, from designing the shell to integrating the electronics or even designing new instruments to measure storms or plastic in the ocean.

ArgoNimaux is the most popular for the youngest, who can choose to track a marine animal week by week, in collaboration with researchers, and also compare their tracks with ocean data. They can see the impact of the ocean variations on marine animals, and learn more about the animals' behaviour, their migrations, foraging trips, etc.

And with the newest branch, ArgoHydro, students can measure in situ data (precipitation, soil moisture, lake and river levels) and correlate them with satellite data (Precipitation, Soil Moisture, water level,...). There also they can design their own buoy, or instrument(s) onboard UAVs, with the added value that they can do the measurements close to their school. ArgoHydro is designed to complement the international Global Learning and Observation to Benefit the Environment (GLOBE) Program. This activity is also held in the frame of the Surface Water and Ocean Topography (Swot) satellite, developed by Nasa and Cnes.

Material is available in French, but also in English for the main information on the project and on the data.

## **Corresponding author:**

**Danielle De Staerke (CNES, France)**, [danielle.destaerke@cnes.fr](mailto:danielle.destaerke@cnes.fr)



# Outreach & data services showcases

All All (OSTST, France)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Oral

**Abstract:**

time slot for outreach showcases, short (1-2 slides) presentation of an Outreach and/or data services activity.

**Corresponding author:**

All All (OSTST, France), vrosmorduc@cls.fr

# The Copernicus marine service wave reanalysis : WAVERYYS

**Lotfi Aouf (Division Marine et Océanographie Météo-France, France);** Stephane Law-Chune (Mercator-Ocean international, France); Alice Dalphinnet (Meteo-France, France); Yann Drillet (Mercator-ocean international, France)

**Session:** Application development for Operations

**Presentation type:** Oral

## **Abstract:**

The global wave reanalysis of the Copernicus Marine service WAVERYYS has been completed in July 2019 and covers the altimetry period from 1993 to 2018. More than 20 wave parameters will be released in September 2019. WAVERYYS is performed by the wave model MFWAM with a grid size of 20 km and driven by 3-hourly ERA5 winds provided by ECMWF atmospheric system. WAVERYYS assimilates both altimeters wave data including the latest mission S3A in SAR mode, and SAR directional wave spectra provided by Sentinel-1A and 1B. WAVERYYS is the first wave reanalysis including a surface currents forcing from the currents reanalysis performed by CMEMS global ocean system (GLORYS2).

This work consists in validating the wave parameters provided by the reanalysis WAVERYYS. We compared significant wave heights of the wave reanalysis with the ones from independent altimeter HY2A which is processed and provided by the CNES. The results show a good normalized scatter index of SWH globally ~10%. One can mention also a better performance of scatter index of SWH from WAVERYYS by 10 to 15% in comparison with ERA5 wave products. Results on the validation with the buoys will be also discussed. We also investigated the performance of WAVERYYS and ERA5 in different ocean regions.

We shed light on the added value of including wind/waves interactions in the wave reanalysis in particular for years with strong sea surface temperature anomalies such as 2010.

Further discussions and comments will be presented in the final presentation

## **Corresponding author:**

**Lotfi Aouf (Division Marine et Océanographie Météo-France, France),** [lotfi.aouf@meteo.fr](mailto:lotfi.aouf@meteo.fr)

# Water-Watch: a New Phase of the Operational Monitoring of Lakes, Wetlands, and River Reaches for Natural Hazards and Regional Security

Charon Birkett (University of Maryland, United States); Martina Ricko (KBR, USA); Hunter Yang (KBR, USA); Brian Beckley (KBR, USA)

**Session:** Application development for Operations

**Presentation type:** Oral

## **Abstract:**

Water-Watch is a new NASA/USDA funded operational program offering water-related products for lakes, reservoirs, river reaches, and wetland zones. These will be derived from the i) NASA/CNES and ESA/ISRO/CNES series of radar altimeters, ii) the Landsat/MODIS series of multispectral imagers, and iii) the SRTM, ASTER, and ICESat-2 DEM's. The products will be a combination of water level, surface extent, water storage, and bathymetry. The main stakeholders are the USDA/Foreign Agricultural Service, various Wetland-related organizations, and USACE/NGA.

There is an increasing demand for a global monitoring service that in particular captures the variations in the smallest (1 to 100 km<sup>2</sup>) reservoirs and water holdings in arid and semi-arid regions. Here, water resources are critical to both agriculture and regional security. There is also a demand for surface water level products across wetland zones in respect of inland fisheries and assessments of catch potential. Observations of river reaches in gauge-poor regions has also been requested in lieu of spring melts and flood hazards.

In addition to meeting operational requirements, recent efforts to create (up to) 25yr timelines has also shown that great care needs to be taken with respect to the merger of results from multiple instrument platforms. This is in regards to the formation of high quality Earth Data Records or for the creation of Long-Term Status Indicators which inform end users of deviations from normal conditions.

The additional application of hydrological modelling and the recording and monitoring of hypsometry is also being added to the program. Although not as efficient as (say) direct water level observation, preliminary studies have shown that these alternate methods offer a secondary "inferred" water level product that can be used to highlight seasonal and inter-annual variability to determine trends and inter-decadal changes.

## **Corresponding author:**

Charon Birkett (University of Maryland, United States), [cmb@essic.umd.edu](mailto:cmb@essic.umd.edu)

# Utilization of Satellite Altimetry Data in Monitoring Intraseasonal Oscillations in the Indian Ocean

**Subrahmanyam Bulusu (University of South Carolina, United States);** Heather Roman-Stork (University of South Carolina, Columbia, USA); Corinne Trott (University of South Carolina, Columbia, USA)

**Session:** Application development for Operations

**Presentation type:** Oral

## **Abstract:**

The Indian Ocean experiences ISOs on a variety of time scales, including the 30-90 days Madden-Julian Oscillation (MJO) events, the quasi-biweekly 10-20 day signal, and the 3-7 day signal representative of weather/synoptic-scale events as a response to oscillations of the monsoon trough. These ISOs are responsible for variation from mean conditions of monsoonal rainfall and are central in modulating active (wet) and break (dry) monsoon conditions. The MJO is an atmosphere-ocean coupled event that regulates wet and dry conditions in the tropical Indian and Pacific Oceans. MJO-related ISO events drive a unique ocean-atmosphere feedback loop of alternating upwelling and downwelling Rossby waves that drive concurrent outgoing longwave radiation (OLR) anomalies and fluctuations in mixed layer depth. The synoptic structure and atmospheric dynamics of the quasi-biweekly mode have been well investigated and are related to westward-propagating surface pressure cells, but the oceanic response is not as well understood. The 3-7 day synoptic/weather signal is closely related to the active and break phases of oscillations of the monsoon trough. There is still insufficient quantification of the relationship between these ISOs and how surface waters in the Indian Ocean react with respect to sea level anomalies (SLA). Altimetric derived SLAs, unlike sea surface temperature (SST) and salinity, do not experience precipitative contamination due to propagation of convective monsoon conditions or riverine input, but instead represent the dynamic response of the ocean to ISOs well. Through the analysis of ISOs and SLA, one can develop a clear spatial and temporal understanding of how oceanic conditions respond to atmospheric events. In this work, we focus on local and basin-wide signals, zonal and meridional propagation, and variability of ISOs with respect to the strength of the summer monsoon season over a 25 years period (1993-2018). This study examines the relationship between larger- and shorter-period ISOs in SLA and shows the usefulness of altimetry data in Indian monsoon studies.

## **Corresponding author:**

**Subrahmanyam Bulusu (University of South Carolina, United States),** sbulusu@geol.sc.edu

# Toward Higher resolution Level3 altimeter products for Assimilation Systems

**Marie Isabelle Pujol (CLS, France);** Yannice Faugère (CLS, France); Mounir Benkiran (MOI, France); Oscar Vergara (CLS, France); Gérald Dibarbouré (CNES, France)

**Session:** Application development for Operations

**Presentation type:** Oral

## **Abstract:**

In 1998, first Level3 along-track, user friendly altimeter products have been developed with support from CNES and delivered to the users on AVISO+. The Level3 processing includes a homogenisation of the SLA for the different altimeters (i.e. reduction of the global and regional biases), allowing the users to directly use the products without any pre-processing. They are widely used for different applications, including assimilation in numerical models. Since 2008, such products are generated and disseminated by the Copernicus Marine Service (CMEMS; previously MyOcean during its demonstration phase). They allow the user to change the physical content of the altimeter measurement in consistency with the model capabilities and characteristics, thus considerably improving the results of the assimilation of the altimeter measurement into the models.

With the future altimeter missions as the large swath SWOT mission, the altimeter processing will face a new challenge: be able to accurately process the signal at finer spatial scales. On the other hand, users and more particularly modelers need to make their system ready for assimilation and propagation of the finer scale structures observed. With that objective, a new generation of along-track products is under development with support from CNES. They are derived from high resolution (20Hz) altimeter measurement and are specifically processed in order to solve finer scales up to ~30 km. Recent development enabled to optimize the Sentinel3 SAR altimeter processing (Boy 2017, Moreau, 2018) and the Jason/Altika noise level (Zaron 2016, Tran 2019) and allow us to better exploit the fine-scale content of the altimetric missions. Experimental datasets, with a nearly 1km (5Hz) sampling, are already available on AVISO+ (<https://www.aviso.altimetry.fr/duacs>) and can be tested by users.

Operational and experimental altimeter products and their impact for numerical models will be presented.

## **Corresponding author:**

**Marie Isabelle Pujol (CLS, France),** mpujol@groupcls.com

# Collaborative Design of Real-Time Displays of Forecast Fields for Targeted End-Users

Ted Strub (Oregon State University, United States)

**Session:** Application development for Operations

**Presentation type:** Oral

## **Abstract:**

Using atmospheric forecasts as the conceptual model, one might 'predict' that the primary future operational use of ocean remote sensing products will be as inputs to data-assimilating (DA) ocean circulation forecast models. Here we present our experience in collaborating with Oregon fishermen to design a web site (NVS Seacast, [nvs.nanoos.org/seacast](http://nvs.nanoos.org/seacast)) displaying forecasts from an experimental DA ocean forecast model. The model assimilates altimeter SLA, satellite-SST, and coastal radar surface velocities along the Oregon Washington coast.

Most people would agree that the information products and systems should be developed in collaboration with their intended end-users. However, the methods involved in 'Collaborative Development' are not well-defined and need to extend far deeper than simply asking potential end-users what they want, for example, surveys that ask whether sea-going end-users need to see depths in meters, feet, fathoms or furlongs. Even with such survey information, those designing the systems still rely on their imaginations to guess how their products inform the decisions of those receiving the products. The more basic problem is one of mutual ignorance: The Information Providers do not understand how the information will be incorporated into the critical decisions made by end-users; while Those with the need for the information contained in the products do not understand the range of data that are available from the Data Providers to be converted into the Information Products. Thus, the entire chain needs to be considered as a whole system to provide the best value to all involved.

In the process used to develop Seacast, a series of group discussions and one-on-one interviews were held between: representative regional commercial fishermen (end-users); those designing and modifying the display web site (Information Producers); and those providing real-time data and model forecasts (Data Providers). The focus was on: (1) What decisions the fishermen need to make for their safety and success, and (2) How the available data about present (and future) ocean conditions could best be converted to Information Products and presented to aid in those decisions. The research also involved a more basic examination of the perceptions of risk and uncertainty for each of the groups. The process led to the identification of the most important information to be communicated to aid in end-user decisions, along with suggestions for visual formats that would be most useful at sea or on land (sometimes different). The data providers also communicated the limitations of the available data (observations and forecasts). The lessons learned have a wide range of possible applications in the development of a range of satellite-derived real-time oceanographic products

## **Corresponding author:**

**Ted Strub (Oregon State University, United States)**, [tstrub@coas.oregonstate.edu](mailto:tstrub@coas.oregonstate.edu)

# Corsica: A 20+ Years Multi-Mission Absolute Altimeter Calibration Site

**Pascal Bonnefond (Observatoire de Paris - SYRTE, France);** Pierre Exertier (GET, France); Olivier Laurain (Géoazur, France); Thierry Guinle (CNES, France); Pierre Féménias (ESA/ESRIN, Italy)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Oral

## **Abstract:**

Initially developed for monitoring the performance of TOPEX/Poseidon and follow-on Jason legacy satellite altimeters, the Corsica geodetic facilities that are located both at Senetosa Cape and near Ajaccio have been developed to calibrate successive satellite altimeters in an absolute sense. Since 1998, the successful calibration process used to calibrate most of the oceanographic satellite altimeter missions has been regularly updated in terms of in situ instruments, geodetic measurements and methodologies. In this study, we present an assessment of the long-term stability of the in situ instruments in terms of sea level monitoring that include a careful monitoring of the geodetic datum. Based on this 20+ years series of sea level measurements, we present a review of the derived absolute Sea Surface Height (SSH) biases for the following altimetric missions based on the most recent reprocessing of their data: TOPEX/Poseidon and Jason-1/2/3, Envisat and ERS-2, CryoSat-2, SARAL/AltiKa and Sentinel-3A&B. For the longest time series the standard error of the absolute SSH biases is now at a few millimeters level which is fundamental to maintain the high level of confidence that scientists have in the global mean sea level rise.

## **Corresponding author:**

**Pascal Bonnefond (Observatoire de Paris - SYRTE, France),** [Pascal.Bonnefond@obspm.fr](mailto:Pascal.Bonnefond@obspm.fr)

# The Harvest Experiment: New Results From the Platform and Moored GPS Buoys

**Bruce Haines (Jet Propulsion Laboratory, California Institute of Technology, United States);** Shailen Desai (Jet Propulsion Laboratory, California Institute of Technology, United States); Adam Dodge (University of Colorado, CCAR, United States); Christian Meinig (NOAA PMEL, United States); Bob Leben (University of Colorado, CCAR, United States); Michael Shannon (University of Colorado, CCAR, United States); Scott Stalin (NOAA PMEL, United States)

**Session:** Regional and Global CALVAL for Assembling a Climate Data Record

**Presentation type:** Oral

## **Abstract:**

We describe the latest satellite radar altimeter calibration/validation (CALVAL) results from the Harvest offshore platform, located 10 km off the coast of central California near Point Conception. The platform has hosted a dedicated CALVAL facility for 27 years, dating to the launch of TOPEX/POSEIDON (T/P) in August 1992. The T/P repeat ground track was designed to take the satellite directly over Harvest every ten days, enabling the development of a continuous calibration record based on direct, overhead passes of the platform. The crucial role of T/P in developing a climate-quality record of sea level and ocean circulation has been inherited by the Jason series of reference missions, which have traced out the same 10-d repeat ground track passing through the platform.

We have conducted a number of campaigns to fortify the in-situ observing systems in the Southern California bight, with Harvest remaining as the focal point. These campaigns have two important purposes: 1) to address risk that the platform, which is no longer actively drilling, may be permanently shut down and dismantled; and 2) to prepare for the increasing demands of future altimeter missions, especially SWOT and Sentinel-6, for denser in-situ monitoring. In this presentation, we describe the latest results from both the Harvest platform and regional campaigns, and discuss prospects for future observing systems.

Based on data collected at Harvest during 93 overflights of the latest (Jason-3) mission, we estimate the sea-surface height (SSH) bias is  $-14$  mm. The SSH bias estimates for legacy (T/P and Jason-1/2) systems are in the range of  $\pm 15$  mm, and none are statistically distinguishable from zero when systematic errors sources—such as the platform geocentric position error—are properly considered.

In August, 2018, two precision GPS buoys were moored in the vicinity of Harvest to assess the potential of such systems to replace CALVAL functions of the platform. Over 110 days of continuous high rate (1-Hz) GPS data were successfully collected by both buoys systems. Significant wave heights in excess of 6 m were experienced during this tandem buoy campaign, enabling a robust evaluation of the GPS buoy performance over a wide range of open-ocean conditions. We characterize the accuracies of both relative and absolute SSH from the buoys, and discuss the prospects for using GPS buoys in place of Harvest and to support the validation of SWOT measurements. Finally, we report on the status of regional tide gauge campaigns in the California bight, focusing on the emerging time series from the lidar system on Santa Catalina Island.

## **Corresponding author:**

**Bruce Haines (Jet Propulsion Laboratory, California Institute of Technology, United States),**  
Bruce.J.Haines@jpl.nasa.gov



# Updated absolute altimeter bias results from Bass Strait, Australia

**Christopher Watson (University of Tasmania, Australia);** Benoit Legresy (CSIRO, Australia); Jack Beardsley (Integrated Marine Observing System, Australia); Arthur Zhou (University of Tasmania, Australia); Matt King (University of Tasmania, Australia)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Oral

## **Abstract:**

Here we present updated absolute altimeter bias results from the Bass Strait altimeter validation facility (40° 39'S, 145° 36' E). This work continues the validation effort from Bass Strait that commenced following the launch of TOPEX/Poseidon in 1992. The site has since evolved to include comparison points that service the Jason-series missions, as well as Sentinel-3A and Sentinel-3B. The facility uses an integrated geometric approach to validation that couples a suite of moored oceanographic sensors, episodically deployed GNSS equipped buoys, a coastal tide gauge and continuously operating GNSS reference stations.

Recent developments at the Bass Strait site have focused on further understanding two techniques of particular interest for the validation of future swath-based altimeter missions. The first involves the use of 5-beam ADCP instruments for the determination of shallow water SSH, current and wave field information. The second involves development of an improved GNSS equipped buoy that is suitable for sustained autonomous deployment. We review progress on these developments and present updated absolute bias results from the Bass Strait comparison points.

## **Corresponding author:**

**Christopher Watson (University of Tasmania, Australia),** [cwatson@utas.edu.au](mailto:cwatson@utas.edu.au)

# Current Results from Multi-mission Calibrations at the Permanent Facility for Altimetry Calibration in west Crete, Greece attaining Fiducial Reference Measurement Standards

**Stelios Mertikas (Technical University of Crete, Greece);** Craig Donlon (European Space Agency, The Netherlands); Pierre Féménias (European Space Agency, Italy); Demetris Galanakis (Space Geomatica, Greece); Ilias N. Tziavos (Aristotle University of Thessaloniki, Greece); George Vergos (Aristotle University of Thessaloniki, Greece); Thierry Guinle (CNES, France); Pierrick Vuilleumier (European Space Agency, The Netherlands); Mingsen Lin (National Satellite Ocean Application Service, China); Ge Chen (Ocean University of China, China); Achilles Tripolitsiotis (Space Geomatica, Greece); Xenofon Fratzis (Technical University of Crete, Greece)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Oral

## **Abstract:**

This work presents the updated results for the calibration & validation of several altimeter satellites (Jason-3, Sentinel-3A, Sentinel-3B, CryoSat-2, HY-2, SARAL/AltiKa) determined at the permanent facility for altimetry calibration, west Crete, Greece. Absolute Cal/Val results are obtained using sea-surface and transponder techniques followed by uncertainty budgets based on Fiducial reference Measurement standards.

The latest Cal/Val absolute bias results are given at first for the Jason-3 based upon the descending Pass No.18 but also on the ascending No.109, at sea and on land with the transponder at the CDN1 Cal/Val site. Biases are also provided for the Sentinel-3A and Sentinel-3B crossing over their orbits at the transponder in the mountains of Crete and continuing along the same orbits with the sea-surface infrastructure in the south of Crete and Gavdos Island. Altimeter results are also produced for Sentinel-3A and Sentinel-3B based on descending and ascending passes over the sea around Gavdos. Updates will be provided for the HY-2B and Qualan Chinese satellites. Relative biases are also presented at crossover locations for several altimeters in the vicinity of the permanent facility for altimeter calibration. Future plans for the upscaling of this infrastructure and for improving the derived results will also be presented to cover the upcoming Sentinel-6/Jason-CS, CRISTAL, SKIM and SWOT.

## **Corresponding author:**

**Stelios Mertikas (Technical University of Crete, Greece),** mertikas@mred.tuc.gr

# Comparisons of Jason-3 and Sentinel-3A and tide gauges

**Eric Leuliette (NOAA, United States);** Amanda Plagge (NOAA/Global Science and Technology, Inc., USA)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Oral

## **Abstract:**

As Jason-3 and Sentinel-3A missions have completed more three years of operations, the system drifts in mean sea level can be determined via the global tide gauge network with uncertainties approaching 1 mm/year. Here we extend previously presented work using the combined TOPEX/Jason-1/Jason-2/Jason-3 dataset to estimate the drift in Jason-3. We also examine the drift in Sentinel-3A using comparisons with the gauges by making comparisons for each half cycle (13.5 days) using both SARM and PLRM processing. We will also demonstrate how a combined time series from Sentinel-3A. Using the results from the Jason-3 and Sentinel-3A missions, we discuss our expectations for the monitoring changes in the bias for Sentinel-6/Jason-CS missions.

## **Corresponding author:**

**Eric Leuliette (NOAA, United States),** [Eric.Leuliette@noaa.gov](mailto:Eric.Leuliette@noaa.gov)

# Global Calibration and Validation of Reprocessed TOPEX Data

**Matthieu Talpe (Jet Propulsion Laboratory, United States)**; Jean-Damien Desjonquères (Jet Propulsion Laboratory, USA); Shailen Desai (Jet Propulsion Laboratory, USA); Bruce Haines (Jet Propulsion Laboratory, USA); Philip Callahan (Jet Propulsion Laboratory, USA); Josh Willis (Jet Propulsion Laboratory, USA)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Oral

## **Abstract:**

In this presentation, we show results from the calibration and validation (cal/val) of the most recent reprocessing of TOPEX side A and B measurements. This latest reprocessing relies on numerical retracking (see presentation from Desjonqueres et al. in the Instrument Processing splinter).

Three approaches are highlighted for this cal/val study. First, we examine results of independent TOPEX cal/val: time series of cycle-averaged statistics and geographic patterns to assess the stability of  $\sigma_0$ , altimeter wind speed, significant wave height (SWH), wet path delay, etc. Second, we present results from Jason-1 vs TOPEX inter-mission cal/val: we utilize the tandem period that extends 20 cycles (TOPEX cycles 344-364 and Jason-1 cycles 1-20) to directly compare respective values of uncorrected sea surface height (orbit – range – MSS), sea surface height anomaly (SSHA),  $\sigma_0$ , SWH, etc. Third, we use an independent measure of geocentric SSHA provided by the Harvest platform (see also presentation from Haines et al. in Cal/Val splinter).

Time series of globally-averaged SSHA crossovers show that the newly retracked SSHA measurements are an improvement over the original TOPEX Geophysical Data Records (GDRs). This improvement is corroborated over the Jason-1 tandem phase, during which the standard deviation of SSHA differences (TOPEX vs. Jason-1) are smaller. Furthermore, the geographical distribution of TOPEX-Jason-1 uncorrected sea surface height differences reveal that north/south hemispherical biases in the altimeter measurements of range, SWH, and  $\sigma_0$  observed in the original TOPEX GDRs have been greatly reduced by this latest retracking approach. We also explore the influence of different orbit solutions on these geographical distributions as an indicator of the amplitude of remaining orbit errors.

## **Corresponding author:**

**Matthieu Talpe (Jet Propulsion Laboratory, United States)**, [matthieu.j.talpe@jpl.nasa.gov](mailto:matthieu.j.talpe@jpl.nasa.gov)

# The first three years of Sentinel-3 altimetry – Reprocessing 2019

**Remko Scharroo (EUMETSAT, Germany);** Bruno Lucas (EUMETSAT, Germany); Salvatore Dinardo (HE Space Operations GmbH, Germany); Carolina Nogueira Loddo (EUMETSAT, Germany)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Oral

## **Abstract:**

Sentinel-3 is part of a series of Sentinel satellites responsible for taking care of a continuous 'health check' of the Earth planet under the umbrella of the Copernicus program. The Copernicus program will launch four Sentinel-3 satellites (from A to D) to achieve this goal from 2016 to 2035. EUMETSAT's Marine Centre is responsible for the processing of the Sentinel-3 science data in the marine environment.

Since Spring 2016 Sentinel-3A's SRAL Synthetic Aperture Radar Altimeter has been successfully contributing to the continuity of the sea level climate data record.

This presentation will provide an overview of the latest evolutions of the Sentinel-3 SRAL processing, the relations between Sentinel-3A and -3B processing, and the strategy that EUMETSAT has adopted to provide the consistent long-term data set while continuing to evolve and improve the processing algorithms and standards.

The latest reprocessing "Spring 2019" is the baseline for a quality analysis of the Sentinel-3A Marine Centre data in a multi-mission setting. The latter shall allow for revisiting the status of the Jason-3 and Jason-2, in comparison with Sentinel-3A. To this goal this presentation aims at: providing multi-mission time series of the main climate records (sea level, significant wave height and wind speed); quantifying cross-overs (mono- and multi- mission); as well as provide over 3 years of global assessment of SAR mode versus Pseudo-LRM.

## **Corresponding author:**

**Remko Scharroo (EUMETSAT, Germany),** [remko.scharroo@eumetsat.int](mailto:remko.scharroo@eumetsat.int)

# Performance of the altimetry constellation: contribution of HY2B mission

**Sylvie Labroue (CLS, France)**; Matthias Raynal (CLS, France); H el ene Roinard (CLS, France); Ghita Jettou (CLS, France); Emeline Cadier (CLS, France); Fran ois Bignalet Cazalet (CNES, France); Nicolas Picot (CNES, France)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Oral

## **Abstract:**

We currently have the largest ever flying constellation for sea level observation with Jason-2, Cryosat-2, HY-2A, AltiKa, Jason-3, Sentinel-3A, Sentinel-3B and HY2B missions. While some of the oldest satellites suffer from problems in delivering observations, the constellation has renewed with 4 satellites launched between 2016 and 2018 and providing data records of excellent quality. Indeed, AltiKa satellite is facing platform mispointing problems since early 2019 and Jason-2 was unavailable during the same period which weakened the constellation observation capability.

This paper aims at giving an overview of the quality of the current altimetry constellation, with a focus on the latest newcomer HY2B mission, launched in October 2018. We address the performance of HY2B payload for sea level for mesoscale observation, based on a few months data set. The analysis of the classical metrics used to quantify altimetry performance (data availability, performance of along track sea level, performances at crossovers and sea level short scale content) shows that this mission provides very good data quality. We also show how it compares with different altimetry missions. The comparison with Jason-3 mission is of specific interest since these two altimeters are classical Ku-band LRM altimeters.

## **Corresponding author:**

**Sylvie Labroue (CLS, France)**, sylvie.labroue@cls.fr

# Global Quality Assessment of SARAL/AltiKa's reprocessed GDR-F dataset

**GHITA JETTOU (CLS, France);** Manon Rousseau (CLS, France); Annabelle Ollivier (CLS, France); Nadège Queruel (CLS, France); François Bignalet-Cazalet (CNES, France); Nicolas Picot (CNES, France)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Oral

## **Abstract:**

The SARAL mission was successfully launched on February, 25th 2013 and delivers high quality sea surface topography measurements since. On July 4th, 2016 an orbit maneuver was performed to move the spacecraft to a new orbit where the satellite altitude is no longer maintained, starting the so-called drifting phase.

Since the beginning of the mission February 2013, the GDR (Geophysical Data Record) product version available is the GDR-T (T for Test, see: SARAL/AltiKa's Handbook ). The OSTST community requested several modifications in order to include upgraded algorithms and new standards. Considering these requests, the new GDR-F products will include a tenth of algorithm improvements: instrumental corrections, SWH look up tables, improved wet tropospheric correction, POE-F orbits, new tide models...

The main objective of this study is to assess quality of the GDR-F product over a preliminary set of data. Several methods will be used, such as the comparison with the actual GDR-T data version, but also by cross-calibration with other altimetry missions (Jason-2, Jason-3). The aim is to give an overview of the future dataset and show the improvements at different scales : climate, mesoscales, coastal areas, high latitudes...

Level 2 production will start in September 2019 and the whole dataset will be delivered to users after complete validation, in early 2020. The yet to come GDR-F data will feed the next generation of multi-mission products (CMEMS/AVISO).

## **Corresponding author:**

**GHITA JETTOU (CLS, France),** [gjettou@groupcls.com](mailto:gjettou@groupcls.com)

# Evaluation and exploitation of CryoSat ocean products for oceanographic studies

**Chris Banks (National Oceanography Centre, United Kingdom);** Francisco Mir Calafat (National Oceanography Centre, United Kingdom); Helen Snaith (British Oceanographic Data Centre, United Kingdom); Christine Gommenginger (National Oceanography Centre, United Kingdom); Andrew Shaw (SKYMAT Ltd., UK); Paolo Cipollini (Telespazio VEGA UK for ESA, UK); Nadim Dayoub (National Oceanography Centre, United Kingdom); Jérôme Bouffard (ESA, Italy); Marco Meloni (Serco for ESA, Italy)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Oral

## **Abstract:**

CryoSat's ability to operate in different operating modes over water surfaces led to the first in-orbit evidence of the value of SAR-mode altimetry, and continues to provide a wealth of information not just over ice but also over ice infested waters, the open ocean and coastal regions. After more than nine years in orbit, CryoSat routinely delivers a number of oceanographic products for global ocean applications. A dedicated operational CryoSat ocean processor (COP) has existed since April 2014 generating data products available in near real time (FDM/NOP), within ~3 days (IOP) and a geophysical ocean product (GOP) available within a month. An improved processing baseline was introduced in late 2017 and the same processing chain has now been applied to provide consistent ocean data products from the start of the mission.

Within the ESA funded CryoOcean-QCV project, the National Oceanography Centre (NOC) in the UK is responsible for routine quality control and validation of CryoSat Ocean Products. Activities include the production of daily and monthly reports containing global assessments and quality control of sea surface height anomaly (SSHA), significant wave height (SWH), backscatter coefficient (Sigma0) and wind speed, as well as a suite of validation protocols involving in situ data, model output and data from other satellite altimetry missions. This presentation will review some of the metrics and results obtained for CryoSat Ocean Products for SSHA, SWH and wind speed when assessed against data from tide gauges, wind and wave buoys, WaveWatch III wave model output, HF radar surface current data and comparisons with Jason-2 and Jason-3. Example metrics include SSHA along-track power spectra and the characterisation of offsets and variability regionally and in different sea states.

In this presentation, we demonstrate the quality and scientific value of the CryoSat data in the open ocean where the altimeter operates mainly in conventional low-resolution-mode (LRM) but also over selected ocean regions where CryoSat operates in SAR-mode.

Finally, scientific exploitation of the CryoSat data for oceanographic studies will be illustrated, focusing on CryoSat sea surface height anomalies. We will present examples of the benefits of CryoSat ocean products for oceanographic studies based on a dedicated Level 3 gridded product, featuring investigations of propagating ocean features (e.g. Rossby-type wave propagation) and their signatures in CryoSat in comparisons with data from other sources including SMOS, Sentinel 3A and 3B.

## **Corresponding author:**

**Chris Banks (National Oceanography Centre, United Kingdom),** [chris.banks@noc.ac.uk](mailto:chris.banks@noc.ac.uk)



# Coastal sea level trends and extremes from Delay-Doppler altimetry

**Luciana Fenoglio (University of Bonn, Germany);** Salvatore Dinardo (HeSpace,Darmstadt, Germany); Christopher Buchhaupt (University of Bonn, Germany); Bernd Uebbing (University of Bonn, Germany); Johanna Staneva (Helmholz Zentrum Geesthacht , Germany); Jürgen Kusche (University of Bonn, Germany); Jérôme Benveniste (ESA-ESRIN, Italy)

**Session:** Coastal Altimetry

**Presentation type:** Oral

## **Abstract:**

A significant part of the World's population lives in coastal areas, which are affected by coastal sea level rise and extreme events. Consequently, accurately measuring relative sea level right at the coast is of utmost importance.

It has been shown that conventional (CA) and SAR satellite altimetry provide accurate sea level measurements only up to few kilometres from the coast, the lower limits depending on the retracking procedure used.

These limits are here revised for the 50 Kilometres stripe along the North Eastern Atlantic coasts, with CryoSat-2 in SAR mode since 2010 and several tide gauge stations co-located with GPS stations.

CryoSat-2 and Sentinel-3A data are considered, with Sentinel-3A from June 2016 to Mai 2018 and CryoSat-2 from October 2010 to Mai 2018. Two SAR products are used.: the first from the Marine Copernicus distribution for Sentinel-3A, retracked by SAMOSA2; the second from the ESA GPOD processor SARvatore distribution, for both CryoSat-2 and Sentinel-3A, retracked by the dedicated coastal retrackers SAMOSA+ and SAMOSA++. Similarly, few Reduced SAR altimetry (RDSAR) products are used : from the Marine Copernicus distribution for Sentinel-3A with standard and STAR retrackers and finally the CryoSat-2 data retracked by TALES and STAR. In addition, we compare to two model datasets: the operation BSH model and the coupled Geestacht COAstal model SysTem GCOAST. In-situ sea level and GPS data are from SONEL and BGK/BfG local organisations.

It is found that limits are 4 and 3 kilometres for CA and SAR respectively, for the best dedicated retracking procedures, which are STAR and SAMOSA++. This reduction is important for both coastal ocean dynamics and sea level change studies, and coastal sea surface height can be recovered with 4 cm accuracy, compared to 2 cm in open ocean. However, in estuaries and in coastal zones with high tidal regimes the results deteriorate. Furthermore, the improved agreement between altimetry and in-situ data near coast largely supports the use of co-located in-situ and altimeter data. A toolbox OverVirtual combines altimetry and in-situ data at coast (over-pass) and in estuaries and rivers (virtual-pass).

The impacts of improved SAR data in the coastal sea level trends and extreme sea level analysis on selected regions worldwide has been investigated. For this, we decompose the sea level variability in the coastal stripe and separate seasonal and long-term components. Sentinel-3 offers the best accuracy in seasonal components and trends for its short repeat period. Here, differences with CryoSat-2 results are related to the different repeat period and not to the accuracy of the measurements. Given the long repeat period of CryoSat-2 (369 days) methods are investigated to overcome the spatial imitations and build regional monthly long time-series from CryoSat-2 data. The coastal sea level trends are small. The sea level at extreme events is in good agreement with in-situ data

**Corresponding author:**

**Luciana Fenoglio (University of Bonn, Germany)**, [fenoglio@geod.uni-bonn.de](mailto:fenoglio@geod.uni-bonn.de)

# Assessment of Sentinel-3A and Sentinel-3B altimeter data in the Coastal Zone

**Nadim Dayoub (National Oceanography Centre, United Kingdom);** Chris Banks (National Oceanography Centre, UK); Christine Gommenginger (National Oceanography Centre, United Kingdom); Andrew Shaw (SKYMAT Ltd, UK); Helen Snaith (National Oceanography Centre, United Kingdom)

**Session:** Coastal Altimetry

**Presentation type:** Oral

## **Abstract:**

The performance of satellite altimetry in the coastal zone has historically been a challenging issue. In recent years, there have been significant developments of specialised radar echo fitting ('retracking') algorithms to improve the quality and quantity of altimeter data closer to the coast. In addition, there have been noticeable developments to improve several geophysical corrections that must be applied to altimeter range data in coastal regions (e.g. wet tropospheric delay). Innovative technological solutions have also been used to deliver better performance near the coast. These include Ka-band altimetry with SARAL/AltiKa and its smaller radar footprint; and Delay Doppler Altimetry (DDA) also known as Synthetic Aperture Radar (SAR) altimetry. SAR mode altimetry uses unfocused along-track synthetic aperture to achieve finer spatial resolution along-track and better precision on retrieved parameters.

The SRAL altimeter currently flying on Sentinel-3A and Sentinel-3B can operate in two modes: 1) conventional Low Resolution Mode (LRM) mode corresponding to the pulse-limited altimeters from the TOPEX/Jason reference series; and 2) SAR mode. The default mode for Sentinel-3 SRAL is to operate in SAR mode globally. However, a SAR reduction technique can be applied to incoherently combine SAR mode individual echoes to recreate LRM-type waveforms, to produce what is known as Pseudo-LRM (PLRM). PLRM waveforms follow the conventional Brown model shape of LRM altimetry and can be retracked in the same manner as LRM waveforms. However, PLRM waveforms suffer from the same contamination issues close to land as conventional LRM altimetry.

This paper presents a comprehensive assessment of Sentinel-3A and Sentinel-3B data in the coastal zone. The analyses consider performance in terms of retrieved sea level, SWH and wind speed, of the evolution of these parameters as a function of distance to the coast and of the impact of geophysical corrections. Results are presented for PLRM waveforms from the Sentinel-3A and Sentinel-3B satellites retracked with the NOC implementation of the Passaro et al. (2014) Adaptive Leading-Edge Sub-waveform (ALES) coastal algorithm. The NOC-ALES Sentinel-3 PLRM results are compared with those obtained for Jason-3 LRM retracked with classical and NOC-ALES retracking. The NOC-ALES S3A and S3B PLRM data are also compared with operational Sentinel-3 SAR data to gauge the quality of SAR mode altimetry in the coastal zone compared to conventional coastal altimetry.

## **Corresponding author:**

**Nadim Dayoub (National Oceanography Centre, United Kingdom),** [nayoub@noc.ac.uk](mailto:nayoub@noc.ac.uk)

# Baltic+ SEAL: Building a Sea Level Product for Climate Research in a Region Featuring Jagged Coastline and Sea-ice Coverage

**Felix L. Müller (Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM), Germany);** Marcello Passaro (DGFI-TUM, Germany); Ole B. Andersen (DTU SPACE National Space Institute, Denmark); Denise Dettmering (DGFI-TUM, Germany); Jacob L. Høyer (Danish Meteorological Institute, Denmark); Milla Johansson (Finnish Meteorological Institute, Finland); Kristine Skovgaard Madsen (Danish Meteorological Institute, Denmark); Eero Rinne (Finnish Meteorological Institute, Finland); Rory Scarrott (MaREI Centre for Marine and Renewable Energy, Environmental Research Institute, University College Cork, Ireland); Christian Schwatke (DGFI-TUM, Germany); Florian Seitz (DGFI-TUM, Germany); Eimear Tuohy (MaREI Centre for Marine and Renewable Energy, Environmental Research Institute, University College Cork, Ireland); Laura Tuomi (Finnish Meteorological Institute, Finland); Americo Ambrozio (DEIMOS, c/o ESA-ESRIN, Italy); Marco Restano (SERCOS, c/o ESA-ESRIN, Italy); Jérôme Benveniste (European Space Agency (ESA-ESRIN), Italy)

**Session:** Coastal Altimetry

**Presentation type:** Oral

## **Abstract:**

The Baltic Sea, a semi-enclosed peripheral sea with depths up to 200 meters, features two conditions that severely limit the use of satellite altimetry in high latitude and coastal regions: (i) the presence of seasonal sea ice coverage, and (ii) the proximity of the coast. New improvements (such as the advent of Delay-Doppler, or SAR, altimetry), improved signal processing (retracking), and advances in sea-ice classification methods and geophysical corrections (wet tropospheric correction, sea state bias), have pushed the exploitation of altimetry observations at the regional scale. It is now necessary to explore these advances in a region which strongly features these conditions to improve product quality and applicability, particularly to high latitude and coastal regions. The European Space Agency-funded Baltic+ Sea Level (Baltic+ SEAL) activity is framed as a laboratory, in which advanced solutions in the pre- and postprocessing of satellite altimetry can be tested, and assessed for integration into global initiatives such as the ESA Sea Level Climate Change Initiative. The project will generate high spatio-temporal resolution grids of sea level anomalies to estimate sea level trends, produce an updated mean sea surface model for the Baltic Sea region, and map seasonal sea level variability. It is exploiting the full data resources available from the altimetry era, improving our understanding and the utility of altimetry for high latitude and coastal regions, through the use of the Baltic Sea region as a testbed. Here, the methodology underpinning version 1.0 of the dataset is presented. Among the processing steps we describe:

- The homogeneous retracking strategy applied for open-ocean, coastal and sea-ice conditions (ALES+),
- The unsupervised classification method developed to detect radar echoes reflected by open-water gaps within the sea-ice layer, and
- The development of the gridded product based on a triangulated surface mesh, characterised by a spatial resolution higher than 0.25 degree and enhanced utility for coastal areas.

The methodology is presented along with use of tide gauge data and external optical images to assess the reliability of current results and algorithms, as well as future development approaches.

The benefits of undertaking this activity are two-fold. Firstly, the advances update our current standards of sea level analysis, and best practice for the Baltic Sea region. Secondly, the activity is establishing a state-of-the-art altimetry processing chain, developed in a region specifically featuring two use-restricting conditions. This chain will be delivered in a manner that is easily exported to other key areas.

**Corresponding author:**

**Felix L. Müller (Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM), Germany), [felix-lucian.mueller@tum.de](mailto:felix-lucian.mueller@tum.de)**

# Volume Transport from In-situ and Altimetry Data Over a Wide Continental Shelf.

**Loreley Lago (Centro de Investigaciones del Mar y la Atmósfera (CIMA- CONICET - UBA), Argentina);**  
Martin Saraceno (Centro de Investigaciones del Mar y la Atmósfera (CIMA- CONICET - UBA), Argentina);  
Alberto Piola (Servicio de Hidrografía Naval Argentina (SHN), Argentina); Guillermina Paniagua (Centro de Investigaciones del Mar y la Atmósfera (CIMA- CONICET - UBA), Argentina); Christine Provost (Laboratoire LOCEAN-IPSL, Sorbonne Université, France)

**Session:** Coastal Altimetry

**Presentation type:** Oral

## **Abstract:**

Within the French-Argentine CASSIS project, two bottom-mounted ADCPs were deployed for 11 months in the northern portion of the Argentine Continental Shelf at 60 km and 154 km from the coast, under Jason-2 satellite track #26. The direct velocities time series obtained are the longest measurements available in the region of study. We also constructed in-situ SSH using a coastal TG and the bottom pressure data from both deployments and inferred the associated along-shore geostrophic circulation. Results showed that the de-tided barotropic component dominates the circulation and that it responds to geostrophy. We also found that the variability of the circulation is uniform throughout the whole region. Therefore, the in-situ data resulted suitable for the estimation of the volume transport over the continental shelf, for the section under track #26 from the coast to the 200m isobath. The mean transport value obtained is of 2.4 Sverdrup (1 Sv is  $10^6 \text{ m}^3 \text{ s}^{-1}$ ) towards the NE for the whole period available, in good agreement with previous numerical model estimations. 20-day low-pass filtered in-situ transport correlates very good (0.7, 95% confidence level) with the transport estimated using satellite altimetry currents. We then computed a time series of satellite transport for the complete period available from altimetry data (25 years). The 25-year altimetry transport variability is dominated by the annual cycle, with maximum values during the austral autumn, and minimum values during the austral spring. Satellite transport is also influenced by oscillations between 12 and 60 days associated to the atmospheric forcing, as this region is continuously affected by the passage of both high and low-pressure systems. In particular, continental shelf transport presents a geostrophic response to local wind variability: when the along-shore wind stress flows to the NE, the sea level rises near the shore, which means that a sea level gradient is formed in the cross-shore direction, causing an intensification of the NE component of the along-shore transport. The opposite happens when the along-shore wind stress flows towards the SW. The present study shows encouraging results to the use of satellite altimetry in continental shelves. Yet altimetry data improvements are necessary to solve higher frequencies, especially for regions whose dynamics is strongly influenced by winds.

## **Corresponding author:**

**Loreley Lago (Centro de Investigaciones del Mar y la Atmósfera (CIMA- CONICET - UBA), Argentina),**  
loreleylago@gmail.com

# Combining coastal altimetry and in situ observations to improve Meridional Overturning Circulation estimates: focus on the Southwestern Atlantic

**Matthieu Le Henaff (Univ. of Miami/CIMAS - NOAA/AOML, United States)**; Marion Kersale (Univ. of Miami/CIMAS - NOAA/AOML, United States); Christopher Meinen (NOAA/AOML, United States); Renellys Perez (NOAA/AOML, United States); Maria Paz Chidichimo (Servicio de Hidrografía Naval / Instituto Franco-Argentino sobre Estudios de Clima y sus Impactos, Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina); Marcello Passaro (Deutsches Geodätisches Forschungsinstitut - TUM, Germany); Christian Schwatke (Deutsches Geodätisches Forschungsinstitut - TUM, Germany); Florence Birol (LEGOS, France); Yannice Faugere (CLS, France)

**Session:** Coastal Altimetry

**Presentation type:** Oral

## **Abstract:**

Since 2009, the Meridional Overturning Circulation (MOC) in the South Atlantic has been observed with arrays of in situ moorings on each side of the basin at 34.5°S. To date, the component of the meridional transport inshore of the shallowest moorings on either side (about 1000 m depth) has been estimated using a time-mean from an ocean model simulation due to lack of better observations. However, because of their position offshore on the shelf break, the portion of the transport that is not directly observed is significant and represents 3 to 4 Sv out of the ~18 Sv total MOC transport at 34.5°S. We aim to use along-track coastal altimetry, combined with existing in situ data, to estimate the unobserved inshore component of the MOC transport at 34.5°S. We first focus on the western edge of the array along South America, evaluating the various coastal altimetry Sea Level Anomaly (SLA) products available by comparison with in situ observations. The resulting best combination of range estimates with atmospheric and geophysical corrections obtained from this comparison will be designated as the reference estimate, while the variability among the various coastal altimetry products will be used as an estimate of the uncertainties in the altimetry estimate. The geostrophic currents derived from the along-track SLA data between the coast and the most inshore mooring will then be used to estimate the missing part of the MOC transport inshore of the mooring array. We will discuss the advantages and limitations of this approach, based on these initial results.

## **Corresponding author:**

**Matthieu Le Henaff (Univ. of Miami/CIMAS - NOAA/AOML, United States)**, mlehenaff@rsmas.miami.edu

# Uncertainties in sea ice thickness products from altimetry. Towards new methods

**garnier florent (LEGOS, France);** sara Fleury (LEGOS, FRANCE); Tanguy Jacober (LEGOS, FRANCE); Antoine Laforge (LEGOS, FRANCE); frédérique rémy (LEGOS, FRANCE); benoit meyssignac (LEGOS, FRANCE)

**Session:** Quantifying Errors and Uncertainties in Altimetry data

**Presentation type:** Oral

## **Abstract:**

Sea ice volume is one of the most sensible indicators of climate change and an integrated measure of sea ice energy and freshwater budget. While sea ice extent and concentration are fairly well observed from space since the 70ies, observation of sea ice thickness is quite recent and yet remain unhomogeneously distributed over space and time (usually over 10 year period and only in Arctic). Consequently, operational sea ice reanalysis only integrate observations of sea ice extend and sea ice concentration. However, recent works (e.g Day et al, 2014, Chevallier et al, 2016, Xie et al, 2018, Blockley et al, 2018) show that the assimilation of sea ice concentration only is not sufficient for relevant estimations of sea ice seasonal variations and climate model projections. Also, because of a longer time correlation compare to sea ice concentrations, model initialization from sea ice thickness observations improves sea ice model physics (Schroder et al, 2018). The development of sea ice thickness observation products adapted to model needs is therefore essential. In this context, the purpose of this presentation is to overview our late development of sea ice thickness observation uncertainties to facilitate the synergy between model and observations.

In this presentation, we first describe the methodology used to derive sea ice freeboard from altimetric power echo measurements and construct 2002-2017 Envisat/Cryosat-2 sea ice radar freeboard time series. In the same time, we describe how freeboard and sea ice thickness uncertainties are calculated in actual sea-ice products.

In a second part, in order to understand the difficulties to derive consistent uncertainties of sea ice thickness, we will list the various sources of uncertainties. In particular, we focus on uncertainties inherent to the « waveform to freeboard » process.

Then, we present a new approach to explicitly simulate uncertainties based on random numbers. One advantage is to avoid prior assumptions such as the uncorrelation of errors.

Finally, the relevancy of these freeboard and sea ice thickness uncertainties for modelling applications and data assimilation will be assessed from comparisons with various independant missions such as ICESat and Operation Ice Bridge (OIB).

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**Corresponding author:**

**garnier florent (LEGOS, France)**, [florent.garnier@legos.obs-mip.fr](mailto:florent.garnier@legos.obs-mip.fr)

# A new way to assess and represent the error budget for any altimeter mission

**Pierre Thibaut (CLS, France)**; Jean Christophe Poisson (CLS, France); Marine Lievin (CLS, France); Laiba Amarouche (CLS, France); Michael Ablain (Magellium, France); Michel Tsamados (UCL, United Kingdom); Robert Cullen (ESA, The Netherlands)

**Session:** Quantifying Errors and Uncertainties in Altimetry data

**Presentation type:** Oral

## **Abstract:**

Historically, for each altimeter mission and before its launch, a performance budget is produced in order to anticipate its final potential and to compare its advantages/drawbacks with respect to other missions. It is usually presented as a simple table containing the level of error of the main contributions to the final error budget (range, orbit, Sea State Bias, Wet and Dry Tropospheric Correction, Ionospheric correction, ...).

Of course, this table is built based on the analysis of previous mission performance and taking into account the technical specificities of the new mission (instrumental characteristics such as radar frequency, radiometer (or not), or evolutions of the on-ground processing). Once the mission is in operation, the same table is computed, based on real observations. However, this table is not satisfactory as several types of errors are given while they have different time and spatial scales of occurrence. The global value for sea level is usually considered as the quadratic sum of all sources of error (sub-mesoscales and mesoscales errors, uncorrelated errors related to the instrumental characteristics and the on-ground retracking; short time temporal errors below 10 days – SSB, Ionosphere, Troposphere, ...; climate scales errors from medium temporal errors (2 months – 1 year) to long-term errors (> 1 year) including inter-annual variations and drifts (important for GMSL studies for example).

A new method, based on Power Spectral Density (PSD) has been developed at CLS (in the frame of the CRISTAL Phase A/B1 study with ESTEC) accounting for spatial and temporal correlated errors, combining them and finally providing maps of errors. It gives the capability to describe the uncertainty variance of each source of error for all frequencies in the spatial and temporal dimensions. This method can either be used to describe the performances over ocean or sea ice regions. A mission performance simulation tool (MPS) has been developed in the frame of this study.

We propose in this talk to describe this method and to provide illustrations/maps of the final errors obtained for different missions over different surfaces.

## **Corresponding author:**

**Pierre Thibaut (CLS, France)**, pthibaut@cls.fr

# Harmonizing the Jason-1, Jason-2, Jason-3 Time Series of Altimeter Rain Flags

**Matthieu Talpe (Jet Propulsion Laboratory, United States);** Jean-Damien Desjonquères (Jet Propulsion Laboratory, USA); Shailen Desai (Jet Propulsion Laboratory, USA); Bruce Haines (Jet Propulsion Laboratory, USA)

**Session:** Quantifying Errors and Uncertainties in Altimetry data

**Presentation type:** Oral

## **Abstract:**

In this presentation, we evaluate the time series of altimeter rain flags provided on the Jason-1 (version E), Jason-2 (version D), and Jason-3 (version D) geophysical data records, and provide recommendations to mitigate inconsistencies.

We first select measurements where the altimeter rain flag is set, only considering measurements over ocean as determined by both the altimeter and radiometer surface type flags on the data products ( $= 0$ ), low latitudes ( $< 50$  degrees N/S), altimeter echo type ( $= 0$ ), and radiometer brightness temperature interpolation flag (not 3). For each exact repeat cycle, 5,000 – 40,000 measurements are flagged as rain. While the cycle-to-cycle variability is high, we observe two major discontinuities: 1) an increasing trend in the number of rain flagged measurements on the Jason-1 GDR-E products, from ~5,000 measurements at the beginning of the mission to ~30,000 at the end, and 2) a consistently higher number of measurements flagged as rain on the Jason-3 products, by about 40%, compared to Jason-2.

We have used the well-documented rain flag algorithm to explore the source of these discrepancies and to provide possible solutions for improved consistency. For the trend in Jason-1 rain flags, we recommend the computation of the rain flag using  $\sigma_0$  instead of AGC, due to the significant drift in the Jason-1 AGC through its lifetime. For the bias in number of rain-flagged measurements in Jason-2 vs Jason-3, we recommend using updated Jason-3 C- and Ku-band MLE-3  $\sigma_0$  calibrations of -0.100 and -0.270 dB, respectively. These calibrations represent an alignment of  $\sigma_0$  values to a reference table used in the rain flag algorithm. These calibrations are slightly different from the values used to generate the rain flag on the Jason-3 GDR-D products, of -0.012 and -0.231 dB, respectively. We show the influence of this new rain flag on cycle-averaged statistics for various parameters such as SSHA, SWH, wind speed, etc.

Finally, we compare the rain flags from the Jason series of products to observations from independent precipitation missions (TRMM and GPM).

## **Corresponding author:**

**Matthieu Talpe (Jet Propulsion Laboratory, United States),** [matthieu.j.talpe@jpl.nasa.gov](mailto:matthieu.j.talpe@jpl.nasa.gov)

# Lessons learned from Sentinel SARM missions in preparation of Jason-CS

**Matthias Raynal (CLS, France)**; Emeline Cadier (CLS, France); Sylvie Labroue (CLS, France); Thomas Moreau (CLS, France); Pierre Féménias (ESA/ESRIN, Italy); François Boy (CNES, France); Nicolas Picot (CNES, France); Remko Scharroo (EUMETSAT, Germany); Franck Borde (ESA/ESTEC, Netherlands)

**Session:** Quantifying Errors and Uncertainties in Altimetry data

**Presentation type:** Oral

## **Abstract:**

The Copernicus Sentinel-3A mission was successfully launched in February 2016. It is a multi-instrument mission to measure surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. To reach the data coverage required by the Copernicus service, its twin Sentinel-3B was launched on 25th of April 2018. After 5 months in a tandem flight configuration (Sentinel-3B 30 seconds ahead of Sentinel-3A), Sentinel-3B was moved to its final orbit, the same as Sentinel-3A but shifted by 140°.

The Jason-CS-A/Sentinel-6A launch is planned end of 2020, this new Copernicus constellation (Jason-CS-B/Sentinel-6B launch expected in 2026) will ensure the continuity with Jasons satellites, providing on the same low inclination orbit high precision measurements to monitor the sea surface topography dynamic and long term evolutions. The onboard altimeter Poseidon4 belongs to a new generation of Delay Doppler instrument. Thanks to the SAR interleaved mode, it will provide both LRM and SARM co-located measurements.

In the frame of the Mission Performance Centre (MPC), a consortium defined by ESA and EUMETSAT in charge of the qualification and the monitoring of the instrument performances, the high level of quality of the Sentinel-3 Topography Mission (STM) datasets was demonstrated. Now, working on the residual small remaining errors, objectives are to improve the processing.

To prepare a seamless transition between Jason-3 and Jason-CS/Sentinel-6 missions what lessons can we learn from these investigations?

## **Corresponding author:**

**Matthias Raynal (CLS, France)**, mraynal@cls.fr

# Improving the DAC de-aliasing model by combining with sub-monthly GRACE gravity data

**Jennifer Bonin (University of South Florida, United States)**; Himanshu Save (University of Texas at Austin, United States); Nadege Pie (University of Texas at Austin, United States)

**Session:** Quantifying Errors and Uncertainties in Altimetry data

**Presentation type:** Oral

## **Abstract:**

The Dynamic Atmospheric Correction (DAC) can be applied to Jason altimetry data to reduce the aliasing impact of high-frequency inverted barometer and dynamic ocean signals. As imperfections in the DAC will result in longer-period aliased errors in the ultimate sea surface height estimates, it is crucial to make this model as accurate as possible. We attempt to improve upon the DAC's Mog2D ocean model by combining with bottom pressure estimates from a near-daily GRACE "swath-style" gravity solution. We compare with Jason sea surface heights to localize those places and frequency regimes where the GRACE series is demonstrably better than the original DAC model. We then create a new altimetry de-aliasing product out of the combination of GRACE and Mog2D, with the current model dominating at the higher frequencies and in the equatorial regions, but GRACE bottom pressures becoming relevant at longer sub-monthly periods and particularly in the southern ocean.

## **Corresponding author:**

**Jennifer Bonin (University of South Florida, United States)**, jbonin@mail.usf.edu

# Surface and Upper Ocean Circulation from the combined use of in situ and space borne observations

**Sandrine Mulet (CLS, France);** Nathalie Verbrugge (CLS, France); H el ene Etienne (CLS, France); Eric Greiner (CLS, France); St ephane Guinehut (CLS, France)

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Oral

## **Abstract:**

Complementary to ocean state estimate provided by modelling/assimilation systems, a multi observation-based approach is available through the MULTI OSERVATIONS (MULTIOBS) Thematic Assembly Center (TAC) of the Copernicus Marine Environment Monitoring Service (CMEMS).

CMEMS MULTIOBS TAC proposes qualified global ocean products based on satellite and in situ observations and data fusion techniques. 4 MULTIOBS products are dedicated to ocean currents. Satellite observations (gravity from GOCE, altimetry, SST and SSS from SMOS), in situ observations (Argo floats and surface drifters), and ECMWF wind stress are used to generate 3D geostrophic currents and 2D geostrophic + Ekman currents at the surface and 15m. They are available in Near-Real-Time or as Multi-Year Products for the past 10 to 25 years.

Methods and products are presented. The performances of 3D and 2D currents are estimated through comparison with independent data such as SVP drifters, Argo drifts at 1000m (YoMaHa database) and ADCP section at the equator. The interest of MULTIOBS for marine resources is illustrated with seals tracks. Finally, ongoing studies are presented such as the gains obtained with a data synergy between altimeter velocities and SST.

## **Corresponding author:**

**Sandrine Mulet (CLS, France),** [smulet@groupcls.com](mailto:smulet@groupcls.com)

# Volume transport and modes of variations of the Malvinas Current at 44.7°S from satellite altimetry and current-meter velocities

**Martin Saraceno (Universidad de Buenos Aires, Argentina);** Ramiro Ferrari (CONICET-UBA, Argentina); Guillermina Paniagua (CONICET-UBA, Argentina); Loreley Lago (CONICET-UBA, Argentina); Alberto Piola (SHN-CONICET-UBA, Argentina); Christine Provost (UPMC-IPSL-LOCEAN, France); Camila Artana (UPMC-IPSL-LOCEAN, Argentina)

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Oral

## **Abstract:**

The southern portion of the Malvinas Current (MC) circulation is examined using satellite altimetry data and in-situ velocity time series gathered at three mooring sites (from March 2015 to May 2017) along the Patagonian Shelf break at 44.7°S. The in-situ data provided the first opportunity to compare altimetry-derived velocities with high temporal resolution near-surface current meter velocities in this tract of MC. Globally, altimetry-derived velocities correlate rather well ( $r > 0.8$ ) with the in-situ velocities at 300 m depth both in strength and direction. The quality of the altimetric surface geostrophic velocities being assessed, altimetry was used to further interpret the observations at the isolated mooring sites and to put them in context of the 24-year-long altimetric time series. Leading modes and temporal scales of variability were analyzed. During the in-situ measurement period, the spatial structure of the two-dominant modes of Mean Sea Level Anomaly that explain more than 50% of the variance were associated to the presence a westward meander of high ADT close to 44.7° S, which affect the MC flow beyond that latitude. The 24-year-long altimetry time series revealed that these patterns are robust. Moreover, we combined altimetric and the in-situ data to compute a volume transport time series of the MC at 44.7°S. The variability of the transport time series is analyzed and compared with estimates obtained of further north in previous studies.

## **Corresponding author:**

**Martin Saraceno (Universidad de Buenos Aires, Argentina),** saraceno@cima.fcen.uba.ar

# The Malvinas Current at the Confluence with the Brazil Current: inferences from 25 years of Mercator Ocean reanalysis.

**Camila Artana (UMPC LOCEAN, France);** Christine Provost (Laboratoire LOCEAN-IPSL, Sorbonne Université, (UPMC, Université Paris 6), CNRS, IRD, MNHN, Paris, France); Jean-Michel Lellouche (MERCATOR-OCEAN, Parc Technologique du Canal, Ramonville St. Agne, France); Rio M<sup>A</sup>rie H<sup>É</sup>lène (ESRIN-ESA European Space Agency, Largo Galileo Galilei, 2 00044 FRASCATI, RM, Italy); Ramiro Ferrari (DCAO/FCEN/UBA, CIMA/CONICET-UBA and UMI IFAECI-3351, Buenos Aires, Argentina); Nathalie Sennéchaël (Laboratoire LOCEAN-IPSL, Sorbonne Université, (UPMC, Université Paris 6), CNRS, IRD, MNHN, Paris, France)

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Oral

## **Abstract:**

Twenty-five years of high-resolution ( $1/12^\circ$ ) ocean reanalysis provide insights on variations in the Malvinas Current (MC) at  $41^\circ\text{S}$ , in the Brazil Current (BC) at  $37^\circ\text{S}$  and in their confluence (Brazil-Malvinas Confluence, BMC) from synoptic to interannual time scales. The modelled fields illustrate the contrast between the highly variable baroclinic BC and the rather stable barotropic equivalent MC. The model confirms that the mean MC transport ( $38.0 \text{ Sv} \pm 7.4 \text{ Sv}$  at  $41^\circ\text{S}$ ) is larger than the mean BC transport ( $26.7 \text{ Sv} \pm 15 \text{ Sv}$  at  $37^\circ\text{S}$ ) and determines the mean latitude of separation of the BC from the slope. An EOF analysis over the 25 years of the reanalysis suggests that changes in the position of the BMC are related to changes in the intensity of the BC at seasonal and semi-annual times scales. At longer time scales, the mean annual position of the Subantarctic (Subtropical) front is highly correlated with the MC (BC) transport time series (correlation coefficient of 0.6 and 0.5 respectively, 90% confidence level). Selected synoptic situations illustrate the model skills in documenting the complex processes of the BMC such as the offshore export of Rio de la Plata Water, the branching of the MC near the Confluence, the rich mesoscale field and the subduction of the MC below the BC with at times large vertical velocities.

Figure caption:

Mean annual position of the STF (a) and SAF (b) defined with model SSH isolines 5 and 30 cm isolines respectively. (c) and (d) annual mean STF and SAF positions on the 2,000 m isobath with MC and BC annual transport superimposed. (e) Mean annual separation distance between the SAF and STF. The red line indicates the mean annual separation averaged over the period 1993-2017.

## **Corresponding author:**

**Camila Artana (UMPC LOCEAN, France)**, [camila.artana@locean-ipsl.upmc.fr](mailto:camila.artana@locean-ipsl.upmc.fr)



# Causes for the intense interannual upwelling events in the tropical Indian Ocean

Wei Qing Han (The University of Colorado, United States)

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Oral

## **Abstract:**

Satellite altimetry observations, in situ datasets and reanalysis products reveal intense interannual upwelling events in the tropical Indian Ocean during 1993-2016. These events primarily occur in the mean upwelling zone of the Seychelles-Chagos thermocline ridge (SCTR) and in the seasonal upwelling area of the Eastern tropical IO (EIO) coastal area, with enhanced EIO upwelling accompanying weakened SCTR upwelling. In the fall of 1997, sea level increased by  $\sim 0.2 - 0.3\text{m}$  over the SCTR island nations and dropped by a similar amount in the EIO coastal area, which not only caused inundation but also significantly reduced (enhanced) upwelling in the SCTR region (EIO coast). The variability and upwelling directly affect sea surface temperature, biological activities, and air-sea CO<sub>2</sub> flux. Surface winds associated with the El Niño and Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) are the major drivers of upwelling variability. ENSO is more important than the IOD over the SCTR region, but they play comparable roles in the EIO. The co-occurrence of El Niño and positive IOD in 1997 is the major cause for the intense upwelling event. Of particular interest is that Eastern Pacific (EP) El Niños overall have much stronger impacts than Central Pacific (CP) El Niños, since the former (latter) has subsidence over the Indo-Pacific warm pool (western Pacific and Indian subcontinent) and thus drive strong (weak) easterlies in the equatorial IO.

## **Corresponding author:**

**Wei Qing Han (The University of Colorado, United States)**, whan@colorado.edu

# Remote Forcing of the Benguela Current System

**Ted Strub (Oregon State University, United States)**; Ricardo Matano (Oregon State University, United States);  
Melanie Fewings (Oregon State University, United States); Corinne James (Oregon State University, United  
States); Vincent Combes (Oregon State University, United States)

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Oral

## **Abstract:**

We investigate the connections (forces and transports) responsible for variability in the Benguela Current System, one of the major global Eastern Boundary Currents (EBCs). Our focus on this Southeast African current system, a site of economically important fisheries and net absorption of heat by the ocean, is on the seasonal and interannual time scales. As is true of other EBCs, signals from the tropical regions reach the Benguela Current through the wave guide along the western coast of South Africa and comparisons are presented between the Benguela and the EBCs in the Eastern Pacific – the California and Humboldt Current Systems. Previous analyses of these connections have primarily examined sea surface heights from tide gauges and altimetry. Here we include altimeter-derived alongshore velocities and winds, along with transports and water-parcel displacements due to those velocities. Our previous work in the two Pacific systems finds a large difference in the pathways and dynamic systems between the tropics and the EBCs in the northern and southern hemispheres, along with the phasing of the velocity signals in relation to latitude. The pathway in the northern hemisphere is more complex, but the phasing is often such that poleward velocities progress poleward, enhancing the actual poleward displacement of the water parcels as they move to higher latitudes. In the southeast Atlantic, there are similarities to both Pacific systems; 1) The pathway between tropics and mid-latitudes in the SE Atlantic is short and direct, similar to the southeast Pacific; but 2) The pathway in the SE Atlantic is dynamically interrupted by the Angola Dome, similar to the interruptions in the northeast Pacific by the Costa Rica Dome. Perhaps more importantly, the Benguela Current System is directly connected to a Western Boundary Current: the Agulhas Current south of the African continent. Model tracers initiated in the Agulhas system are transported to the Benguela and brought to the surface by upwelling. Thus, we ask three questions: 1) Does the phasing of alongshore transports in the SE Atlantic favor or oppose poleward transport on seasonal and/or interannual time scales? 2) Are inputs from the Agulhas Current System more/less important than inputs from the tropics? and 3) Is local forcing more/less important than the distant forcing? These questions are investigated using a combination of satellite data (altimetry, scatterometry, surface heat fluxes) and model fields.

## **Corresponding author:**

**Ted Strub (Oregon State University, United States)**, [tstrub@coas.oregonstate.edu](mailto:tstrub@coas.oregonstate.edu)

# Attenuating the ocean chaotic variability in altimetric observations: from band-pass filtering to machine learning

**Thierry Penduff (CNRS - IGE, France)**; Mickael Lalande (IGE, France); Redouane Lguensat (IGE, France); Sally Close (IGE, France); Sabrina Speich (LMD-ENS, France)

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Oral

## **Abstract:**

The OCCIPUT large-ensemble global ocean simulation (<https://meom-group.github.io/projects/occiput/>) has been used to partition the multi-scale ocean variability into deterministic (forced by the atmosphere) and chaotic (ocean-generated, random) signals. Further studies have shown that these chaotic signals can be large enough in many regions to mask deterministic signals, and hinder the local detection and attribution of climate change in the ocean, such as regional trends in ocean heat content and sea level.

It is thus tempting to try and attenuate the signature of chaotic variability in observational datasets, in order to unveil its atmospherically-forced component, and help identifying the external drivers of the observed variability.

We first developed a band-pass spatial filter, based on the analysis of the OCCIPUT simulation outputs, which proved able to recover from a single member evolution a significant amount of the deterministic variability (0.9 correlation in global average). Applying this filter on real altimetric observations enhances the North Atlantic sea-level variability explained by the NAO by 10% to 60% locally.

An alternative to this filter, based on the U-Net convolutional neural network trained on the OCCIPUT data, showed slightly better skills on the same task, with additional benefits. The attached figure illustrates the observed (top) and U-Net-processed (bottom) SLA fields on Sept. 10th 2016, showing respectively the entangled deterministic/chaotic SLA state in the real ocean on that week, and its estimated deterministic part.

The spectral characteristics of both algorithms (filter and U-Net) is investigated in various regions; we will discuss these results, as well the possible uses of these “denoised” observational data.

## **Corresponding author:**

**Thierry Penduff (CNRS - IGE, France)**, [Thierry.Penduff@cnrs.fr](mailto:Thierry.Penduff@cnrs.fr)

# High-wavenumber variability in the California Current: Evaluating sub-100-km scales with high-resolution altimetry, ADCP, and model output

**Teresa Chereskin (Scripps Institution of Oceanography, United States);** Sarah Gille (Scripps Institution of Oceanography, United States); Matthew Mazloff (Scripps Institution of Oceanography, United States); Bruce Cornuelle (Scripps Institution of Oceanography, United States); Jinbo Wang (Jet Propulsion Laboratory, United States); Dimitris Menemenlis (Jet Propulsion Laboratory, United States); Marcello Passaro (Deutsches Geodätisches Forschungsinstitut der Technischen Universität München, Germany); Christian Schwatke (Deutsches Geodätisches Forschungsinstitut der Technischen Universität München, Germany); Cesar Rocha (Woods Hole Oceanographic Institution, United States)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Oral

## **Abstract:**

The TOPEX/Poseidon and Jason series of altimeters have provided pioneering observations of mesoscale sea surface height variability, resolving oceanic features at scales larger than about 50 to 70 km. More recently, altimeters have offered potential to resolve scales smaller than 50 km via new processing strategies and new types of altimeters, such as Ka-band altimeters and instruments taking advantage of Synthetic Aperture Radar (SAR) mode, Delayed Doppler technology. Looking ahead, the Surface Water Ocean Topography (SWOT) altimeter is anticipated to resolve scales of 10 to 15 km. A challenge, however, in evaluating the performance of these new altimeters arises from the difficulty of obtaining in situ measurements that resolve the small oceanic scales that they are designed to detect. In this study we use high-resolution observations from altimetry and shipboard acoustic Doppler current profiler (ADCP) data, together with high-resolution model output, to explore the characteristics of upper ocean variability at scales smaller than 100 km, typical of the oceanic submesoscale. We focus on the California Current, targeted as a key region for SWOT cal/val. We use regional and global model configurations to explore the mechanisms driving high-frequency and high-wavenumber variability. One hypothesis is that remote tidal forcing from outside the region is responsible for generating high-frequency and high-wavenumber energy, resulting in a spatial distribution of internal wave variance that is diminished in the lee of topographic barriers and enhanced where waves break. We assess model performance relative to current meter observations in the time domain and relative to ADCP data and high-resolution nadir altimetry (from Jason-1/2, AltiKa, and Sentinel-3) in the spatial domain.

## **Corresponding author:**

**Teresa Chereskin (Scripps Institution of Oceanography, United States),** tchereskin@ucsd.edu

# Constrained scales in ocean forecasting

**Gregg Jacobs (Naval Research Laboratory, United States)**; Joseph D'Addezio (Naval Research Laboratory, USA); Brent Bartels (Perspecta, USA); Pete Spence (Perspecta, USA); Max Yaremchuk (Naval Research Laboratory, USA); Bob Helber (Naval Research Laboratory, USA); Scott Smith (Naval Research Laboratory, USA); Clark Rowley (Naval Research Laboratory, USA)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Oral

## **Abstract:**

As we look to understand the submesoscale circulation through SWOT in combination with numerical models, we must first understand the scale limitations imposed by existing altimeter space-time resolution on present model systems. The approach is through evaluation relative to dense real world data provided by 1000 drifters deployed in January 2016 as part of the LAgrangian Submesoscale ExpeRiment (LASER) campaign in the Gulf of Mexico that persisted for 3 months and sampled eddy features over a wide range of mesoscale and submesoscale features. All available satellite altimeter observations are assimilated into a 1 km resolution ocean model. In this situation, the ocean model generates features that are smaller than the resolution of existing altimeter data. We define constrained scales as those in which the forecast system has skill, and we determine these by successively filtering small-scale variability from model experiments to reach a minimum error relative to the ground truth data that were not assimilated. We also vary the decorrelation scales of the assimilation system (a second order auto-regressive correlation function) to determine the decorrelation scale that produces the smallest forecast trajectory errors. We find the constrained scales are larger than those defined by a Gaussian filter with e-folding scale of 58 km or  $\frac{1}{4}$  power point of 220 km. The decorrelation scale of 36 km used in the assimilation provides lowest trajectory errors. Filtering unconstrained variability from the model solutions reduces 24-hour trajectory errors by 20%. Multi-scale analyses have been proposed to best assimilate future SWOT observations. These systems update the background successively by using existing nadir altimeter observations with SWOT to first correct the mesoscale and then correct the smaller submesoscale field. The results here provide a breakpoint in assimilation length scale separating the first and second steps of the multi-scale analysis procedure.

## **Corresponding author:**

**Gregg Jacobs (Naval Research Laboratory, United States)**, [gregg.jacobs@nrlssc.navy.mil](mailto:gregg.jacobs@nrlssc.navy.mil)

# The ocean mesoscale regime of the reduced-gravity quasi-geostrophic model

**Roger Samelson (Oregon State University, United States);** Dudley Chelton (Oregon State University, USA);  
Michael Schlax (Oregon State University, USA)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Oral

## **Abstract:**

A statistical-equilibrium, geostrophic-turbulence regime of the stochastically forced, one-layer, reduced-gravity, quasi-geostrophic model is identified in which the numerical solutions are representative of global mean, mid-latitude, open-ocean mesoscale variability. A nominal best fit to observed SSH variance, autocorrelation, eddy, and spectral statistics is obtained for dimensional SSH stochastic-forcing variance production rate  $1/4 \text{ cm}^2/\text{d}$ , an SSH damping rate  $1/62 \text{ 1/wk}$ , and a stochastic forcing autocorrelation timescale near or greater than 1 wk. This ocean mesoscale regime is nonlinear and appears to fall near the stochastic limit, at which wave-mean interaction is just strong enough to begin to reduce the local mesoscale variance production, but is still weak relative to the overall nonlinearity. Comparison of linearly-inverted wavenumber-frequency spectra shows that a strong effect of nonlinearity, the removal of energy from the resonant linear wave field, is resolved by the gridded altimeter SSH data. These inversions further suggest a possible signature in the merged altimeter SSH dataset of signal propagation characteristics from the objective analysis procedure.

## **Corresponding author:**

**Roger Samelson (Oregon State University, United States),** [rsamelson@coas.oregonstate.edu](mailto:rsamelson@coas.oregonstate.edu)

# SWOT-ACC, Satellite and ship-based investigation of mesoscale-submesoscale interactions in the Antarctic Circumpolar Current.

**Benoit LEGRESY (CSIRO, Australia)**; Helen PHILLIPS (University of Tasmania, IMAS, Australia); Kurt POLZIN (WHOI, United States); Nathan BINDOFF (University of Tasmania, IMAS, Australia); Clement AUGER (CSIRO, Australia)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Oral

## **Abstract:**

The Southern Ocean is a major player in the heat and carbon uptake and transport, with the Antarctic Circumpolar Current (ACC) being the strongest current in the world, with hotspots occurring where the current interacts with topographic features. In recent years, studies have pointed to fine-scale processes that are able to dominate biogeochemical transfers. During the 1-day repeat phase, one SWOT track will cross the ACC South of Tasmania, upstream from Macquarie Ridge, a highly energetic ocean environment. This region has a high signal-to-noise ratio in SWOT measurements compared to adjacent ACC areas. It is of great interest, with expected sub-mesoscale signals in the form of internal waves, sub-mesoscale eddies and other potential small-scale features while crossing some sharp fronts of the ACC. The daily-repeat SWOT measurement allows the detection of the coherence of features and their connection to in situ observations (ship-based, floats, moorings, drifters, gliders).

This area is one of 5 main hot-spots in the ACC where the Eddy Heat Flux is particularly strong and the place of a standing meander of the ACC. We have been investigating this area for meso-submeso-scale processes. An oceanographic cruise dedicated to explore the frontal physics at higher resolution was carried out in October-November 2018 in the area led by IMAS/CSIRO/ACE-CRC.

We show some results of the higher resolution sampling during this cruise, showing small scale dynamic height signals of significant (10cm) amplitude in the area.

We also show a spectral analysis of along track existing altimeter data pointing to a very favourable area for strong mesoscale - sub-mesoscale feature SNR.

We conclude with an inventory of elements pointing to the interest of the area which justifies to repeat a cruise during the fast sampling phase of SWOT, to transform the in-situ studies into a monitoring during the whole SWOT mission.

## **Corresponding author:**

**Benoit LEGRESY (CSIRO, Australia)**, [benoit.legresy@csiro.au](mailto:benoit.legresy@csiro.au)

# Nonlinear short-term SSH evolution during the 2015/16 El Niño event in the tropical western Pacific

**Bo Qiu (University of Hawaii at Manoa, United States)**; Shuiming Chen (University of Hawaii at Manoa, USA); Brian Powell (University of Hawaii at Manoa, USA); Patrick Colin (Coral Reef Research Foundation, Palau); Dan Rudnick (Scripps Institution of Oceanography, USA); Martha Schonau (Scripps Institution of Oceanography, USA)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Oral

## **Abstract:**

Due to the presence of a well-defined permanent thermocline, low-frequency upper ocean circulation variability in the tropical western Pacific Ocean is effectively captured by the linear baroclinic Rossby wave dynamics. A careful examination of the circulation variations surrounding Palau using the in-situ temperature measurements, satellite altimetry data, and data-assimilated ECCO2 state estimate reveals that linear dynamics fails to describe the observed large-amplitude upper ocean variations on the monthly time scales. These short-timescale variations are particularly active during the transition period from El Niño to La Niña conditions. As an El Niño event terminates and the tropical trade winds rebound, downwelling baroclinic Rossby waves are generated across the off-equatorial Pacific basin. When these wind-forced Rossby waves propagating into the western North Pacific basin, they deform the pre-existing, horizontally-sheared, North Equatorial Countercurrent (NECC) and subject it to barotropic instability. By breaking down into large-amplitude eddies, the unstable NECC generates rapidly-evolving upper ocean changes with sea level and upper ocean temperature fluctuations exceeding 0.5 m and 10°C, respectively, over a period of 1~2 months around Palau.

## **Corresponding author:**

**Bo Qiu (University of Hawaii at Manoa, United States)**, bo@soest.hawaii.edu



# Synergetic use of altimetry and surface drifters to increase resolution and accuracy of sea level anomaly and geostrophic current maps in the Gulf of Mexico

**Sandrine Mulet (CLS, France)**; H el ene Etienne (CLS, France); Maxime Ballarotta (CLS, France); Yannice Faugere (CLS, France); G erald Dibarboure (CNES, France); Nicolas Picot (CNES, France)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Oral

## **Abstract:**

Strong improvements have been made in our knowledge of the surface ocean geostrophic circulation thanks to satellite observations. However, the synergy of different sources of observation (satellites and in-situ) is mandatory in order to go toward higher resolution. In this study, we combined altimetric along track Sea Level Anomalies (SLA) with geostrophic velocity estimated from surface drifters in order to map SLA and associated geostrophic current anomalies in the Gulf of Mexico.

First, an important work is done to pre-process drifter data to extract the geostrophic component of the signal in order to be consistent with physical content of altimetry. This step includes estimate and remove of Ekman current, Stokes drift and wind slippage. Two kind of drifters are used:

- Drifters from Woods Hole Group Company (this company, part of CLS group, launches their own drifter in the Gulf of Mexico for their downstream services).
- The drifters launched in the framework of the Lagrangian Submesoscale ExpeRiment(LASER) campaign (January-April 2016).

Second, drifters and along track SLA from Jason2, HY2, Saral and Cryosat-2 are combined through multivariate objective analysis to map a daily time series of SLA and associated geostrophic current anomalies from 01/09/2015 to 30/04/2016.

Finally, comparisons with independent data show the better agreement of maps merging both altimetry and drifters especially for the meridional component of geostrophic current. A spectral analysis underlines also the improvement.

## **Corresponding author:**

**Sandrine Mulet (CLS, France)**, [smulet@groupcls.com](mailto:smulet@groupcls.com)

# Marine Gravity from the first two cycles of the Jason-2 LRO extension of Life mission

**Ole Baltazar Andersen (Dr, Denmark); Adili Abulatitijiang (DTU Space, Denmark)**

**Session:** The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

**Presentation type:** Oral

## **Abstract:**

In July 2017 Jason-2 was put in a End-of-Life orbit the so-called GM/LRO orbits. The design of the orbit was such that after approximately 2 cycles or a little more than 2 years complete coverage with a equal track spacing of 4 km across track would be achieved to the huge benefit of marine geodesy. The optimal Jason-2 LRO orbit was chosen to be 27 km lower than the nominal orbit and designed to have a fallback geodetic sub-cycle of approximately 145 days. This sub-cycle was selected as a "coarse geodetic grid", i.e. as a safety net if full geodetic cycles cannot be completed. The strategy was inherited from Jason-1 EoL trying to optimize all sub-cycles to make it valuable to oceanography as well (shorter ones for sea-state and mesoscale, and longer ones for geodesy).

The first GM/LRO cycle was completed in summer of 2018. During the first cycle safe-hold modes created a number of small set of 8-km gaps that are sometimes next to the ongoing and incomplete 145-day sub-cycle. Approximately 13% of the data have been lost to safe hold modes.

During the second GM/LRO cycle (presently incomplete), a longer safehold of several month was encountered during the spring of 2019 and after the restart of the instrument in May 2019, it has been decided to revind the Gm to fill in this long safehold-gap before continue into the third cycle.

In this presentation the first two cycles of Jason-2 GM/LRO data and the importance of these for marine gravity field modelling. The Jason-2 waveforms should be superior to the Jason-1 waveforms and we analyse the effect on this for gravity field modelling.

## **Corresponding author:**

**Ole Baltazar Andersen (Dr, Denmark)**, oa@space.dtu.dk

# ESA's new satellite-only gravity field model via the direct approach (DIR-R6)

Sean Bruinsma (CNES, France)

**Session:** The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

**Presentation type:** Oral

## **Abstract:**

The recently completely recalibrated and reprocessed Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) gravity gradient data were used by GFZ and CNES to generate a new gravity field model via the direct approach (DIR-R6). This work was done on behalf of the European Space Agency (ESA) within the consortium of the GOCE High Level Processing Facility (GOCE-HPF).

DIR-R6 is a satellite-only global gravity field model developed in spherical harmonics to maximum degree and order 300. It has been inferred from (the combination of):

- GOCE gravity gradient data (4 components)
- SLR data on LAGEOS 1/2
- KBR and GPS data on GRACE.

Due to the instrumental behavior of the GOCE satellite gradiometer, the gravity gradient observation equations must be preprocessed and filtered. Here, within the direct numerical method, the filtering has been done using a low pass filter with a cut-off period of 8 seconds. The GOCE GPS-SST data are used only to geolocate the gradients. The low-to-medium degree spherical harmonic coefficients of the gravity field are determined using GRACE GPS-SST and KBR data, as well as LAGEOS SLR data, from GFZ's release 6 models. All data are combined at normal equation level, which are solved using Cholesky decomposition. We applied the spherical cap regularization to stabilize the low-order spherical harmonic coefficients for the polar gaps in the GOCE data. Furthermore, Kaula regularization is used at the high degrees.

When compared to the previous gravity field models based on GOCE data, for instance to the earlier releases of ESA's GOCE models, DIR-R6 is more accurate, especially in its medium to high resolution. This is demonstrated among others by GPS/leveling, orbit determination tests, and notably by means of an oceanographic evaluation in which drifter-inferred currents are compared with currents computed using a MDT based on the DIR-R6 geoid.

## **Corresponding author:**

**Sean Bruinsma (CNES, France)**, sean.bruinsma@cnes.fr

# New CNES-CLS18 Mean Dynamic Topography of the global ocean from altimetry, gravity and in-situ data

**Sandrine Mulet (CLS, France);** Marie-Hélène Rio (ESA, Italy); Hélène Etienne (CLS, France); Nicolas Picot (CNES, France); Gérald Dibarboure (CNES, France)

**Session:** The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

**Presentation type:** Oral

## **Abstract:**

The Mean Dynamic Topography (MDT) is a key reference surface for altimetry. It is needed for the calculation of the ocean absolute dynamic topography, and under the geostrophic approximation, the estimation of surface currents. Those are required for a wide range of applications as the management of fishery resources, the monitoring of potential pollution, maritime security... Also, the MDT is the missing component for the optimal assimilation of altimeter data into operational ocean system as those run under the Copernicus Marine Environment Monitoring Services (CMEMS).

CNES-CLS Mean Dynamic Topography solutions are calculated by merging information from altimeter data, GRACE and GOCE gravity data and oceanographic in-situ measurements from drifting buoy velocities and hydrological profiles. The objective of this communication is to present the newly updated CNES-CLS18 MDT. The main novelties compared to the previous CNES-CLS13 solution is the use of updated input datasets: the GOCO05S geoid model (instead of DIR4) and the CNES-CLS15 Mean Sea Surface are used together with drifting buoy velocities (SVP-type and Argo floats) and hydrological profiles (CORA database) available from 1993 to 2016 (instead of 1993-2012). The new solution also benefits from improved data processing (in particular, a new Ekman model is used to extract the geostrophic component from the buoy velocities) and methodology.

An evaluation of this new solution compared to the previous version and to other existing MDT is done through comparison to independent in-situ data. Further validation by “super-users” have also been performed. Compared to the CNES-CLS13 solution, the new CNES-CLS18 MDT shows improved performance everywhere and more significantly in coastal areas and in strong western boundary currents.

## **Corresponding author:**

**Sandrine Mulet (CLS, France),** [smulet@groupcls.com](mailto:smulet@groupcls.com)

# A new combined mean dynamic topography model – DTUUH19MDT

**Per Knudsen (DTU Space, Denmark); Ole Andersen (DTU Space, Denmark); Nikolai Maximenko (University of Hawaii at Manoa, USA); Jan Hafner (University of Hawaii at Manoa, USA)**

**Session:** The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

**Presentation type:** Oral

## **Abstract:**

Within the ESA supported Optimal Geoid for Modelling Ocean Circulation (OGMOC) project an optimally combined geoid model was derived. It is based on the GOCO05C setup, though the newer DTU15GRA altimetric surface gravity was used in the combination. The OGMOC geoid model was optimized to avoid striations and orange skin like features. Subsequently the model has been augmented using the EIGEN-6C4 coefficients to d/o 2160. Also, a newly updated mean sea surface was used. Compared to the DTU15MSS, the DTU18MSS has been derived by including re-tracked CRYOSAT-2 altimetry also, hence, increasing its resolution. Some issues in the Polar regions have been solved too.

Initially, a new geodetic DTU19MDT was derived using the OGMOC geoid model and the new DTU18MSS mean sea surface. The processing scheme was similar to the one used for the previous geodetic DTU17MDT model. The filtering was re-evaluated by adjusting the quasi-gaussian filter width to optimize the fit to drifter velocities. The results show that the new MDT improves the resolution of the details of the ocean circulation. Subsequently, the drifter velocities were integrated to enhance the resolution of the MDT. As a contribution to the ESA supported GOCE++ project DYCOT a special concern was devoted to the coastal areas to optimize the extrapolation towards the coast and to integrate mean sea levels at tide gauges into that process. The presentation will focus on the coastal zone when assessing the methodology, the data and the final model DTUUH19MDT.

## **Corresponding author:**

**Per Knudsen (DTU Space, Denmark), [pk@space.dtu.dk](mailto:pk@space.dtu.dk)**

# Improvements and limitations of recent mean sea surface models: importance for Sentinel-3.

Marie Isabelle Pujol (CLS, France); Yannice Faugère (CLS, France); Gérald Dibarboure (CNES, France);  
Nicolas Picot (CNES, France)

**Session:** The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

**Presentation type:** Oral

## **Abstract:**

Previous studies underlined the improved accuracy of the recent Mean Sea Surface (MSS) models. Despite the improvement, residual errors were shown to be significant for wavelengths shorter than ~100km. The MSS errors represent nearly 30% of the SLA variance along the Sentinel-3A tracks and are on the same order of magnitude as the instrumental noise floor of this altimeter (Pujol et al, 2018).

In that context, reducing the MSS model errors at short wavelengths remains necessary to improve the quality of sea level anomalies along new repeat ground tracks. This is particularly important to take full benefit of the noise-reducing SARM technology (and in the future of SWOT).

In this study, we nearly 2 years of Sentinel-3A measurements to build a new local MSS (also known as mean profile) along the new ground track. We also combine this data with the gridded CNES/CLS model to ensure both large scale accuracy and multi-mission consistency. The result is a so-called hybrid mean profile. The high precision of SARM data makes it possible to yield improve the smaller scales even with only 2 years of data. The MSS-related error is reduced by more than 50% for critical wavelengths ranging from 15 to 100 km (Dibarboure et al, 2019). The hybrid mean profile defined with 1Hz sampling is now currently used in the Sentinel-3A altimeter processing and contributes to reduce the errors of the along-track Level-3 products available on CMEMS.

## **Corresponding author:**

Marie Isabelle Pujol (CLS, France), mpujol@groupcls.com

# Impact of internal tide correction on the DUACS maps accuracy

**Yannice Faugere (CLS Space Oceanography Division, France);** Clement Ubelmann (CLS, France); Loren Carrere (CLS, France); Chloe Durand (CLS, France); Gerald Dibarboure (CNES, France)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Oral

## **Abstract:**

The along track altimeter products used to generate the DUACS gridded Sea Level Anomalies products currently disseminated in CMEMS are not corrected from the internal tide effects. Recent studies highlighted the existence of residual tidal variability in the grids (Zaron, 2019), representing a pollution of the 2D mesoscale signal retrieved. An experimental dataset has been produced using a prior correction (Zaron model) for the along track data following the OSTST 2018 recommendation. The impact of this correction on the map accuracy has been assessed here over a 5-year period. Various diagnoses were implemented including comparisons to independent dataset to quantify the improvement. A tuning of the mapping algorithm is finally considered to optimize the effect of this correction.

## **Corresponding author:**

**Yannice Faugere (CLS Space Oceanography Division, France),** [yfaugere@cls.fr](mailto:yfaugere@cls.fr)

# Progress towards GOT5: high latitudes and minor constituents

Richard Ray (NASA/GSFC, United States)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Oral

**Abstract:**

Owing to new high-resolution radar technologies and to new high-inclination satellites, satellite altimetry is finding more and more applications in high latitudes and in near-coastal waters. SWOT especially will address both. The community is well aware that tide models are less accurate in coastal and high-latitude regions. Especially Cryosat-2 and GRACE have now highlighted serious tide-model problems in high latitudes. For these kinds of applications the GOT4 series of ocean tide models is unsatisfactory and in need of updating. From tests done so far, the FES2014 model is an impressive advancement in near-coastal waters, and it's becoming difficult for purely empirical approaches to improve upon it, at least in the T/P latitudes. The main data source for refining tides in polar seas is currently Cryosat-2, and I will discuss work done with these data (including with colleagues Ed Zaron and Ole Andersen). Cryosat has very long alias periods for sidereal tides (K1 and K2), and these and lunar tides do benefit from the sun-synchronous Envisat and SARAL data. I will also discuss some minor constituents which are not so critical for tide prediction purposes but which are of interest in their own right. This includes several constituents in the terdiurnal band.

**Corresponding author:**

Richard Ray (NASA/GSFC, United States), richard.ray@nasa.gov



# Internal tides fate and energy budget off the Amazonian shelf

**Florent Lyard (CNRS/LEGOS, France);** Loren Carrere (CLS, France); Michel Tchilibou (LEGOS, France);  
Jerome Chanut (MERCATOR-OCEAN, France); Simon Barbot (LEGOS/CLS, France)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Oral

## **Abstract:**

In the perspective of the forthcoming SWOT mission, the NEMO hydrodynamical model performances in reproducing realistic tidal dynamics, barotropic and baroclinic are being investigated and hopefully improved in a CMEMS financed project. In parallel with global ocean experiments, we conduct more detailed diagnostics using regional experiments. In our presentation, we analyze the internal tides generation, propagation and dissipation and examine the associated energy budget off the Amazonian shelf. Analysis is based on regional NEMO high resolution simulations (1/36) and the vertical modes decomposition. We will address the coherent versus incoherent internal tides issue, and the limitations of the harmonic approach in characterizing the full internal tides dynamics. Comparisons will be made with simulations produced from the unstructured, non-diffusive T-UGOm model.

## **Corresponding author:**

**Florent Lyard (CNRS/LEGOS, France),** florent.lyard@legos.obs-mip.fr

# Decomposition of the multimodal multidirectional M2 internal tide field

**Zhongxiang Zhao (University of Washington, United States);** Jinbo Wang (Jet Propulsion Laboratory, California Institute of Technology, United States); Dimitris Menemenlis (Jet Propulsion Laboratory, California Institute of Technology, United States); Lee-Lueng Fu (Jet Propulsion Laboratory, California Institute of Technology, United States); Shuiming Chen (University of Hawaii at Manoa, United States); Bo Qiu (University of Hawaii at Manoa, United States)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Oral

## **Abstract:**

The M2 internal tide field contains waves of various baroclinic modes and various horizontal propagation directions. This paper presents a technique for decomposing the sea surface height (SSH) field of the multimodal multidirectional internal tide. The technique consists of two steps: First, different baroclinic modes are decomposed by two-dimensional (2D) spatial filtering, utilizing their different horizontal wavelengths; second, multidirectional waves in each mode are decomposed by 2D plane wave analysis. The decomposition technique is demonstrated using the M2 internal tide field simulated by the MITgcm. This paper focuses on a region lying off the US West Coast ranging 20–50N, 220–245E. The lowest three baroclinic modes are separately resolved from the internal tide field; each mode is further decomposed into five waves of arbitrary propagation directions in horizontal. The decomposed fields yield unprecedented details on the internal tide's generation and propagation, which cannot be observed in the harmonically fitted field. The results reveal that the mode-1 M2 internal tide in the study region is dominantly from the Hawaiian Ridge to the west, but also generated locally at the Mendocino Ridge and continental slope. The mode-2 and mode-3 M2 internal tides are generated at isolated seamounts, as well as the Mendocino Ridge and continental slope. The Mendocino Ridge radiates both southbound and northbound M2 internal tides for all three modes. Their propagation distances decrease with increasing mode number: Mode-1 waves can travel over 2000 km; while mode-3 waves can only be tracked for 300 km. The decomposition technique may be extended to other tidal constituents and to the global ocean. In the end, its application to 1-year synthetic SWOT data is demonstrated.

## **Corresponding author:**

**Zhongxiang Zhao (University of Washington, United States),** [zzhao@apl.washington.edu](mailto:zzhao@apl.washington.edu)

# Comparison of global and regional internal tide and gravity wave models with observations

Brian Arbic (University of Michigan, United States)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Oral

## Abstract:

In recent years a growing number of modeling groups have included tidal forcing in high-resolution, three-dimensional global ocean general circulation models (OGCMs). Inclusion of tides in high-resolution OGCMs allows for modeling of non-stationary internal tides, and a partially resolved supertidal internal gravity wave (IGW) continuum spectrum, both new additions to the list of phenomena that global models can simulate. Such models have been, or are being, applied to problems in satellite altimetry, field experiment design, basin-scale ocean acoustics, and (soon) achieving a better understanding of ocean mixing. Because they are being used for a growing number of applications, it is very important to validate these models against available altimetric and in-situ observations. In this talk I will show comparisons of four high-resolution OGCMs with explicit tidal forcing--HYCOM, MITgcm, NEMO, and MOM6--to an array of observations. We compare the stationary internal tides in all four models to altimetry, the nonstationary internal tide in HYCOM to altimetry, and the IGW continuum kinetic energy spectrum in global HYCOM and MITgcm to McLane profiler spectra. We also show the IGW continuum kinetic energy spectra in regional MITgcm simulations, forced at their boundaries by the global simulation but with even higher horizontal and vertical resolution, to McLane profiler spectra. We show the HYCOM and MITgcm temperature variance and kinetic energy, integrated over several frequency bands of interest, next to values computed from an archive of thousands of moorings. The surface ocean geostrophic kinetic energy in HYCOM and MITgcm is compared to AVISO. The surface kinetic energy in HYCOM and MITgcm are compared to drifters. Finally, the barotropic tides in HYCOM are compared to altimeter-constrained barotropic tide models. General themes emerging from these comparisons are: (1) models run without an extra explicit damping, to account for unresolved internal wave breaking, tend to have stationary internal tides that are too large, (2) the spatial geography of nonstationarity in the internal tide field is mapped reasonably well by these models, (3) very-high-resolution regional models have IGW spectra that lie closer to observations than global models do, as long as the regional models include internal tide forcing at their boundaries, (4) similarly, the IGW spectrum in global models tends to lie closer to observations when model resolution is high, and (5) the correlation coefficients between HYCOM and either AVISO or in-situ data are higher than those for MITgcm, probably because of extensive tuning done for HYCOM because of its operational nature. Note that a very large number of co-authors contributed to this work.

## Corresponding author:

Brian Arbic (University of Michigan, United States), [arbic@umich.edu](mailto:arbic@umich.edu)

# CFOSAT: New wind and wave observations from the nadir and near-nadir SWIM Ku-Band instrument

**Daniele HAUSER (CNRS, France)**; lotfi Aouf (Meteo-France, France); Bertrand Chapron (Ifremer-Lops, France); Fabrice Collard (Ocean Data Lab, France); Alice Dalphinnet (Meteo-France, France); Lauriane Delaye (AcRI-ST, France); Christophe Dufour (CNRS-Latmos, France); Flavien Gouillon (CNES, France); Antoine Grouazel (Ifremer-Lops, France); Gilles Guitton (Ocean Data Lab, France); Laura Hermozo (CNES, France); Jean-Michel Lachiver (CNES, France); Alexey Mironov (ocean data lab, France); Alexis Mouche (Ifremer-Lops, France); Frederic Nougier (Ifremer-Lops, France); Annabelle Ollivier (CLS, France); Raquel Rodriguez (CNES, France); Patricia Schippers (ACRI-ST, France); Céline Tison (CNES, France); Cedric Tourain (CNES, France)

**Session:** CFOSAT

**Presentation type:** Oral

## **Abstract:**

CFOSAT is a new oceanographic satellite mission which has been successfully launched on October 29th 2018. It was jointly developed by the French and Chinese space agencies (CNES, CNSA, NSOAS). Its payload is composed of two Ku-Band radar instruments, namely SWIM (“Surface Waves Investigation and Monitoring”), which operates in a near-nadir geometry (0-10° from nadir) and scans in azimuth over 360°, and CSCAT which is a fan-beam rotating wind-scatterometer operating at larger incidences (20-55°). SWIM was designed to provide new information on the directional spectra of ocean waves along with the more conventional observations of wind and significant wave height obtained from the nadir altimetric signal.

During this conference, we will focus on the SWIM results obtained over several months of observations. We will first recall the data processing principles of the SWIM data and the main products. Then, based on the common analysis of the expert research group organized for the CAL/VAL, the performance of the SWIM instrument will be presented, and the main results from the nadir beam and off-nadir beams will be discussed. In particular we will present the capacity of SWIM to provide both the significant wave height and the detailed properties of the waves such as the dominant wavelength and direction for several components of the wave field. This assessment relies on comparisons between SWIM data, satellite altimeter products, wave forecast model products (WAM from ECMWF and Meteo-France, WW3), in situ data, and other satellite data (altimeters, SAR).

We will also illustrate from case studies the interest of the spectral information on ocean waves to study wave growth and evolution, wave/current interactions, wave behaviour under sea ice and the importance of open ocean forcing conditions for coastal studies.

First tests of assimilation of spectral data will also be illustrated. The results show a significant impact on integrated wave parameters (SWH and mean period) in the analysis and forecast periods. This opens promising applications for operational wave forecasting.

## **Corresponding author:**

**Daniele HAUSER (CNRS, France)**, daniele.hauser@latmos.ipsl.fr

# Performance analysis of the SWIM ground-segment solution for retracking nadir echos

**Annabelle Ollivier (cls, France);** Fanny Piras (cls, France); Maeva Dalila (cls, France); Gautier Dekeyne (cls, France); Cedric Tourain (cnes, France); Jean Michel Lachiver (cnes, France); Alice Dalphinnet (MeteoFrance, France)

**Session:** CFOSAT

**Presentation type:** Oral

## **Abstract:**

The new satellite mission CFOSAT has been launched on October 29th, 2018. It provides, for the first time, colocated and global observations of the surface ocean wind and wave. Wind vectors and ocean wave spectral parameters will be derived from a combination of two Ku-Band radar instruments: a 6 beams incidence diffusiometer (nadir, 2°, 4°, 6°, 8° and 10°) measuring sigma0 profiles and wave spectra (SWIM) and wind scatterometer mode (SCAT).

At 0°, SWIM is a nadir altimeter acquiring at a 5Hz rate. And for the first time in a reference ground segment, the retracking used to extract ocean parameters is the so-called Adaptive retracker uses an adaptive model which takes into account the roughness of the surface. This solution, deriving four geophysical parameters: Epoch, Significant Wave Height, Sigma0 and Mean Square Slope, was chosen for its particularly good performances at deriving precise and high rate Significant Wave Height.

The aim of this presentation is to present the global performances of the ground segment retracking algorithm for the SWIM altimeter. During this talk, after an introduction of the retracking itself, global performances of the geophysical parameters will be presented and assessed via several diagnoses, including (but not limited to) comparisons with models and other altimetric missions such as Jason-3, Altika and Sentinel-3.

This presentation will also focus on the parameter "Mean Square Slope" related to the surface and derived by this algorithm. This new parameter will not only ensure a continuity of estimations between typical Brownian waveforms and peaky waveforms, (acquired over Arctic leads or bloom events for instance), but will also give useful information about the roughness of the surface.

Finally, we will illustrate and quantify the capacity of these data to improve the MeteoFrance models assimilating altimetric data.

## **Corresponding author:**

**Annabelle Ollivier (cls, France),** [aollivier@groupcls.com](mailto:aollivier@groupcls.com)

# Validation of CFOSAT data in the German Bight and Baltic Sea

**Luciana Fenoglio (University of Bonn, Germany);** Christopher Buchhaupt (University of Bonn, Germany);  
Jürgen Kusche (University of Bonn, Germany)

**Session:** CFOSAT

**Presentation type:** Oral

## **Abstract:**

Satellite altimetry provide measurement of sea state in terms of significant wave height and wind speed

but does not provide the directions of the two fields. The CFOSAT satellite mission will instead provide with its two radar instruments, the azimuthally scanning radar SWIM and the wind scatterometer SCAT, respectively directional spectra of ocean wave and wind vectors at the same time and at a global scale. CFOSAT will bring major information for monitoring the wind and wave fields and for modelling.

The institute AMPG/Uni Bonn has developed new algorithms for the processing and retracking of altimeter waveforms or both Low-Resolution Mode (LRM) and Delay Doppler Altimetry (DDA). The two sub-waveform retrackers TALES and STAR are parameter retrackers and provide the three basic parameters range, significant wave height and wind speed. Validation of SAR altimetry against those data have been performed in previous activities. The CFOSAT data will be used in synergy.

First investigations will focus on the validation of the CFOSAT geophysical products. CFOSAT data will be validated against contemporaneous altimeter data in SAR and LRM mode, in-situ and models. Region selected is the German coast of North Sea and Baltic Sea

## **Corresponding author:**

**Luciana Fenoglio (University of Bonn, Germany),** fenoglio@geod.uni-bonn.de

# Rain flags for SWIM on-board CFOSAT: methods and assessment

**Bruno PICARD (Fluctus SAS, France);** Mathilde Siméon (CLS, France); Jean-Christophe Poisson (CLS, France); Jean-Alexis Daguzé (CLS, France); Victor Gressani (IFREMER, France); Annabelle Ollivier (CLS, France); Cédric Tourain (CNES, France)

**Session:** CFOSAT

**Presentation type:** Oral

## **Abstract:**

CFOSAT is a joint mission of the Chinese (CNSA) and French (CNES) space agencies with the goal to monitor the ocean surface winds and waves and to provide information on related ocean and atmospheric science and applications.

CFOSAT carries two radar instruments: SWIM (Surface Waves Investigation and Monitoring), a wave scatterometer supplied by CNES; and SCAT (wind SCAT terometer), a wind-field scatterometer supplied by CNSA. SWIM's 6 rotating beams enable it to measure wave properties (direction, wavelength, amplitude and partitions), while SCAT measures wind intensity and direction.

SWIM is a new CNES Ku-band radar instrument, based on the technology of a spaceborne radar altimeter. It is the first ever space radar concept that is mainly dedicated to the measurement of ocean waves directional spectra and surface wind velocities through multi-azimuth and multi-incidence observations. Orbiting on a 519 km sun-synchronous orbit, its multiple Ku-band (13.575 GHz) beams illuminating from nadir to  $10^\circ$  incidence and scanning the whole azimuth angles ( $0-360^\circ$ ) provide with a 180 km wide swath and a quasi-global coverage of the planet between the latitudes of  $\pm 82,5^\circ$ .

When it is well known on classical Ku-band altimetry missions, the impact of the atmosphere on the wave spectra is still to be assessed.

For the current presentation, we will focus on the worked performed in the frame of CNES SALP - CaSyS (Calval Systematic for SWIM) project concerning the impact of rain event on the data quality. As for classical altimetry, rain flagging is an important step in the calibration/validation process: this latter aims at characterizing the performance of the products, providing a point-by-point assessment of the quality of each individual observation.

For nadir measurements, a wavelet transform approach is applied to identify rain cells, inspired by the method developed for AltiKa [Tournadre et al. 2015]. . As the waveform shape is directly impacted when the radar footprint crosses a rain cell, along-track variations of waveform parameters are detected using a continuous wavelet transform and a threshold is used to discriminate detected events that are related to rainy conditions.

For off-nadir measurements, another statistical method ( $v\_geo$  flag) is applied and computed for each beam. Thresholds are applied on the low frequency variability of the  $\sigma_0$  profiles, whose shape is also directly impacted by the local attenuations of the radar footprint.

In order to set up a qualitative and quantitative reference for the study of the impact of rain on observations, a "combined" rain rate product is built from observations provided by instruments dedicated to the atmosphere

monitoring. The goal is to create a reference allowing to distinguish as well as possible between rain and no rain event and to potentially fix an upper limit to the rain rate above which the impact on SWIM measurements is critical. Three different data sources have been used: SSMI-S (Special Sensor Microwave Imager-Sounder) on-board the F17 satellites under the Defense Meteorological Satellite Program (DMSP), Windsat radiometer on-board Coriolis and GMI on-board the Global Precipitation Mission. SWIM data have been systematically collocated with the rain data from these three missions and the closest observation in time is kept, together with the time lag between the altimeter and the rain observation. Taking into account the correlation time of rain events, only the collocation with a time lag lower than 5 minutes are kept.

The wavelet-based flag and the v-geo flag are both validated against this database. Then, the number of observations impacted by rain events are characterized, in terms of geographical distribution of their occurrences.

**Corresponding author:**

**Bruno PICARD (Fluctus SAS, France)**, [bpicard@satobsfluctus.eu](mailto:bpicard@satobsfluctus.eu)



# The assimilation of CFOSAT wave data in the wave model MFWAM : Ready for operational use ?

**Lotfi Aouf (Division Marine et Océanographie Météo-France, France);** Alice Dalphiné (Météo-France, France); Daniele Hauser (CNRS/LATMOS, France); Bertrand Chapron (IFREMER, France); cedric tourain (CNES, France)

**Session:** CFOSAT

**Presentation type:** Oral

## **Abstract:**

During the first months of the calibration/validation phase of CFOSAT, the wave scatterometer SWIM shows good skill to detect dominant wave trains composing the directional wave spectra, and also an accurate significant wave heights at the nadir look. The level 2 wave products include directional wave spectra from several beams 6, 8 and 10°. The expectations are very high in terms of operational wave forecasting and also a better directional sea state properties for the ocean/wave coupling at the air/sea interface. This work consists in preparing the assimilation of CFOSAT wave data in the operational global wave model MFWAM of Météo-France. Several assimilation runs have been implemented during the verification phase including upgraded processing to improve the level 2 products. We investigated the contribution of the assimilation of several SWIM wave products such the combined wave spectra and the wave spectra at the different beams. the optimization of the assimilation system has been implemented by accounting the azimuthal wavelength cutoff for SWIM wave spectra. The validation of the results has been performed in comparison with independent altimeters data and buoys.

The results show a significant improvement of integrated wave parameters in different ocean basins. One can mention that the comparison with independent altimeters wave data indicates a better scatter index of significant wave height roughly 20%, when we assimilated the SWIM nadir wave height and combined wave spectra. We also examined the persistency of the assimilation which stays efficient after 3 days in the forecast period. In this study we examined the impact of using SWIM wave data in storm cases and cyclonic seasons in the indian and Atlantic oceans.

Further discussions and comments will be presented in the final paper.

## **Corresponding author:**

**Lotfi Aouf (Division Marine et Océanographie Météo-France, France),** [lotfi.aouf@meteo.fr](mailto:lotfi.aouf@meteo.fr)

# The altimeter product suite for Sentinel-6/Jason-CS mission

**Remko Scharroo (EUMETSAT, Germany);** Carolina Nogueira Loddo (EUMETSAT, Germany); Cristina Martin-Puig (EUMETSAT, Germany); Bruno Lucas (EUMETSAT, Germany)

**Session:** The Future of Altimetry

**Presentation type:** Oral

## **Abstract:**

The Sentinel-6 (Jason-CS) mission will follow TOPEX and the Jason-series of “reference altimeter missions”. But it is in many ways a totally new type of mission, a different platform (similar to CryoSat) and a different altimeter (dissimilar from any of the previous altimeters). Not only will it be the first Synthetic Aperture Radar (SAR) altimeter used on one of the reference missions, it will also be the first altimeter that operates in a continuous high-rate pulse mode, 100% of the time. This particular operating mode allows simultaneous production of Low Resolution (LR) mode measurements on-board as well as the processing of SAR echoes (High Resolution, HR, processing) on-ground. Both types of measurements will be provided in separate families of Sentinel-6 altimeter data products.

Like Sentinel-3, Sentinel-6 Altimeter Level 1 products will be made available containing all the individual echoes in the time domain (L1A) or the measurement data and waveforms without geophysical corrections (L1B). Level 2 (L2) products will contain the geophysical measurements of sea level, wind speed, and significant wave height, at 20-Hz and 1-Hz, from both LRM and SAR altimetry. They will also contain an appropriate set of geophysical corrections, outlined in this presentation, aimed at providing sea level measurements at the cutting edge of what is feasible. The product standards are aligned with the upcoming Jason-3 GDR-F standard.

Another novelty for the Sentinel-6 mission is the production of a Microwave Radiometer Level 2 user product, aimed at furthering the use of microwave radiometer measurements of water vapour to a wider community.

This presentation will show how the Sentinel-6 products compare with the products of the Jason-series and of Sentinel-3 and how continuity is ensured.

## **Corresponding author:**

**Remko Scharroo (EUMETSAT, Germany),** [remko.scharroo@eumetsat.int](mailto:remko.scharroo@eumetsat.int)

# Overview and Status of the Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) Mission

**Michael Kern (European Space Agency, Netherlands);** Robert Cullen (ESA, Netherlands); Tania Casal (ESA, Netherlands); Tommaso Parrinello (ESA, Italy); Michael Ludwig (ESA, Netherlands); Gerhard Ressler (ESA, Netherlands); Patricia Marcos (ESA, Netherlands); Ignacio Navas Traver (ESA, Netherlands); Claudine Verlinden Verdier (ESA, Netherlands); Antonio Gabriele (ESA, Netherlands); Arnaud Lecuyot (ESA, Netherlands); Mark Drinkwater (ESA, Netherlands); Jerome Bouffard (ESA, Italy); Cristina Martin-Puig (EUMETSAT, Germany); Ole Andersen (DTU Space, Denmark); Annett Bartsch (BGEOS, Austria); Sinead Farrell (University of Maryland, USA); Sara Fleury (LEGOS, France); Simon Gascoin (CNRS, France); Amandine Guillot (CNES, France); Angelika Humbert (AWI, Germany); Eero Rinne (FMI, Finland); Andrew Shepherd (University of Leeds, UK); Michiel van den Broeke (Utrecht University, Netherlands); John Yackel (University of Calgary, Canada)

**Session:** The Future of Altimetry

**Presentation type:** Oral

## **Abstract:**

Evolution in the European Union's Copernicus Program and the Copernicus Space Component (CSC) is foreseen in the mid-2020s to meet priority user needs not addressed by the existing infrastructure, and/or to reinforce services by monitoring capability in the thematic domains of CO<sub>2</sub>, polar, and agriculture/forestry. This evolution will be synergistic with the enhanced continuity of services provided by the next generation of the existing Copernicus Sentinels (Copernicus 2.0).

This presentation gives an overview of the scientific/user and technical requirements for the Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) Mission, a High Priority Candidate Mission (HPCM) currently studied in Phase A/B1 by ESA.

The primary objectives of the candidate mission are:

1. To measure and monitor the variability of Arctic and Southern Ocean sea-ice thickness and its snow depth. Seasonal sea ice cycles are important for both human activities and biological habitats. The inter-annual variability of sea ice is a sensitive climate indicator; it is also essential for long term planning of any kind of activity in the polar regions. Knowledge of snow depth will lead to improved accuracy in measurements of sea ice thickness and is required for improving forecast models. On shorter timescales, measurements of sea ice thickness and information about Arctic Ocean sea state are essential to support maritime operations in ice-covered waters.

2. To measure and monitor the surface elevation and changes therein of glaciers, ice caps and the Antarctic and Greenland ice sheets. The two ice sheets of Antarctica and Greenland store the majority of Earth's fresh water and continued observations are important for understanding their contributions to sea level and climate change. Monitoring grounding line migration and elevation changes of floating and grounded ice sheet margins is important to identify and track emerging instabilities, which can negatively impact the stability of the ice sheets and result in future sea level rise.

The mission also has several secondary objectives: a) to contribute to the observation of global ocean topography as a continuum up to the poles;

b) to support applications related to coastal and inland waters. Observation of water level at the (Arctic) coast as well as of rivers and lakes is a key quantity in hydrological research; c) to support applications related to high latitude snow cover and permafrost.

**Corresponding author:**

**Michael Kern (European Space Agency, Netherlands), Michael.Kern@esa.int**

# Observing the Ocean Surface Topography at High Resolution by the Surface Water and Ocean Topography (SWOT) Mission

Lee-Lueng Fu (JPL - CalTech, United States); Rosemary Morrow (LEGOS/OMP CNRS/CNES/IRD/University Toulouse, France)

**Session:** The Future of Altimetry

**Presentation type:** Oral

## **Abstract:**

This paper presents the oceanographic objectives and plans of calibration and validation, science investigations and applications for the Surface Water and Ocean Topography (SWOT) Mission. This international mission, planned for launch in 2021, will make high-resolution observations of the ocean surface topography as a next-generation altimetry mission utilizing the technique of radar interferometry. With measurement over a swath of 120 km (20 km nadir gap), SWOT will map the entire earth within  $\pm 77.6$  degree latitudes every 21 days. Over the ocean, this new measurement will extend the two-dimensional resolution of ocean surface topography estimated from conventional radar altimetry from 150 km wavelength to possibly 15 km, offering opportunities to study the oceanic dynamic processes at these scales that act as one of the main gateways connecting the interior of the ocean to the upper layer. SWOT has a non-sun-synchronous orbit, specifically designed to observe and improve our understanding of the barotropic and baroclinic tides. As such, it will provide a unique opportunity to observe both low-frequency geostrophically balanced motions and high-frequency internal tides and gravity waves, and their non-linear interactions. We will present an overview of the SWOT Science Team's work in understanding these dynamical surface topography signals, from high-resolution and high-frequency modeling, and from in-situ and satellite observations.

The first 90 days of the mission (after the commissioning phase for engineering check-out and adjustment) will be flown in a 1-day repeat fast-sampling phase for calibration and validation. This unique, rapid temporal sampling will allow enhanced understanding of the SSH measurement at 15-150 km wavelengths in terms of signals and measurement errors. In particular, there will be two measurements a day at the crossover diamond-shaped regions, where the two-dimensional measurement at twice daily interval will provide the maximum amount of information on rapidly changing signals and errors. We are engaging the international community to participate in in-situ observations under the 1-day orbit swaths, to evaluate and link the SWOT sea surface height measurements to the observed internal oceanic processes in different regions and seasons.

The mission's science team will be renewed in 2020. The topics of oceanographic investigations cover mesoscale and submesoscale processes; modeling and data assimilation; tides, waves, and high-frequency processes; calibration and validation; coastal and estuarine processes. We will present some of the innovative techniques being developed to reduce the effects of measurement errors in the 2D SSH fields, and to address the challenges posed by the coarse temporal sampling and presence of internal tides in the construction of high-level gridded products and assimilated ocean state estimation.

## **Corresponding author:**

Lee-Lueng Fu (JPL - CalTech, United States), [lee-lueng.fu@jpl.nasa.gov](mailto:lee-lueng.fu@jpl.nasa.gov)

# Perspectives for Surface Current reconstruction combining future high-resolution Altimetry and Doppler current data

**Clement Ubelmann (CLS, France)**; gerald dibarboire (cnes, france); lucile gaultier (ODL, france); yannice faugere (CLS, france)

**Session:** The Future of Altimetry

**Presentation type:** Oral

## **Abstract:**

In the next decade, new spaceborne instruments should revolutionize the observation of Ocean surface dynamics at fine scales. SWOT and follow-up missions will bring high-resolution measurements of the surface dynamic topography, and Doppler current mission (such as Skim or WaCM) may fly in orbit to provide direct total surface current observations.

The synergy of dynamic topography and surface current is obviously very promising as many dynamic processes share signatures on one or both variables, but this may be challenging.

This study investigates, from Observing System Simulation Experiments, the potentials for reconstructing the surface current using various mapping approaches combining Sea Surface Height and total surface current. It first suggests the problem is not trivial. Indeed, the high-frequency signals of fine-scale altimetry (e.g. internal waves) and surface current (e.g. inertial oscillations) are important, but under-sampled in time potentially leading to strong aliasing in the estimates.

After showing that basic mapping approaches processing altimetry and total current separately would fail, we will show that specific inversion schemes accounting for oscillating covariances can be very efficient in compensating for the moderate observation revisits of the high-frequency processes.

Even to reconstruct the total current with direct observations of the same variable, the altimetry revealed still essential to constrain the degrees of freedom in the inversion, through accurate separation of balanced and unbalanced dynamics.

## **Corresponding author:**

**Clement Ubelmann (CLS, France)**, cubelmann@cls.fr

# First Results of Grazing Angle GNSS-R Altimetry from Sea Ice and Ocean Surfaces Using the Spire CubeSat Constellation

**Dallas Masters (Spire Global, Inc., United States);** Vu Nguyen (Spire Global, Inc., United States); Takayuki Yuasa (Spire Global Singapore PTE Ltd., Singapore); Oleguer Nogués-Correig (Spire Global UK Ltd., UK); Linus Tan (Spire Global Singapore PTE Ltd., Singapore); Timothy Duly (Spire Global, Inc., USA)

**Session:** The Future of Altimetry

**Presentation type:** Oral

## **Abstract:**

Spire Global, Inc. operates the world's largest and rapidly growing constellation of cubesats performing GNSS based science and Earth observation. Currently, the Spire constellation consists of 75+ 3U cubesats, with 25+ satellites capable of performing a variety of GNSS science, including radio occultation, ionosphere measurements, and precise orbit determination. These satellites have been primarily tasked to perform radio occultation (RO) to produce accurate profiles of atmospheric temperature, pressure, and water vapor and to collect millions of daily ionospheric total electron content measurements. Previous work has shown that grazing angle reflections of GNSS signals off of ocean and sea ice surfaces serendipitously collected during radio occultation measurements had the potential for being developed into new Earth observations of sea surface heights and sea ice. These GNSS-R techniques using the phase observables from grazing angle reflections collected by orbiting RO receivers did not get much traction, most likely because the RO missions were either not capable of operationally collecting these reflections or that mission priorities precluded their collection in favor of conventional RO measurements.

Recently, with the launch of dedicated GNSS-R missions, such as TechDemoSat-1 (TDS-1) and the eight-satellite CYGNSS constellation, phase observations of grazing angle reflections have again garnered interest and shown that the technique can perform 10 cm-level precision altimetry over sea ice, lakes, and ice sheet surfaces. But these measurements have been limited to a few collections using the raw intermediate frequency (IF) modes on these satellites and have not been able to produce reliable statistics of the measurements, e.g., the likelihood of coherent reflections and their spatial and temporal distributions across various Earth surface types. To address this issue and to pursue an operational system for collection of grazing angle GNSS reflections, Spire recently reprogrammed its STRATOS GNSS science receiver to perform this measurement on currently orbiting RO satellites. To accomplish this, the open loop tracking used in RO collection was modified to perform open loop prediction and tracking of grazing angle reflections between 5-30 deg elevation. This software mode was subsequently uploaded to one orbiting satellite and tested successfully on the first attempt, acquiring 50 Hz in-phase and quadrature samples of GNSS reflections from sea ice and ocean surfaces. Initial results confirm coherency of reflections over sea ice surfaces and some open ocean surfaces. Full altimetric processing has been performed on a few cases, confirming the precision of the technique over sea ice and open oceans where reflections were coherent. In comparing the height estimates of in areas of sea ice to ice thickness estimates from SMOS, we noted similar gradients, supporting the theory that the L-band GNSS signals penetrate the sea ice and are mostly reflecting from the water-ice interface under the ice. This would make the technique a sensor of sea ice draft, which would potentially complement other sensors such as ICESat-2 and Cryosat-2 that sense the top layer of sea ice. A production period has now begun on multiple Spire satellites that will result in large quantities of diverse measurements from space in a relatively short time. We will present further results of this new and potentially revolutionary technique to use existing orbiting RO satellites to perform grazing angle GNSS-R altimetry.

## **Corresponding author:**

**Dallas Masters (Spire Global, Inc., United States),** [dallas.masters@spire.com](mailto:dallas.masters@spire.com)

# Assessment of ICESat-2 Performance over the Arctic Ocean During its First Year in Orbit

**Sinead Farrell (University of Maryland, United States)**; Kyle Duncan (University of Maryland, USA); Ellen Buckley (University of Maryland, United States); Marissa Dattler (University of Maryland, United States); John Kuhn (NOAA Laboratory for Satellite Altimetry, United States); Laurence Connor (NOAA Laboratory for Satellite Altimetry, United States); Eric Leuliette (NOAA Laboratory for Satellite Altimetry, USA)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Oral

## **Abstract:**

After a successful launch on the 15th September 2018, the Advanced Topographic Laser Altimeter System (ATLAS) on ICESat-2 has been acquiring photon counting elevation data over Earth's polar regions to 88 degrees latitude. We show initial ATLAS performance over the Arctic Ocean and subpolar seas, during ICESat-2's first year of operations. ATLAS height measurements can be used to derive sea ice freeboard, the height of the sea ice above local sea level, and, in ice-free areas, the sea level anomaly (SLA). Early results suggest excellent agreement in sea ice freeboard across all six ATLAS laser beams. The observations reveal very fine details of sea ice topography including rough, multi-year sea ice floes, pressure ridges within the ice cover, and smooth, level ice surfaces including refrozen leads. ATLAS sea ice observations are validated through comparisons with high-resolution airborne altimetry, obtained during dedicated flight surveys over the central Arctic and Beaufort Sea in Spring 2019. We also assess SLA and dynamic ocean topography (DOT) estimates derived from ATLAS data. We cross-calibrate ICESat-2 SLA and DOT measurements with complementary radar altimeter data from CryoSat-2 and Sentinel-3 in the Arctic Ocean, along with Jason-2/3 and SARAL/AltiKa data in the ice-free areas south of the marginal ice zone. We summarize the utility of ICESat-2 for measuring sea surface height and sea ice freeboard in the polar oceans, and explore its capabilities for measuring seasonal and inter-annual variability during its mission lifetime.

## **Corresponding author:**

**Sinead Farrell (University of Maryland, United States)**, [sinead.farrell@noaa.gov](mailto:sinead.farrell@noaa.gov)



# Sentinel-3 LAND Altimetry products and intended evolutions

**Pierre Femenias (ESA, Italy);** Sylvie Labroue (CLS, France); Matthias Raynal (CLS, France); Jouzeau Arnaud (CLS, France); Nicolas Taburet (CLS, France); Graham Quartly (PML, UK); Alan Muir (MSSL, UK); McMillan Malcolm (CPOM - Univ of Lancaster, UK)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Oral

## **Abstract:**

The Copernicus Sentinel-3 (S3) mission is today flying in constellation following the successful launch of the S3B satellite (April 2018) and associated commissioning phase. The first satellite, S3A, was launched in February 2016 and is nominally operated in routine phase since October 2017 along now with S3B, this latter being 140° ahead of S3A on the same orbit plane.

The S3 Surface Topography Mission (STM), built on the heritage of ESA's ERS, Envisat and CryoSat missions, is primarily an ocean mission, however, the STM mission is intended to provide continuity with the ESA CryoSat High-Resolution sea-ice and land ice surface measurements used to derive floating ice thickness and ice sheet topography over the two poles, as well as to provide measurements of River and Lake Heights (RLH) for large rivers, their tributaries and lakes to at least the quality of the RA-2 on ESA ENVISAT mission.

The European Space Agency (ESA) is responsible for the generation, performance and delivery of the S3 LAND products to the Copernicus Services and user community.

In order to better answer new needs and requirements from the Copernicus Services and user community, ESA is looking into an evolution of the S3 LAND Payload Data Ground Segment (PDGS), offering more flexibility and adequacy of the processing per surface types (e.g. Inland waters, land ice, Sea-ice) through tailored and dedicated processing chains, and user products.

The expected evolutions of the ground processing will cover in particular the inclusion of the zero-padding (i.e. over-sampling of the waveforms), the implementation of the Hamming weighting function for the sea-ice and inland water surfaces processing and the implementation of the waveform centering for the processing of the ice sheet margins.

This paper aims at presenting the status of the ESA S3 LAND products, their current performances, and the intended plans for improved end-to-end "L0 to L2" processing chains per surface types as an intended evolution of the ESA S3 LAND PDGS and products.

## **Corresponding author:**

**Pierre Femenias (ESA, Italy),** Pierre.Femenias@esa.int

# River levels from multi-mission satellite altimetry, a statistical approach

**Karina Nielsen (DTU Space, Denmark);** Angelica Tarpanelli (Research Institute for Geo-Hydrological Protection, Italy); Elena Zakharova (Institute of Water Problem, RAS, Moscow, Russia); Jérôme Benveniste (European Space Agency, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Oral

## **Abstract:**

The river level from altimetry is mainly portrayed at virtual stations.

Hence, at locations where repeat missions such as Envisat, AltiKa (before June 2016), the Jason missions and the recently launched missions Sentinel-3A and 3B cross the river. These missions can provide us with river levels at a temporal resolution equivalent with the repeat time of the given missions. For the Jason missions, Envisat/AltiKa, and the Sentinel-3, this is 10, 35 and 27 days, respectively.

For missions such as CryoSat-2 and AltiKa (after June 2016) the virtual station approach is not an option due to the drifting track pattern. Hence, construction of time series of water level is challenging due to the topographic contribution present at each and that the amplitude of the water level might be different also.

The water level variations in rivers, hence the phases of annual signals and the amplitude, can be quite different. The seasonal pattern in Arctic rivers, for instance, is dominated by a flood wave in the spring when the ice and snow start to melt.

In the Lena river, the water rises with up to 20-25 meter within a few weeks. In general narrow rivers are more sensitive to sudden events, such as extreme rain, compared to large rivers. Hence, we might not capture the entire signal at the virtual stations.

Here we use data from CryoSat-2, SARAL/AltiKa, and Sentinel-3A/3B for a river segment to make a joint solution of the river level. We experiment with different approaches to reconstruct the river level time series. One of the approaches is a state-space model composed of a process part consisting of an AR1 process and an observational part, where the error follows a mixture between a Gaussian and a Cauchy distributions. The spline functions account for the change in topography

and a potential variation in the water level amplitude along the river.

The model approach has the advantage that the river level time series can be reconstructed at any location along the considered river segment.

Here We show the results for rivers (Lena, Ob, Po, Mississippi, and the Amazon) of different sized and in different environments. When validating with in situ data we find that we are able to map the river levels, especially for the smaller rivers, in greater detail compared to what can be obtained at the virtual stations.

The presented work is funded by ESA through the projects Ridesat and ArcFlux.

**Corresponding author:**

**Karina Nielsen (DTU Space, Denmark)**, [karni@space.dtu.dk](mailto:karni@space.dtu.dk)

# Status and evolutions of ESA CryoSat data products

**Jerome Bouffard (European Space Agency - ESA, Italy);** Marco Meloni (SERCO c/o ESA, Italy); Tommaso Parrinello (ESA, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Oral

## **Abstract:**

With the effects of a fast-changing Climate becoming more and more apparent in Polar Regions, it becomes increasingly important to understand how Earth's ice fields are responding. Launched in 2010, the ESA's CryoSat satellite was the first European Polar mission specifically designed to address this issue in measuring changes in the thickness of the sea ice and the elevation of the ice sheets and mountain glaciers. CryoSat has also demonstrated to be a valuable source of observations for measuring variations of inland water storage and ocean dynamics. The necessity to ensure long-term continuity and quality of altimetry measurements at high latitudes associated to the excellent technical status of the satellite's systems, are the main rationals to extend the CryoSat mission's operation as long as possible. The CryoSat data products require to continuously evolve and need to be routinely quality-controlled and thoroughly validated in order to address a growing number of Science Challenges. This paper provides an overview of recent ice and ocean product evolutions and Cal/Val activities performed by ESA and its partners. This paper also details the new concept of the "CryoSat ThEMatic PrOducts" (aka Cryo-TEMPO), which will aim at maximizing the use of CryoSat for thematic applications. For that, the Cryo-TEMPO framework should allow bringing together multi-disciplinary scientists and altimetry experts in order to define the future standards for ESA CryoSat products, including improved and targeted geophysical parameters associated to traceable quality indicators.

## **Corresponding author:**

**Jerome Bouffard (European Space Agency - ESA, Italy),** [jerome.bouffard@esa.int](mailto:jerome.bouffard@esa.int)

# Snow depth on sea ice from altimetry for 2013-2018 Arctic and Austral winters

**Sara Fleury (LEGOS/CTOH, France);** Florent Garnier (LEGOS/CTOH, France); Frédérique Rémy (LEGOS, France); Florence Birol (LEGOS/CTOH, France); Jérôme Bouffard (ESA, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Oral

## **Abstract:**

Snow depth at the top of sea ice is a key parameter of the climate change due to its isolation and albedo properties, which condition the sea ice growth and melt, the heat absorption and the primary production under the ice. Moreover, for several reasons that will be described in this presentation, the lack of knowledge about the snow depth can impact sea ice thickness retrieval using altimetry with an error that can reach up to 100% in the worst cases.

Nevertheless, there exists currently no reliable snow depth product over Arctic and Austral sea ice. Indeed, the Warren (1999) climatology, frequently used to convert freeboard to sea ice thickness, has been built with data obtained decades ago, before the first impacts of the climate changes, and the meteorological re-analyses fail to faithfully reproduce snow falls in polar regions.

A study published in [Guerreiro et al., 2016] has shown that the difference of the scattering properties of the Ku-band and the Ka-band can provide a good proxy of the snow depth using an adapted processing chain, Alti Snow Depth (ASD). As a first demonstrator, the ASD chain has been applied on the Ka measurements, issued from Saral/AltiKa, a French-Indian satellite, and on the corresponding Ku measurements, issued from the European satellite altimeter CryoSat-2/SIRAL. These two altimeters are based on different technics and the ratio between the surface areas illuminated by each radar is about one order of magnitude.

In order to make the AltiKa LRM measurements comparable to the CryoSat-2 SAR measurements, these last ones have been pre-processed by the CNES in a degraded PLRM mode. The evaluation of the ASD product in regards with the Operation Ice Bridge snow radar data shows a good correlation ( $R=0.67$ ), much better than all previous solutions. Nevertheless the results were limited to two winter campaigns.

This talk will present the results for the period extended to the five CryoSat-2/Saral common years (2013-2018) and to Austral sea ice, the GOP product dedicated to ocean from ESA. Their performance in regards with several in-situ datasets will be analysed.

Acknowledgement: this work has been supported by the CryoSeaNICE ESA project

**Corresponding author:**

**Sara Fleury (LEGOS/CTOH, France)**, [sara.fleury@legos.obs-mip.fr](mailto:sara.fleury@legos.obs-mip.fr)

# Delivering the Lake Essential Climate Variables - an update from ESA CCI Lakes

**Jean-François Crétaux (LEGOS, France)**; Simis Stefan (PML, United Kingdom); Calmettes Beatriz (CLS, France); Merchant Chris (University of Reading, United Kingdom); Duguay Claude (H2O Geomatics, Canada); Giardino Claudia (CNR, Italy); Coulon Bruno (CLS, France); Hervé Yesou (SERTIT, France); Eirik Malnes (NORUT, Norway); Pablo Blanco (TRE-ALTAMIRA, Spain)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Oral

## **Abstract:**

Lakes and enclosed inland seas are integrators of environmental, anthropogenic and climatic changes occurring within their catchments. The factors that drive lake conditions vary widely across space and time, and lakes, in turn, impact their surrounding environments in important and diverse ways. Remote sensing can offer unique insights into the response of lakes to change, at a global level. The ESA Climate Change Initiative Lakes (CCI-Lakes) project will provide the first consistent dataset of essential climate variables for a global selection of lakes, in response to the updated GCOS definition of the Lakes ECV (GCOS 2016). This is a multi-disciplinary task combining expertise in the remote observation of lake water level, lake water extent, ice cover, surface water temperature and surface water reflectance. It is crucial to reach consistency between the individual variables, which are observable at varying spatial resolutions and temporal intervals, and available from sensor records which do not always overlap in time. The CCI Lakes project, however, also presents an opportunity for limnologists and climate modellers worldwide to evaluate and contribute to the first attempt to combine state-of-the-art remote sensing methods for these variables. The CCI Lakes team is currently preparing the first climate data record based on current satellite sensor capabilities

## **Corresponding author:**

**Jean-François Crétaux (LEGOS, France)**, [jean-francois.cretaux@legos.obs-mip.fr](mailto:jean-francois.cretaux@legos.obs-mip.fr)

# Relationship between Sea Level and Sea Surface Salinity in the Maritime Continent

Severine Fournier (JPL, United States); Tony Lee (JPL, United States)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Poster

**Poster number:** SC1\_001

## **Abstract:**

The Maritime Continent is a tropical chokepoint of the global ocean circulation system. Ocean currents in this region, especially the Indonesian throughflow, regulate Indo-Pacific oceanic exchanges (including heat, freshwater, nutrients, carbon). These currents influence physical process, marine biogeochemistry, and climate variability in the Indo-Pacific sector. Sea level variations in the Maritime Continent have significant implications to the regional ocean currents. Previous studies of sea level variations in this region have focused mostly on the wind forcing (both local and remote). However, the Maritime Continent is heavily influenced by regional water cycle across various time scales, thereby inducing large variations of sea surface salinity (SSS). In this study, we examine the relation of SSS and sea level anomaly (SLA) satellite observations on intraseasonal, seasonal, and interannual time scales. We also estimate the contributions of upper-layer salinity to SLA variations on these time scales. The implications to the Indonesian throughflow will also be discussed.

## **Corresponding author:**

**Severine Fournier (JPL, United States)**, [severine.fournier@jpl.nasa.gov](mailto:severine.fournier@jpl.nasa.gov)



# Impact of 2014-2016 El Niño on the South Indian Ocean heat content: local versus remote forcing

**Denis Volkov (NOAA-AOML / University of Miami, United States);** Denis Volkov (NOAA-AOML/University of Miami, USA); Michael Rudko (NOAA-AOML/University of Miami, USA); Sang-Ki Lee (NOAA-AOML, USA); Hong Zhang (UCLA, USA)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Poster

**Poster number:** SC1\_002

## **Abstract:**

The South Indian Ocean (SIO) is one of the major heat accumulators among the oceanic basins. During the 2014-2016 El Niño, its heat content south of 10°S dramatically decreased. This led to the associated drop in the mean sea level by 6 cm, which constitutes about 50% of the regional mean sea level rise in 1993-2018. The variability of heat content and sea level in the SIO is strongly influenced by processes in the equatorial Western Pacific. During La Niña/El Niño conditions, the stronger/weaker than average trade winds lead to the accumulation/reduction of heat and sea level rise/fall in the Western Pacific. The anomalies of heat content and sea level rapidly propagate into the SIO via the Indonesian Throughflow and coastally trapped waves, and extend along the West Australia coast. Subsequently, Rossby waves generated at the eastern boundary propagate these anomalies into the interior of the SIO. Besides this mechanism, local processes linked to both the El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole also affect the variability of heat content and sea level in the SIO. Using observations (satellite altimetry and Argo profiles of temperature and salinity) and an ocean state estimate from Estimating the Circulation and Climate of the Ocean, we investigate the relative contribution of remote (originated in the Pacific) and local processes in the variability of heat content and sea level in the SIO. We find that remote processes are more effective at decadal time scales, and they were responsible for heat accumulation during the La Niña conditions in 2005-2012. On interannual time scales, while both remote and local processes are equally important in the southeastern part of the Indian Ocean, the contribution of local processes increases westward. The negative anomalies of heat content and sea level at eastern boundary induced by the 2014-2016 El Niño did not reach the interior of the SIO. Instead, the concurrent negative anomalies in the ocean interior were generated by local wind forcing correlated with ENSO. Furthermore, while negative anomalies were still present in the eastern SIO in 2016-2017, positive anomalies emerged west of 95°E. These latter anomalies were generated by the concurrent intensification of southeasterly trade winds. Furthermore, they were responsible for the partial recovery of the SIO heat content and sea level after the dramatic drop during the 2014-2016 El Niño.

## **Corresponding author:**

**Denis Volkov (NOAA-AOML / University of Miami, United States),** denis.volkov@noaa.gov

# Investigating vertical land motion and potential systematic errors in altimetry using a filter-based estimation approach

**Mohammad-Hadi Rezvani (Discipline of Geography and Spatial Sciences, University of Tasmania, Australia);** Chris Watson (Discipline of Geography and Spatial Sciences, University of Tasmania, Australia); Matt King (Discipline of Geography and Spatial Sciences, University of Tasmania, Australia); Benoit Legresy (CSIRO Marine and Atmospheric Research, Australia)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Poster

**Poster number:** SC1\_003

## **Abstract:**

Vertical land motion (VLM) is important for a range of geophysical and climate applications. VLM is used to improve the understanding of solid Earth rheology as is relevant to models of Glacial Isostatic Adjustment or elastic deformation – it is also vital as the connection between relative and absolute estimates of sea level change. We develop a refined filter-based approach to quantify ongoing linear or non-linear land motions, such as those that result from surface mass changes (e.g., those that occur near to glaciers), through combination of data from multi-mission satellite altimeters, long-running tide gauges, and coastal GNSS stations. To this end, a space-time Kalman filter is designed to incorporate multi-mission crossover, altimeter minus gauge, and GNSS observations. This flexible approach allows estimation of linear or non-linear land motions, and considers mission-specific bias drifts. Initial results from testing in the Baltic Sea are present prior to showing results from a global analyses.

## **Corresponding author:**

**Mohammad-Hadi Rezvani (Discipline of Geography and Spatial Sciences, University of Tasmania, Australia),** mohammadhadi.rezvani@utas.edu.au

# Investigating sea state trends and variability with new climate-quality satellite altimeter products

**Ben Timmermans (National Oceanography Centre (UK), United Kingdom);** Christine Gommenginger  
(National Oceanography Centre (UK), United Kingdom)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Poster

**Poster number:** SC1\_004

## **Abstract:**

Please be advised: Our intent is to submit to the general session: "Science Results from Satellite Altimetry", rather than any of the dedicated splinter sessions, but this is not listed on this abstract submission page.

## **Abstract:**

Accurate knowledge and understanding of the sea state and its variability is crucial to numerous oceanic and coastal engineering applications, but also to climate change and related impacts including coastal inundation threats from storm surge, waves resulting from extreme weather and ice-shelf break-up. An increasing duration of altimeter observations of the sea state motivates a range of global analyses, including the examination of changes in ocean climate. For ocean surface waves in particular, the recent development and release of products providing observations of altimeter-derived significant wave height make long term analyses fairly straightforward.

In this study we make use of products presented by Ribal et al. (2019), and the recently released product developed through the European Space Agency Climate Change Initiative (CCI) for Sea State, to compare temporal trends in averages and extremes of significant wave height. In particular we focus on the statistical robustness of the results at different temporal and spatial scales, and explore geographic sensitivity to changes or loss of source data. We compare these results with the current state of knowledge, and conclusions of other investigations based on a range of data sources including in situ observations. In addition, we compare with reanalysis and simulated data sets, and consider their importance as possible source data for evaluation of temporal trends, given the availability of global observations from satellite, and the historical difficulty of validation in remote regions.

## **Corresponding author:**

**Ben Timmermans (National Oceanography Centre (UK), United Kingdom),** [ben.timmermans@gmail.com](mailto:ben.timmermans@gmail.com)

# Observational constraint on greenhouse gas and aerosol contributions to global ocean heat content changes

**Benoit Meyssignac (CNES/LEGOS, France);** Elodie Charles (CLS, France); Aurelien Ribes (CNRM, Météo-France, France)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Poster

**Poster number:** SC1\_005

## **Abstract:**

Observations and climate models are combined to identify an anthropogenic warming signature in the upper ocean heat content changes (OHC) since 1971. We use a new detection and attribution analysis developed by Ribes et al. (2015) which uses a symmetric treatment of the magnitude and the pattern of the climate response to each radiative forcing. A first estimate of the OHC response to natural, anthropogenic, greenhouse gas and other forcing is derived from a large ensemble of CMIP5 simulations. Observational datasets from historical reconstructions are then used to constrain this estimate. A spatio-temporal observational mask is applied to compare simulations with actual observations and to overcome reconstruction biases. Results on the 0-700m layer show that the global OHC has increased significantly since 1971 in response to GHG emissions by  $2.37 \pm 0.34$   $10^7$  J/m<sup>2</sup>/y. 33% of this increase has been compensated by other anthropogenic influences (mainly aerosols), which induced an OHC decrease. The natural forcing has also induced a slight global OHC decrease since 1971, compensating an extra 7% of the OHC increase due to GHG. Compared to previous studies we have separated the effect of the anthropogenic forcing into the effect of the GHG forcing and the effect of the other anthropogenic forcing. This has been possible by using a new D&A method and by analysing at the same time the global OHC trends over 1957-1980 and over 1971-2005. This bivariate method takes advantage of the different time variation of the GHG forcing and the aerosol forcing since 1957 to separate both effects. The next step is to develop a similar approach to provide an observational constraint on greenhouse gas and aerosol contributions to global mean sea level rise

## **Corresponding author:**

**Benoit Meyssignac (CNES/LEGOS, France),** benoit.meyssignac@legos.obs-mip.fr

# Investigating Regional Sea Level Budget Closure During the Altimeter Era

**Thomas Harvey (University of Colorado Boulder, United States);** Ben Hamlington (NASA Jet Propulsion Laboratory, USA); Steve Nerem (University of Colorado Boulder, United States); Thomas Frederikse (NASA Jet Propulsion Laboratory, USA)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Poster

**Poster number:** SC1\_006

## **Abstract:**

It is well known that regional sea level is influenced by multiple processes operating on a range of timescales. Separating the relative contributions of each of these processes has important implications for our ability to understand both contemporary and future sea level change. With available observations, it is now possible to conduct sea level budget studies--similar to those done on global scales--on a regional level. Here, we focus on the time period from 1993 to present, starting from trends measured by satellite altimeters and tide gauges and then quantifying the contributions from relevant processes. We show that after identifying steric expansion, mass redistribution, large-scale ocean dynamics, GIA, and localized land motion as the major components of relative regional sea level change, extended observations of each component allow for budget closure within bounds of uncertainty. To account for relative sea level change measured by tide gauges, co-located GPS stations provide rates of vertical land motion which are primarily influenced by GIA in addition to more localized uplift due to mass redistribution. Comparisons between regional relative sea level from tide gauges and open ocean altimetry as well as steric measurements provide the foundation for the ocean dynamics and steric components of the budget, respectively. The results of this study highlight the advancements in the understanding that can be obtained regarding regional sea level variability as a result of the improved observational network that is available over the past decades.

## **Corresponding author:**

**Thomas Harvey (University of Colorado Boulder, United States),** [thomas.harvey@colorado.edu](mailto:thomas.harvey@colorado.edu)

# Extended Global Mean Sea Level Budget Study

Hamlington Benjamin (NASA Jet Propulsion Laboratory, United States); J.T. Reager (NASA JPL, USA);  
Hrishi Chandanpurkar (NASA JPL, USA)

**Session:** Science I: Climate data records for understanding the causes of global and regional sea level variability and change

**Presentation type:** Poster

**Poster number:** SC1\_007

## **Abstract:**

Since 2002, the Gravity Recovery and Climate Experiment (GRACE) mission has provided accurate measurements of variations in Earth's gravity field, leading to new insights on a wide range of topics. Particular advancement has been made in our understanding of how water moves through the Earth System, with implications for understanding climate and human impacts. This movement of water is particularly relevant for the study of sea level on global scales. The two dominant drivers of changes in global mean sea level (GMSL) are thermal expansion due to the warming ocean, and changes in ocean mass associated with this water movement between land to ocean. With the addition of GRACE and the Argo profiling floats to the sea level observing network since 2002 and 2004, respectively, recent efforts have been made to "close the GMSL budget" through comparisons to satellite altimeter observations. While the combined global mean trends from GRACE and Argo agree reasonably well with the altimeter-measured GMSL, there is some disagreement on shorter timescales.

Additionally, despite the advances that have been made, the available record length limits our understanding. The GRACE mission ended in mid-2017, leaving the data record at only 15-years in length. To continue the record started by GRACE, the GRACE Follow-On (GRACE-FO) mission launched in 2018 with new data soon to be publicly released. However, the relatively short record from the two missions coupled with the gap between them still present challenges in examining long time-scale climate processes and limits budget studies to times when GRACE data is available. There have been numerous efforts to extend the steric sea level record prior to the Argo time period and thus infer the global change due to TWS, but there is considerable disagreement amongst the available steric products. A longer TWS record would allow for the evaluation of these steric datasets, while providing the opportunity to study the GMSL budget over the full length of the satellite altimeter record (1993 to present).

We apply a novel multivariate data analysis technique to meet the following objectives: 1) Extend the monthly data record of satellite-measured TWS back to 1979 to produce a dataset appropriate for studying lower-frequency natural variability, and 2) Fill gaps in the GRACE record to provide a continuous dataset of TWS from 2002 to 2017 that is consistent with GRACE measurements. This longer record of TWS allows for the study of longer-term natural variability that could impact the way we interpret the satellite sea level records, and allows for improved sea level budget studies that yield new insights into GMSL change.

## **Corresponding author:**

**Hamlington Benjamin (NASA Jet Propulsion Laboratory, United States),**  
benjamin.d.hamlington@jpl.nasa.gov

# Applying the pulse-pair processing to high PRF nadir altimeter data: sensitivities to geophysical parameters and possible applications

Pierre Rieu (CLS, France); François Soulat (CLS, France); Thomas Moreau (CLS, France); François Boy (CNES, France)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Poster

**Poster number:** IPM\_001

## **Abstract:**

The pulse-pair technique [Zrnic, 1977] is widely used for estimating the first two moments of the Doppler spectrum of geophysical signals, i.e. the mean (Doppler centroid or Doppler shift) and the width. Doppler centroid estimation through pulse-pair processing is routinely performed in SAR imagery [Madsen, 1989] and in the SKIM candidate mission, that uses a near-nadir Doppler radar to estimate the Doppler shift induced by surface currents [Arduin, 2018].

In nadir altimetry, the correlation of complex pulses has already been studied with low-PRF altimeter data ([Abileah, 2013] on Envisat and [Quartly, 2015] on AltiKa) but, due to sparse data, sensitivities to geophysical parameters were not brought to light. For high-PRF altimeters (CryoSat-2, Sentinel-3), the Doppler history of scatterers is used through a Delay-Doppler processing [Raney, 1998], and pulse-pair processing has not yet been analyzed to our knowledge.

We have implemented the pulse-pair processing in our S3 prototype processor, and one cycle of data have been processed. The Doppler shift estimates are found to be very sensitive to several effects (surface slopes, mispointing, heterogeneous surface backscattering ...) and in perfect agreement with the model derived by [Rodriguez, 1994], thus allowing direct parameter estimation. We detail our implementation of the processing and analyze the observed sensitivities to geophysical parameters. Possible applications of this easy-to-implement and computationally efficient processing are presented, ranging from mispointing monitoring to data quality flagging (correlated errors).

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**Corresponding author:**

**Pierre Rieu (CLS, France)**, prieu@groupcls.com



# Exploring the potential of Sentinel-3 fully-focused SAR altimeter range data for enhanced detection of coastal currents along the Northwestern Atlantic Shelf

Hui Feng (University of New Hampshire, United States); Alejandro Egido (NOAA – Laboratory for Satellite Altimetry, United States); Doug Vandemark (University of New Hampshire, United States)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Poster

**Poster number:** IPM\_002

## **Abstract:**

Fully-focused Synthetic Aperture Radar (FF-SAR) is a novel SAR altimetry data processing technique that accounts for the phase evolution of the targets in the scene, making it possible to focus the complex echoes along the aperture. The process combines coherently all the available radar returns on the surface to improve the resolution and measurement precision, and can potentially reduce the along-track resolution to its theoretical limit equal to  $L/2$ , where  $L$  is the antenna length.

Our study in the OSTST-2018 presented a preliminary assessment of the FF-SAR mode range data from Cryosat-2 (CS2) altimetry in the Nova Scotian Shelf (NSS). With the pseudo-low resolution mode (PLRM) data as a baseline, CS2 FF-SAR parameters (range, wave height,  $\sigma_0$ , and range-gradient derived geostrophic current  $V_g$ ) were examined to demonstrate the improvements of FF-SAR over PLRM, particularly in the detection of nearshore currents in the NSS. Clearly, we found that 1) the noise reduction (i.e. precision improvement) of the FF-SAR data (i.e. range and range-derived current) is apparent and 2) finer-scale signals are identified in the FF-SAR data.

However, the uneven time-space coverage in CS2 SAR mode data in the region limits its further evaluation and application. As a natural continue to the work, we propose to apply the established evaluation strategy to the SAR mode datasets from Sentinel-3A/3B altimeters that by design provide regular time-space coverage along the northwestern atlantic shelf (from the Mid-Atlantic Bight, the Gulf of Maine to Nova Scotia shelf). In the further analysis, the objectives include 1) to explore a more objective cross-shelf length scale to derive along-shelf coastal current  $V_g$ , 2) to investigate whether or not geophysical corrections (e.g. tide, DAC, etc.) should be applied for an improved detection of the NSS coastal currents, and 3) understand what small-scale signals identified in FF-SAR data represent, such as current, internal waves, or just non-geophysical noises. To reach these, past and ongoing in situ hydrographic and current measurements, and modeling datasets in the region will be used to provide expected mean and dynamical circulation features from the shelf break up to the coast.

## **Corresponding author:**

Hui Feng (University of New Hampshire, United States), hui.feng@unh.edu

# Evaluation of FF-SAR Altimetry Observations over the Open Ocean

Alejandro Egido (NOAA / GST Inc., United States); Furqan Ahmed (NOAA / GST Inc., United States)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Poster

**Poster number:** IPM\_003

**Abstract:**

Fully-focused synthetic aperture radar altimetry is a novel technique for the processing of SAR altimetry data. In this paper we evaluate the performance of the FF-SAR technique for a statistically significant amount of data, encompassing six full Sentinel-3 cycles, in a wide variety of sea state conditions and compare it to the currently available delay/Doppler processing.

**Corresponding author:**

Alejandro Egido (NOAA / GST Inc., United States), [alejandro.egido@noaa.gov](mailto:alejandro.egido@noaa.gov)

# Impact of the Sentinel-3A SRAL PTR Evolution on the L2 Marine Measurements

Salvatore Dinardo (He Space, Italy); Michele Scagliola (ARESYS, Italy); Lisa Rechia (ARESYS, Italy)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Poster

**Poster number:** IPM\_004

## **Abstract:**

The Sentinel-3A SRAL Point Target Response (PTR) Half-Power Width is drifting over the time. This drift has been estimated to be around -0.5 mm per year and is significant, being around five times the PTR width drift as measured for Envisat Altimeter and CryoSat-2 Altimeter.

In this work, we analyse the impact of this Sentinel-3A SRAL PTR evolution on the stability of the L2 marine geophysical measurement (sea level and wave height) in SAR mode over the full period of the mission.

A Sentinel-3A STM (surface Topography Mission) pole to pole L1b pass was selected and the waveforms in this pass have been retracked with a numerical SAR retracker embedding the evolving real Sentinel3-A SRAL PTR as measured during the CAL1 calibration during the mission time. By comparison of the significant wave height obtained by means of the numerical retracker, using the CAL1 PTR, and the the significant wave height from L2 marine measurements, an impact assessment of the PTR stability will be performed.

The impact in term of stability of the SRAL PTR evolution on the L2 marine measurements will be reported and discussed. The dependency of the impact with the sea state conditions will be investigated.

## **Corresponding author:**

**Salvatore Dinardo (He Space, Italy)**, [salvatore.dinardo@eumetsat.int](mailto:salvatore.dinardo@eumetsat.int)

# ICESat-2 Altimetry of the Open Ocean

**James Morison (Polar Science Center APL/Univ. of Wash., United States)**; Suzanne Dickinson (Polar Science Center APL/Univ. of Wash., USA); David Hancock (NASA Goddard Space Flight Center, USA); LeeAnne Roberts (NASA Goddard Space Flight Center, USA); John Robbins (john.w.robbins@nasa.gov, USA)

**Session:** Instrument Processing: Measurement and Retracking

**Presentation type:** Poster

**Poster number:** IPM\_005

## **Abstract:**

Abstract:

The Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) has been developed primarily to measure the height of the Earth's ice at high spatial resolution but it also provides satellite ocean altimetry unlike any other. To achieve high resolution it uses the Advanced Topographic Laser Altimeter System (ATLAS), a photon-counting, multi-beam lidar pulsing at 10 kHz. At the speed of the spacecraft, each beam of ATLAS illuminates 15 m patch of the surface every 0.7 m of along-track distance. Given the low reflectance of the ocean surface, of all the photons detected by ATLAS, on the order of one photon per pulse returns from the ocean surface. ATLAS determines the apparent height of the reflecting surface for each one of these photons along with the apparent height of a lower density of noise photons. Averaged over along-track distance these heights form a histogram of heights reminiscent of the waveforms of other radar (e.g., CryoSat-2) and analog lidar (e.g., ICESat-1) satellite altimeters. However, we have adopted a different philosophy in processing the ICESat-2 data over the ocean. Rather than retracking a wave form from a footprint, we treat every photon height as an individual point measurement of surface height averaging less than a meter apart, but with a x-y location uncertainty on the order of 10 m. By a histogram trimming method, we determine which of these heights over an adaptively chosen ocean segment length (typically 7-km) are from true surface reflected photons versus noise photons. The resultant received height histogram is deconvolved with an instrument impulse response (IIR) histogram representing the height uncertainty largely associated with the lidar transmit pulse width. This produces an ocean surface height histogram that, with its first four moments, is the primary ICESat-2 ocean product. In addition, the along-track distance heights of the histogram comprising the received histogram are preserved and form a cloud that clearly resolves ocean surface waves. We analyze the spatial series of surface photons heights to characterize surface waves and calculate the correlation of photon return rate and surface height that constitutes the EM sea state bias in the mean sea surface height (SSH). This presentation will demonstrate some of the capabilities of ICESat-2 over the ocean and discuss our initial efforts at calibration and validation.

## **Corresponding author:**

**James Morison (Polar Science Center APL/Univ. of Wash., United States)**, morison@apl.washington.edu

# Single-receiver ambiguity resolution for Sentinel-3 Precise Orbit Determination at the Copernicus POD Service

**Emilio Calero (GMV AD, Spain);** Heike Peter (PosiTim UG, Germany); Jaime Fernández (GMV AD, Spain);  
Pierre Féménias (ESA/ESRIN, Italy)

**Session:** Precision Orbit Determination

**Presentation type:** Poster

**Poster number:** POD\_001

## **Abstract:**

Single-receiver GPS ambiguity resolution methods are beneficial for the precise orbit determination results of the Copernicus Sentinel satellites. The availability of so-called bias products for the GPS satellite is, however, mandatory to do the ambiguity-fixing with a single receiver. The GPS wide-lane bias product from CNES/CLS is widely used but also other products recently became available, e.g., the CODE bias product.

The continuous availability and reliable latency of such bias products is essential for operational orbit determination as it is done at the Copernicus POD Service for the Sentinel-1, -2, and -3 satellites.

The impact of the ambiguity-fixed carrier phases on the resulting Sentinel-3 orbit products is analysed. Different bias products are also compared based on Sentinel-3 orbit results. Due to the different latencies of the orbital products it is carefully investigated for which product lines dedicated bias products might be available in time.

This study will give an overview of the work done at the Copernicus POD Service to follow up recent developments in the frame of single-receiver ambiguity resolution for POD of the Copernicus Sentinel-3 satellites.

## **Corresponding author:**

**Emilio Calero (GMV AD, Spain),** [ecalero@gmv.com](mailto:ecalero@gmv.com)

# Status of precise orbit determination of altimetry satellites at DGFI-TUM

**Sergei Rudenko (Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM), Germany); Mathis Bloßfeld (DGFI-TUM, Germany); Julian Zeithöfler (DGFI-TUM, Germany)**

**Session:** Precision Orbit Determination

**Presentation type:** Poster

**Poster number:** POD\_002

## **Abstract:**

The status of precise orbit determination of current altimetry satellites, such as Jason-2, Jason-3, Cryosat-2 and SARAL, and the past altimetry satellite Jason-1 at DGFI-TUM using SLR and DORIS measurements and the “DGFI Orbit and Geodetic parameter estimation Software” will be presented. The impact of various factors, such as reference frame realizations, Earth’s time-variable gravity field models, as well as satellite attitude modeling on the orbit quality will be discussed.

## **Corresponding author:**

**Sergei Rudenko (Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM), Germany), [sergei.rudenko@tum.de](mailto:sergei.rudenko@tum.de)**

# Performance of the Sentinel-3 A and B GPS Receivers and associated GPS-Based Orbit Solutions

**Aurore Sibois (Jet Propulsion Laboratory, California Institute of Technology, United States);** Shailen D. Desai (Jet Propulsion Laboratory, California Institute of Technology, United States); Bruce J. Haines (Jet Propulsion Laboratory, California Institute of Technology, United States)

**Session:** Precision Orbit Determination

**Presentation type:** Poster

**Poster number:** POD\_003

## **Abstract:**

We present the latest results from our evaluation of the Global Positioning System (GPS) tracking data from the Sentinel-3 mission satellites, Sentinel-3A (S3A) and Sentinel-3B (S3B). For each spacecraft, we report tracking data statistics (e.g. typical GPS track duration, number of GPS satellites tracked) and discuss the in-flight calibration of the GPS antenna. The in-flight tracking performance of the S3A and S3B receivers is assessed through various internal (e.g. post-fit residuals, radial orbit precision as measured by overlaps of neighboring daily solutions) and external (e.g. sea surface height crossover variance and withheld satellite laser ranging residuals) metrics computed from our precise GPS-based orbit solutions. We also compare the performance of the GPS receivers on-board S3A and S3B with those of the higher-altitude Jason-2 (JA2) and Jason-3 (JA3) altimetry missions. S3A and S3B carry receivers manufactured by RUAG while JA2 and JA3 carry BlackJack and IGOR+ (BlackJack heritage) GPS receivers, respectively.

## **Corresponding author:**

**Aurore Sibois (Jet Propulsion Laboratory, California Institute of Technology, United States),**  
aurore.e.sibois@jpl.nasa.gov

# Analysis of surface wind speed from Jason-3 and Sentinel-3A in the Peru-Chile EBUS

Orlando Astudillo (CEAZA, France); Boris Dewitte (LEGOS, France); Abderrahim Bentamy (LOPS, France); Frédéric Frappart (LEGOS, France)

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Poster

**Poster number:** IPC\_001

## **Abstract:**

The near-shore surface mesoscale atmospheric circulation in the upwelling systems off Peru and Chile is influential on the Sea Surface Temperature through Ekman transport and pumping. There has been a debate whether or not the so-called “wind drop-off”, that is a shoreward decrease of the surface wind speed near the coast, can act as an effective forcing of upwelling through Ekman pumping. Although the wind drop-off has been simulated by high-resolution atmospheric models, it has not been well documented due to uncertainties in the scatterometry-derived wind estimates associated with land contamination. A previous study used along-track altimetry-derived surface wind speed data from ENVISAT, Jason-1, Jason-2, and SARAL satellites, to document the spatial variability of the mean wind drop-off near the coast as estimated from the inversion of the radar backscattering coefficient. In this study, we analyzed the performances of the recently launched Jason-3 and Sentinel-3A altimetry missions to analyze the surface wind speed in the Peru-Chile Equatorial boundary upwelling system.

## **Corresponding author:**

Orlando Astudillo (CEAZA, France), [orlando.astudillo@gmail.com](mailto:orlando.astudillo@gmail.com)



# Sea state bias for retracked TOPEX altimeter data

Hui Feng (University of New Hampshire, United States); Doug Vandemark (University of New Hampshire, USA); Ngan Tran (CLS/Space Oceanography Division, France); Desai Shailen (JPL, USA)

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Poster

**Poster number:** IPC\_002

## **Abstract:**

For radar altimeter missions, precise retrievals of geophysical parameters are often estimated by a so-called “retracking” scheme that fits an analytical model to the measured waveforms. Recently new TOPEX retracked datasets provided by JPL are available for evaluation, including a set of retracked products by (Maximum Likelihood Estimator) MLE3 that estimates three parameters (range, wave height, and return power) and MLE4 that estimates four parameters (the slope of the waveform trailing edge that is related to off nadir angle in addition to the three) (Thibaut et al., 2010).

New empirical sea state bias (SSB) models corrected for the range bias associated with ocean surface waves will be produced based on the new TOPEX retracked datasets. These sea state bias (SSB) models were developed in terms of the latest geophysical data record corrections (e.g. orbits, tides, wet/dry path delays, and so on) with the retracking revised range, wave height and wind speed data by several intensive retracking schemes, i.e. MLE3, MLE4 and etc.

The SSB model creation methods involve using a multi-year ensemble of yearly SSB correction models produced using direct sea level anomaly data coincident with altimeter wind speed and wave height (2D SSB), or wind speed, wave height and wave period (3D SSB). In the 3D case the wave period data are from global wave model hindcast data of an NCEP wind forced WAVEWATCH III model run in IFREMER. New SSB models based on retracked datasets will be derived for both TOPEX Side B and Side A and for both Ku and C band, and will be assessed against current TOPEX GDR SSB models in terms of a set of metrics, such as the tandem Jason/TOPEX orbit datasets, ascending vs. descending passes, 3DSSB vs. 2DSSB, and direct based SSB models vs. collinear difference based SSB, and others.

## **Corresponding author:**

Hui Feng (University of New Hampshire, United States), hui.feng@unh.edu

# Understanding the level of error within sea state bias models

**Alexa Putnam (University of Colorado, Colorado Center for Astrodynamics Research, United States);**  
Shailen Desai (Jet Propulsion Laboratory, USA); Robert Steven Nerem (University of Colorado, Colorado Center  
for Astrodynamics Research, USA)

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Poster

**Poster number:** IPC\_003

## **Abstract:**

The sea state bias remains the largest error for estimating sea level using satellite radar altimetry. Empirical approaches using in-flight observations of sea surface height are typically used to determine models for the sea state bias. These observations contain signals such as dynamic ocean topography, orbit errors, as well as ionosphere, troposphere, tide and mean sea surface modeling errors, which all contribute to errors in the sea state bias estimates. In this presentation we investigate the relative contribution of these error sources to provide an error assessment of the empirical sea state bias models.

In an effort to evaluate errors in the sea state bias estimates, we have executed a series of validation methods that test various estimation approaches. These methods examine the correlation between components within sea level anomaly measurements and the model variables, year-to-year model variation, the dependency on the span of data used for estimation, as well as the impact that model differences have on the estimated global mean sea level. The presented results will summarize the estimation and validation methods, and results from the error analysis.

## **Corresponding author:**

**Alexa Putnam (University of Colorado, Colorado Center for Astrodynamics Research, United States),**  
alex.putnam@colorado.edu

# A new side-lobe correction for Sentinel-3A Microwave Radiometer: definition and assessment

**Mathilde Siméon (CLS, France); Marie-laure Frery (Cls, France); Franck Borde (ESA, Netherlands); Christophe Goldstein (CNES, France)**

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Poster

**Poster number:** IPC\_004

## **Abstract:**

The Sentinel-3A Surface Topography Mission has been launched on February 2016 and is now in its third year of operation. Its objectives are to serve primarily the marine operational users but also allow the monitoring of sea ice and land ice, as well as inland water surfaces.

A two-channels microwave radiometer (23.8 and 36.5 GHz) similar to the Envisat and ERS MWR sensors is combined to the altimeter in order to correct the altimeter range for the excess path delay (WTC for wet tropospheric correction) resulting from the presence of water vapor in the troposphere.

Brightness temperatures for each band are computed from the MWR raw measurements using an instrument model to consider calibration, losses and thermal behaviour. Finally, any contamination of the antenna measurement outside the main beam, such as sky or on-earth sidelobes is removed. Sidelobes aiming on Earth represent the main contributor. But it is complex to estimate as it depends on the observed scene. It is of great importance to estimate the most precise side-lobe correction, as it can contaminate the brightness temperatures of a few Kelvins near coastlines.

The current Sentinel-3 sidelobe correction is inherited from Envisat and uses both its antenna power pattern and measured temperatures. Even though Sentinel-3 and Envisat MWR are close (same frequencies, similar observation geometry), the footprints are significantly different, and the antenna power pattern is very specific to each instrument. It is obvious that using Envisat side-lobe correction leads to an overestimation of the sidelobe correction in coastal areas, therefore it is not suited to Sentinel3.

We will present here the thorough analysis of Sentinel-3A antenna pattern that has been conducted to estimate the importance of sidelobes and its asymmetry. By performing simulations of the side-lobe contribution to the antenna measurement from a given high-resolution scene, we pinpointed several methodological sources of errors that can impact the sidelobe-correction of a few Kelvins. Following these results, we will introduce the improvements brought to the Envisat sidelobe correction method to generate side-lobe correction maps for Sentinel-3A.

Then we will talk about the assessment of the MWR performances over ocean as well as coastal areas using the new side-lobe correction. The assessment will be performed on brightness temperatures by statistical analysis. The impact on the wet tropospheric correction quality is assessed using global metrics (differences of SSH variance at cross-overs) and comparison to in-situ measurements (GPS and radiosondes).

## **Corresponding author:**

**Mathilde Siméon (CLS, France)**, [msimeon@groupcls.com](mailto:msimeon@groupcls.com)

# From ERA-Interim to ERA5: impact of the latest ECMWF reanalysis in the computation of radar altimeter Wet Path Delays

**Telmo Vieira (Universidade do Porto, Faculdade de Ciências; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR), Portugal); M. Joana Fernandes (Universidade do Porto, Faculdade de Ciências; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR), Portugal); Clara Lázaro (Universidade do Porto, Faculdade de Ciências; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR), Portugal); Nelson Pires (Universidade do Porto, Faculdade de Ciências; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR), Portugal)**

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Poster

**Poster number:** IPC\_005

## **Abstract:**

The accurate determination of sea surface heights (SSH) using satellite altimetry requires Wet Path Delays (WPD) estimations with the same accuracy. The most accurate way to measure the effect of the wet troposphere in the altimetric signals is from on-board Microwave Radiometers (MWR) measurements. However, the WPD retrievals from MWR become invalid and cannot be used over coastal and inland waters and, in addition, some satellites do not possess an on-board MWR (e.g. CryoSat-2). An alternative WPD source can be atmospheric parameters provided by Numerical Weather Models (NWM), e.g. those from the European Centre for Medium-Range Weather Forecasts (ECMWF).

ERA-Interim, the fourth reanalysis from ECMWF, has been used in the context of tropospheric corrections for satellite altimetry. It provides parameters at 6-hours intervals and  $0.75^{\circ} \times 0.75^{\circ}$  spatial sampling. This reanalysis has recently been replaced by the latest ERA5 reanalysis, which has a much higher spatial ( $0.25^{\circ} \times 0.25^{\circ}$ ) and temporal (1-hour) resolutions and an improved troposphere modelling, with particular interest for the WPD computation. ERA5 is the first ECMWF reanalysis available at 1-hour intervals and provides many improvements, in comparison with its predecessor ERA-Interim. The relevance of model reanalyses is well recognised, for example in climate applications or over periods for which the ECMWF operational model was less accurate (before 2004).

Motivated by these improved resolutions, the focus of this study is the global assessment of the impact of using ERA5 in the computation of WPD. Firstly, this assessment is performed in order to quantify the impact of using different resolutions of ERA5, mainly the temporal resolution and, secondly, to evaluate the global improvement of ERA5 over ERA Interim. Aiming to identify the best compromise between spatial/temporal resolutions, accuracy and computational time, WPD estimated from ERA5 using various combinations of these resolutions were inter-compared. Additionally, the same WPD computed from ERA5, as well as computed from ERA-Interim are compared with independent retrievals from MWR.

Independent comparisons with WPD derived from MWR (on board EnviSat and Jason-2) show that the effect of using ERA5 at 1-h instead of 6-h intervals is small, significant only for latitudes  $30^{\circ}$ - $60^{\circ}$ S and  $30^{\circ}$ - $60^{\circ}$ N. Results indicate that hourly intervals do not have significant impact on the WPD from ERA5, being a temporal resolution of 3-h high enough to ensure the same level of accuracy. Concerning the spatial resolution, this study shows that the effective useful spatial resolution of ERA5 is a bit worse than its native resolution, since ERA5 spatial samplings better than  $1^{\circ} \times 1^{\circ}$  do not generate significant improved WPD estimations.

Results also show that the global RMS of the differences MWR-ERA5 is 1.2 cm, varying with latitude between 0.6 and 1.7 cm. Considering the differences between retrievals from MWR and WPD computed from ERA-Interim, the global RMS is 1.4 cm, varying with latitude between 0.8 and 1.9 cm. These results show a global improvement of 0.2 cm from ERA-Interim to ERA5, however for some latitude bands the improvement can reach 0.4 cm. These results illustrate the considerable impact of using the ERA5 in the computation of radar altimeter wet path delays.

As recognized for the previous atmospheric models, results obtained from the independent comparisons show that ERA5 cannot map the WPD small space and time scales, evidencing the limitations of the latest ECMWF reanalysis, being the measurements from MWR, whenever valid, the most accurate way to account for the effect of the wet troposphere in satellite altimetry. Results of this study provide relevant information to ensure that when NWM-derived WPD are used in satellite altimetry, the best compromise is achieved between accuracy and computational time.

**Corresponding author:**

**Telmo Vieira (Universidade do Porto, Faculdade de Ciências; Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR), Portugal), [telmo.vieira@fc.up.pt](mailto:telmo.vieira@fc.up.pt)**

# Small scales variability of the wet tropospheric correction

**Marie-Laure Frery (CLS, France);** Bruno Picard (Fluctus SAS, France); Francois Soulat (CLS, France); Nicolas Picot (CNES, France); Gérald Dibarboure (CNES, France); Nathalie Steunou (CNES, France)

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Poster

**Poster number:** IPC\_006

## **Abstract:**

The wet tropospheric correction (WTC) is a major source of uncertainty in altimetry budget error, due to its large spatial and temporal variability. For most of the current and future nadir altimetry missions, a nadir microwave radiometer (MWR) provides brightness temperature (TB) observations from which the WTC is retrieved.

For the future SWOT mission, two radiometers will be aboard, respectively pointing at the center of each swath. The WTC over the whole swath will be estimated by linear interpolation between the two retrieved WTC.

The spatial and temporal variability of the WTC has been characterized by Stum et al in 2011 by analysis of MWR and model estimations. In this study, scanning radiometers were used in order to estimate the correlation radius in the zonal and meridional directions. The study was performed globally over ocean.

In the study presented here, two methods will be used to estimate the small scales variability of the wet tropospheric correction (below 20-30 km). Over ocean, we will use Jason-1 Geodetic phase/Jason2 matchups, comparing the WTC estimated for each mission as the distance between the two missions is varying. The method was initially developed by G. Dibarboure to estimate the SSH spatial variability in Karin/Swot\_nadir comparisons.

Over land or coastal areas, using high density GPS networks, analyses of the differences between each couple of GPS stations providing Zenithal Tropospheric Correction will be analyzed with respect to the distance that separate them.

## **Corresponding author:**

**Marie-Laure Frery (CLS, France),** [mdenneulin@groupcls.com](mailto:mdenneulin@groupcls.com)

# Side-by-side evaluation of Ku- and Ka-band sea state bias variability using Jason-3 and AltiKa data

**Doug Vandemark (Univ. of New Hampshire, United States);** Hui Feng (Univ. of New Hampshire, United States); Ngan Tran (CLS, France); Bertrand Chapron (IFREMER, France)

**Session:** Instrument Processing: Propagation, Wind Speed and Sea State Bias

**Presentation type:** Poster

**Poster number:** IPC\_007

## **Abstract:**

This study involves computation and analysis of 2D and 3D sea state impacted altimeter range bias (SSB) models for the Ka-band (AltiKa) and Ku-band (Jason-3) radar. These models are derived using the so-called direct method based on altimeter sea level anomaly (SLA) data, sea state estimates, and their relation determined nonparametric spline smoothing estimator. Specific objectives are 1) to use the near-final quality AltiKa data to newly evaluate on-orbit Ka-band SSB signatures (magnitude and variability) in multiple dimensional space, 2) to compare on-orbit AltiKa SSB to past field-observed electromagnetic (EM) radar bias observations and theoretical EM bias predictions, 3) to document similarities and differences for the satellite-derived SSB features at Ka-band vs. Ku-band, and 4) and offer interpretation of the observed differences between on-orbit Ka-band and Ku- band SSB models in terms of long-wave tilt, long-wave short-wave hydrodynamic interactions, and wind stress impacts from this combination of observations and theory. Data indicate that the Ka-band SSB has a reduced wind speed dependence compared to Ku-band. To first-order, this accords with an overall attenuation of the underlying sea state nonlinearities due to the increase of short wind-wave impacts. Overall implications for future Ka-band missions such as SWOT will be discussed.

## **Corresponding author:**

**Doug Vandemark (Univ. of New Hampshire, United States),** [doug.vandemark@unh.edu](mailto:doug.vandemark@unh.edu)

# Outreaching hydrology from space & SWOT (updates)

Vinca Rosmorduc (CLS, France); Nicolas Picot (CNES, France)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_001

**Abstract:**

Hydrology from space is one of the rising remote sensing field of application, with huge issues - environmental, human, economic... - to take into account. Among the issues, there's also the question of explaining how to use those data (from current as well as future satellites) to people not so used to remote sensing, why, how they are made, etc. -- in one word, outreaching hydrology from space. Some portals exist, such as the THEIA portal for land applications through which a number of space data dedicated to land applications (including hydrology) are available (<https://www.theia-land.fr/en>).

SWOT will be a cornerstone of hydrology from space, and will also be a completely new concept. Some pieces of explanations exists through the CNES space technology training courses (animations available on demand with a license), but more can be done -- and will be, with a major focus on hydrology, but not forgetting the ocean, and the complementarity with currents techniques, including nadir altimetry.

**Corresponding author:**

Vinca Rosmorduc (CLS, France), [vrosorduc@cls.fr](mailto:vrosorduc@cls.fr)



# RUS: Research and User Support for Sentinel Products

**Simon Boitard (NOVELTIS, France); Mathilde Cancet (NOVELTIS, France); Eric Jeansou (NOVELTIS, France); Florian Poustomis (NOVELTIS, France); Eric Guzzonato (CS SI, France); Jordi Farres (ESA, Italy)**

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_002

## **Abstract:**

The Research and User Support (RUS) opened on September 2017 to promote the uptake of Copernicus data, and to support the scaling up of R&D activities with Copernicus and in particular Sentinel-1 and Sentinel-3 data.

RUS addresses the following main issues:

- 1- Knowledge issues: what can be done with Copernicus data?
- 2- Technical issues: how to prepare the data and set-up/integrate customised processing chains?,
- 3- Physical issues: Earth Observation (EO) data storage limitations and processing power needed to exploit the data.

The free solutions provided by RUS to tackle these different issues are:

- 1- Access to hands-on trainings and webinars on Sentinel data covering various subjects from ocean color to ship detection;
- 2- Personalized advice and assistance from Sentinel expert team if needed;
- 3- Access to a powerful computing environment based on scalable virtual machine (up to 40 cores, 256GB RAM and 50TB of storage capacity) with all the necessary tools (software, toolboxes, downloading tools...) for Sentinel data processing already preinstalled.

The RUS service, which is offered at no cost to the user, is available for a large community of users from academic and public institutions, research entities to Small and Medium Enterprises (SME).

Access priority to the RUS Service is given to persons working for entities located in countries represented in the European Commission (EC) and participating to Copernicus program.

This presentation will detail the solutions and the benefits RUS can offer to the EO community with a focus on Sentinel-3 altimetry, sea surface temperature and ocean color data.

The RUS Service is funded by the EC, managed by the European Space Agency, and operated by Communications & Systèmes – Systèmes d'Informations (CS SI) and its partners: Serco SPA, Noveltis, Along-Track, and CS Romania.

**Corresponding author:**

**Simon Boitard (NOVELTIS, France), [simon.boitard@noveltis.fr](mailto:simon.boitard@noveltis.fr)**

# Exploring ocean eddy characteristics through the DynEd atlas

**Yannice Faugere (CLS Space Oceanography Division, France);** Antoine Delepouille (CLS, France); Nicolas Granier (CLS, France); Alexandre Stegner (LMD, France); Briac Levu (LMD, France)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_003

## **Abstract:**

The DynEd (Dynamic Eddy) database of surface intensified eddies has been built for a 17 year period (2000-2017) in two specific areas: the Mediterranean Sea and the Arabian Sea. This database contain the physical and the dynamical characteristics of mesoscale eddies detected from the cross analysis of DUACS gridded altimetric products (formerly distributed in AVISO, now in CMEMS) and Argo profiles. Among other characteristics the typical size, the intensity and the trajectory of each detected eddy were calculated. An iterative method was used on the surface geostrophic velocities in order to compute the cyclogeostrophic velocity components. The addition of these ageostrophic terms leads to a significant velocity increase for some mesoscale anticyclones. Then, the estimations of the three-dimensional eddy structures were deduced from the co-localization of surfacing Argo temperature/salinity data into altimeter-detected eddy areas. We were then able to quantify the typical temperature, salinity and density anomalies associated to the recurrent mesoscale anticyclones which control the regional circulation of the Mediterranean Sea.

A Graphical User Interface was developed to easily explore the database and enable the collocation of eddies with both Space (SST and Ocean Color) and in situ observations. This work showed that the combination of DUACS products and the in-situ Argo data sets could provide a regional characterization of the three-dimensional structure of individual eddies, far beyond the classical composite eddy analysis. A presentation of the Dyned Atlas tool and database will be given here.

## **Corresponding author:**

**Yannice Faugere (CLS Space Oceanography Division, France),** [yfaugere@cls.fr](mailto:yfaugere@cls.fr)

# TUDaBo: a G-POD service for SAR and RDSAR Products

Luciana Fenoglio (University of Bonn, Germany); Christopher Buchhaupt (University of Bonn, Germany)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_004

## **Abstract:**

The TUDaBo processor has been first developed at TU Darmstadt as an offline processor prototype to generate RDSAR data and validate the SARvatore G-POD service in SAR mode. It has then been enhanced to produce RDSAR data in coastal zone and SAR L1B and L2 data co-located to RDSAR. Various processing options have been implemented. Currently the software is being tested at the University of Bonn.

To allow open access of the processor results the processor is run through the ESA's G-POD service. Currently only the RDSAR processor for open ocean CryoSat-2 data is available to registered users. SAR processing will be available after final testing as well. Further options for the extension of the processing to coastal zone and to Sentinel-3 data are foreseen.

This contribution gives a brief introduction of both the applied SAR-RDSAR algorithms and of their particular features. Further on examples and results are given to show their quality and performance in comparison to publicly available SAR and RDSAR data from other processors.

## **Corresponding author:**

Luciana Fenoglio (University of Bonn, Germany), fenoglio@geod.uni-bonn.de

# PO.DAAC's Redesigned Web Portal

Jessica Hausman (JPL, United States); Sandra Cosic (Raytheon, USA)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_005

## **Abstract:**

Demo

PO.DAAC's data holdings and number of missions it supports are growing. It can be difficult for a user to know what all is available. To make it easier for users to discover information and navigate the site, PO.DAAC's web portal has been redesigned. This demonstration will show, not only the new design and layout, but the new capabilities and information now available. Resources are easier to identify and know what services those resources provide. "Data in Action" articles provide information on how various datasets can be used. Search and discovery is improved, not only within the portal itself, but also external search engines. Mission pages will make it easier to know what data and resources are associated with it.

## **Corresponding author:**

**Jessica Hausman (JPL, United States)**, [jessica.k.hausman@jpl.nasa.gov](mailto:jessica.k.hausman@jpl.nasa.gov)

# PO.DAAC in the Cloud: Data Services and Access

**Jessica Hausman (JPL, United States); Michael Gangl (JPL, USA); Michelle Gierach (JPL, USA); Catalina Oaida (Raytheon, USA); Suresh Vannan (JPL, USA)**

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_006

## **Abstract:**

PO.DAAC is facing new challenges as upcoming satellite missions will produce very high volumes of data. SWOT will produce 20 TB of data a day, and bring a new user community to PO.DAAC, hydrologists. To provide data and services, within a time latency users are accustomed to, SWOT, and additional missions, will be served from the cloud. Many services that PO.DAAC provides will be transferred onto the cloud, so the functionalities that are needed will still be available, such as search and discover, subsetting and data download. Additional services will also be available, such as a data subscription notice, data transformations, GIS capabilities, OpenAPIs and Jupyter Notebooks. This way if users want to move to the cloud, so they can do their analysis next to the data, instead of downloading they can do their analysis, possibly quicker, than their current system performs. Users will still be able to download data, but use PO.DAAC services, to greatly reduce the data volume and time of download.

## **Corresponding author:**

**Jessica Hausman (JPL, United States), [jessica.k.hausman@jpl.nasa.gov](mailto:jessica.k.hausman@jpl.nasa.gov)**

# Some cool things we do with ERDDAP

John Wilkin (Rutgers University, United States)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_007

## **Abstract:**

The ocean science community trend toward data delivery via web services that follow the so-called FAIR data principles (findable, accessible, interoperable, reusable) has greatly assisted our development of real-time ocean forecast systems that assimilate diverse inputs of satellite and coastal in situ data. The further embrace of Climate-Forecast (CF) metadata conventions and the sub-setting facilities in THREDDS and ERDDAP make our software tools for data acquisition easily re-useable for new applications, requiring little more than the redefinition of the bounding box that encompasses the model domain. For some novel data streams such as sensors on lobster traps, fishing trawls and animal tags, the ability of ERDDAP to easily re-serve simple data formats such as Excel as a FAIR web service has further expanded the scope of data inputs.

To monitor the impact and quality of respective data sources on the system, we track the provenance of all observation platforms closely through all steps of the data assimilation. With ERDDAP search and subset capabilities, the quick browse slide sorter, and the versatile RESTful output interface, it is straightforward to construct simple dashboards for monitoring data availability, making model-data comparisons, and exporting data to other tools for more in-depth analysis.

The presentation will introduce the essentials of ERDDAP capabilities, and demonstrate how we deploy these to enable search, subset and export of inputs and outputs to the Rutgers University coastal ocean forecast system, and to browse the system performance in comparison to other models.

## **Corresponding author:**

John Wilkin (Rutgers University, United States), [jwilkin@rutgers.edu](mailto:jwilkin@rutgers.edu)

# Aviso+ products & services: what's new?

**Laurent Soudarin (CLS, France)**; Françoise Mertz (CLS, France); Vinca Rosmorduc (CLS, France); Catherine Schgounn (CLS, France); Caroline Mercier (Akka, France); Thierry Guinle (CNES, France); Florence Birol (LEGOS/CTOH, France)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_008

## **Abstract:**

Aviso (Archiving, Validation and Interpretation of Satellite Oceanographic data) is a service set up by CNES to process, archive and distribute data and products from altimetry satellite missions. Its portal AVISO+ ([www.aviso.altimetry.fr](http://www.aviso.altimetry.fr)) is the entry point for 10000 registered users to freely access more than 40 products from CNES and CTOH not only for ocean-oriented applications but also for hydrology, coastal, ice applications. In addition, the website proposes information (handbooks, use case, outreach material, . . . ) to discover the products and their use.

This presentation gives an overview of available products and services. We also present here all the recent novelties, and those to come.

## **Corresponding author:**

**Laurent Soudarin (CLS, France)**, [laurent.soudarin@cls.fr](mailto:laurent.soudarin@cls.fr)



# Feedback loops in product development for Sentinel-3 and Sentinel-6 altimeter missions

**Remko Scharroo (EUMETSAT, Germany);** Carolina Nogueira Loddó (EUMETSAT, Germany); Cristina Martín-Puig (EUMETSAT, Germany); Bruno Lucas (EUMETSAT, Germany); Estelle Obligis (EUMETSAT, Germany)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_009

## **Abstract:**

The Sentinel-3 mission is now operating for over 3 years. During this time the altimeter processing chain has been updated regularly as the result of fixing anomalies, enhancing performance, or reacting to user feedback. Lessons learned from this experience are used for the development of the Sentinel-6/Jason-CS ground segment and product evolution plans.

This poster gives an overview of the products available for both missions, their intended use, and the way user feedback drives evolutions of the processing chain and how the consistency of the radar altimeter data from those missions is guaranteed through annual reprocessing.

The Sentinel-6 mission will start with the launch of Jason-CS A in 2020, followed by Jason-CS B in 2025.

## **Corresponding author:**

**Remko Scharroo (EUMETSAT, Germany),** [remko.scharroo@eumetsat.int](mailto:remko.scharroo@eumetsat.int)

# Altimetry Applications Program Status

**Margaret Srinivasan (Jet Propulsion Laboratory, California Institute of Technology, United States); Gary Geller (Jet Propulsion Laboratory, California Institute of Technology, United States); Adeline Gicquel-Brodtke (Jet Propulsion Laboratory, California Institute of Technology, United States)**

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_010

## **Abstract:**

The 27 years of ocean altimetry measurements from the TOPEX/Poseidon and Jason mission series satellites has provided researchers and operational users an unprecedented time series of data. This continuous record is the result of an enduring partnership between NASA, CNES, and others organizations and it continues to support operational, commercial, and environmental applications. With the launch of Jason-CS/Sentinel-6 in 2020, and more planned missions into the next decade, this resource of valuable data will be used by researchers and operational users across the globe to monitor ocean circulation and to improve our understanding of the role of the ocean in climate and weather.

The Altimetry Applications Program, which focuses on the NASA-CNES missions, engages existing ocean altimetry data users but also provides information to potential users by highlighting the how the observations from these missions can be applied.

Altimetry data has proved valuable for many practical applications including;

- International ocean forecasting systems,
- Ship routing and sport sailing,
- Precision marine operations: cable-laying, oil production, shipping
- Naval operations,
- Fisheries management,
- Marine mammal habitat monitoring,
- Hurricane forecasting and tracking,
- Debris tracking
- Storm surge forecasting

These applications will be the focus of efforts to provide data and information products to existing and new users, and to highlight how valuable this time series of data is for societal benefit.

## **Corresponding author:**

**Margaret Srinivasan (Jet Propulsion Laboratory, California Institute of Technology, United States),**  
margaret.srinivasan@jpl.nasa.gov

# SAR and SARin Altimetry Processing on Demand for Cryosat-2 and Sentinel-3 at ESA G-POD

**Jérôme Benveniste (ESA/ESRIN, Italy);** Salvatore Dinardo (He Space/EUMETSAT, Germany); Giovanni Sabatino (Progressive Systems/ESRIN, ITALY); Marco Restano (SERCO c/o ESA/ESRIN, ITALY); Américo Ambrózio (DEIMOS/ESRIN, ITALY)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_011

## **Abstract:**

The scope of this presentation is to feature the G-POD SARvatore service to users for the exploitation of CryoSat-2 and Sentinel-3 data, which was designed and developed by the Altimetry Team in the R&D division at ESA-ESRIN. The G-POD service coined SARvatore (SAR Versatile Altimetric Toolkit for Ocean Research & Exploitation) is a web platform that allows any scientist to process on-line, on-demand and with user-selectable configuration CryoSat-2 SAR/SARin and Sentinel-3 SAR data, from L1A (FBR) data products up to SAR/SARin Level-2 geophysical data products.

The G-POD graphical interface allows users to select a geographical area of interest within the time-frame related to the Cryosat-2 SAR/SARin FBR and Sentinel-3 L1A data products availability in the service catalogue. The processor prototype is versatile, allowing users to customize and to adapt the processing according to their specific requirements by setting a list of configurable options. Pre-defined processing configurations (Official CryoSat-2, Official Sentinel-3, Open Ocean, Coastal Zone, Inland Water (20Hz & 80Hz), Ice and Sea-Ice) are available. After the task submission, users can follow, in real time, the status of the processing. The output data products are generated in standard NetCDF format, therefore being compatible with the multi-mission "Broadview Radar Altimetry Toolbox" (BRAT, <http://www.altimetry.info>) and typical tools.

Initially, the processing was designed and optimized uniquely for open ocean studies. It was based on the SAMOSA model developed for the Sentinel-3 Ground Segment. However, since June 2015, the SAMOSA+ retracker is available as a dedicated retracker for coastal zone, inland water and sea-ice/ice-sheet. A new retracker (SAMOSA++) has been recently developed and will be made available in the future. The scope is to maximize the exploitation of CryoSat-2 and Sentinel-3 data over all surfaces providing user with specific processing options not available in the default processing chains.

Recent improvements include: 1) A Join & Share Forum to allow users to post questions and report issues ([https://wiki.services.eoportal.org/tiki-custom\\_home.php](https://wiki.services.eoportal.org/tiki-custom_home.php)); 2) A data repository to better support the growing Altimetry Community avoiding the redundant reprocessing of already processed data (<https://wiki.services.eoportal.org/tiki-index.php?page=SARvatore+Data+Repository&highlight=repository>).

To respond to the request of hydrologists, and simulate data that a river gauge would provide, SARvatore will soon include a post-processing service to convert water level estimates in L2 data to virtual station water level values, which are typically required by hydrologists.

The service is open, free of charge (supported by the ESA SEOM Programme Element) for worldwide scientific applications and available at [https://gpod.eo.esa.int/services/CRYOSAT\\_SAR/](https://gpod.eo.esa.int/services/CRYOSAT_SAR/), [https://gpod.eo.esa.int/services/CRYOSAT\\_SARIN/](https://gpod.eo.esa.int/services/CRYOSAT_SARIN/), [https://gpod.eo.esa.int/services/SENTINEL3\\_SAR/](https://gpod.eo.esa.int/services/SENTINEL3_SAR/).

## **Corresponding author:**

**Jérôme Benveniste (ESA/ESRIN, Italy),** [jerome.benveniste@esa.int](mailto:jerome.benveniste@esa.int)

# The BRAT and GUT Couple: Broadview Radar Altimetry and GOCE User Toolboxes

Jérôme Benveniste (ESA/ESRIN, Italy); Américo Ambrózio (DEIMOS/ESRIN, ITALY); Marco Restano (SERCO c/o ESA/ESRIN, Italy)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_012

## **Abstract:**

The scope of this work is to showcase the BRAT (Broadview Radar Altimetry Toolbox) and GUT (GOCE User Toolbox) toolboxes.

The Broadview Radar Altimetry Toolbox (BRAT) is a collection of tools designed to facilitate the processing of radar altimetry data from all previous and current altimetry missions, including Sentinel-3A L1 and L2 products. A tutorial is included providing plenty of use cases on Geodesy & Geophysics, Oceanography, Coastal Zone, Atmosphere, Wind & Waves, Hydrology, Land, Ice and Climate, which can also be consulted in <http://www.altimetry.info/radar-altimetry-tutorial/>.

BRAT's last version (4.2.1) was released in June 2018. Based on the community feedback, the front-end has been further improved and simplified whereas the capability to use BRAT in conjunction with MATLAB/IDL or C/C++/Python/Fortran, allowing users to obtain desired data bypassing the data-formatting hassle, remains unchanged. Several kinds of computations can be done within BRAT involving the combination of data fields, that can be saved for future uses, either by using embedded formulas including those from oceanographic altimetry, or by implementing ad-hoc Python modules created by users to meet their needs. BRAT can also be used to quickly visualise data, or to translate data into other formats, e.g. from NetCDF to raster images.

The GOCE User Toolbox (GUT) is a compilation of tools for the use and the analysis of GOCE gravity field models. It facilitates using, viewing and post-processing GOCE L2 data and allows gravity field data, in conjunction and consistently with any other auxiliary data set, to be pre-processed by beginners in gravity field processing, for oceanographic and hydrologic as well as for solid earth applications at both regional and global scales. Hence, GUT facilitates the extensive use of data acquired during GRACE and GOCE missions.

In the current version (3.2), GUT has been outfitted with a graphical user interface allowing users to visually program data processing workflows. Further enhancements aiming at facilitating the use of gradients, the anisotropic diffusive filtering, and the computation of Bouguer and isostatic gravity anomalies have been introduced. Packaged with GUT is also GUT's Variance/Covariance Matrix (VCM) tool, which enables non-experts to compute and study, with relative ease, the formal errors of quantities – such as geoid height, gravity anomaly/disturbance, radial gravity gradient, vertical deflections – that may be derived from the GOCE gravity models.

BRAT and GUT toolboxes can be freely downloaded, along with ancillary material, at <https://earth.esa.int/brat> and <https://earth.esa.int/gut>.

## **Corresponding author:**

Jérôme Benveniste (ESA/ESRIN, Italy), [jerome.benveniste@esa.int](mailto:jerome.benveniste@esa.int)

# NOAA CoastWatch/OceanWatch Altimetry Products

Jessica Burns (GST/NOAA, United States); John Kuhn (NOAA, United States); Eric Leuliette (NOAA, United States)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_013

## **Abstract:**

The NOAA/NESDIS Laboratory for Satellite Altimetry provides near-real time (NRT) and delayed-time (DT) gridded Level-3 sea level anomaly (SLA) products publicly available for download through ftp and NOAA's CoastWatch/OceanWatch ([coastwatch.noaa.gov](http://coastwatch.noaa.gov)). These are global gridded multiple altimeter optimal interpolation grids with a spatial resolution of 0.25° longitude/latitude. The NRT dataset is available daily from February 2017 through the present and the DT dataset is available for the period 2013 - 2018. Currently, homogeneous Jason-2, Jason-3, AltiKa, CryoSat-2, Sentinel-3A, and Sentinel-3B data from the Radar Altimeter Database System (RADS) are used in the processing of the NRT dataset and this dataset is also part of NOAA's OceanWatch Monitor. Within the NRT and DT SLA data files, the NOAA/NESDIS Laboratory for Satellite Altimetry also provides NRT and DT zonal and meridional components of the geostrophic current. The daily geostrophic currents are also global ocean with a spatial resolution of 0.25° longitude/latitude. The NRT geostrophic currents are available from March 2019 through the present and the DT currents are available for years 2013-2018. Recently, we have been working on reprocessing more years of SLA grids and geostrophic currents. Additionally, with more years of geostrophic currents, we are considering an Eddy Kinetic Energy product.

CoastWatch/OceanWatch also provides homogeneous along-track significant wave height, wind speed and sea level anomaly from RADS. These altimetry datasets are available through a Granule Selector Tool and can be overlaid with NPP and NOAA-20 VIIRS, Sentinel-3 Ocean and Land Colour Instrument, and Sentinel-2 Multispectral Instrument data.

## **Corresponding author:**

Jessica Burns (GST/NOAA, United States), [jessica.burns@noaa.gov](mailto:jessica.burns@noaa.gov)

# Homogeneous along-track sea level anomalies (Level-2+) data set for all altimetry missions

**Sabine Philipps (CLS, France);** Marine Lievin (CLS, France); Isabelino Denis (CNES, France); Thierry Guinle (CNES, France); Carolina Nogueira Loddo (EUMETSAT, Germany)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_014

## **Abstract:**

Since the launch of TOPEX/Poseidon and ERS-1 in the early 90's more than 10 other Altimetry missions were launched and operated by different agencies. The level 2 data (destinated to expert users) are distributed using different file formats (binary, netcdf) and contain different geophysical standards used to compute the sea level anomaly. Some dataset evolve rapidly and are regularly reprocessed, whereas other datasets, especially from finished missions are seldom reprocessed or not at all (and therefore do not profit from new standards).

In the frame of the SALP (Service d'Altimétrie et de Localisation Précise) project supported by CNES (Centre National d'Etudes Spatiales) and of the Sentinel-3 Marine Altimetry L2P-L3 Service (operated under an EUMETSAT contract in the frame of the Copernicus Programme funded by the European Union) level 2P data are available to users for all the altimeter missions (TOPEX/Poseidon, Jason-1/2/3, ERS-1/2, Envisat, Saral/AltiKa, Sentinel-3A/B, GFO, Cryosat-2, HY-2A) in delayed time on AVISO+ (<https://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/along-track-sea-level-anomalies-l2p.html> ).

Hereafter the value-added sea level anomaly L2P products are presented. They are easy to use (netcdf format) homogenous along-track mono-mission products, providing as much as possible the same updated corrections and models for the altimeter missions, in order to facilitate inter-mission comparisons. The products contain the sea level anomaly as well as all the corrections used to compute it. The sea level anomaly is provided with a validity flag, enabling users to discard data with spurious measurements. Furthermore an inter-mission bias is applied in order to have consistent time series since TOPEX/Poseidon.

The sea level anomaly level 2P products can be for example used for mean sea level computation, but they are also the input data for level 3 products (Taburet et al. 2019, DUACS DT-2018: 25 years of reprocessed sea level altimeter products).

A reprocessing of the whole level-2P sea level anomaly dataset (all the missions) is foreseen for early 2020 taking into account the recommendation of new standards from the OSTST.

Level-2P data are also available to users in the following timeliness for Sentinel-3A and Sentinel-3B:

- Near-Real-Time sea level anomaly (L2P data are available on AVISO+ generally less than 4h after the sensing start time of the product)

- Short-Time-Critical sea level anomaly (L2P data are available on AVISO+ generally less than 2 days after sensing start time of the product)

- Near-Real-Time significant wave height

**Corresponding author:**

**Sabine Philipps (CLS, France)**, [sphilipps@groupcls.com](mailto:sphilipps@groupcls.com)

# CTOH altimetry products for ocean, ice and continental surfaces applications

**Sara Fleury (LEGOS, France);** Florence Birol (LEGOS, France); Fabien Blarel (LEGOS, France); Fabien Leger (LEGOS, France); Fernando Nino (LEGOS, France); Frederic Frappart (LEGOS, France); Denis Blumstein (CNES, France); Rosemary Morrow (LEGOS/CTOH, France)

**Session:** Outreach, Education and Altimetric Data Services

**Presentation type:** Poster

**Poster number:** ODS\_015

## **Abstract:**

The Center for Topography of the Oceans and Hydrosphere (CTOH) is a French Observation Service created in 1989 and dedicated to satellite altimetry studies. Its objectives are to 1) maintain and distribute homogeneous altimetric databases for ocean, hydrosphere and cryosphere applications, 2) help scientific users to develop new altimetry derived products and 3) contribute to the development and validation of new processing approaches of the altimetric data for emerging research domains (coastal ocean, oceanic sub-mesoscale phenomena, continental surface water, sea ice, polar caps). The CTOH maintains homogeneous altimetric GDR data bases for the following missions : Topex/Poseidon, GFO, ENVISAT, Jason-1, Jason-2, Jason-3, Saral/Altika, Cryosat2 and Sentinel-3. Except for GFO, all these products are provided in netcdf format. A new version of ERS-2 data, reprocessed by the CTOH, including both ICE-1 and ICE-2 retracers and all the usual corrections is also now available. Both 1Hz and 10/20/40Hz data are available globally (for oceans and continental surfaces). For some products, the CTOH database contains L1 products (waveforms). We also add about 20 recent altimetry corrections and auxiliary parameters in a homogeneous way to all GDRs. It includes tide models, DAC, MSS, geoids, and tropospheric corrections. New geophysical corrections are being developed for continental surfaces applications and distributed. In addition, the CTOH works on developing new altimetric products:

- Coastal products : X-TRACK along-track SLA time series and tidal harmonic constants, reprocessed with a software designed for coastal altimetry processing, cover now the global coastal ocean. A software dedicated to the inter-comparison between coastal altimetry data sets, model outputs and in-situ measurements is also under developments in order to help users with combined analysis including L3 altimetry products.

- Continental hydrology products : including the "Hydroweb" data base for monitoring river and lake levels. Hydroweb integrates the CASH project: Topex reprocessed data over terrestrial surface waters. Water level maps are also developed for 5 rivers: the Amazon, Orinoco, Gange-Brahmapoutre, Congo and Mekong.

- Sea-ice products : Monthly maps of the Arctic Sea Ice Thickness covering the period 2002-2019, from Envisat and CryoSat-2 measurements, is available. Snow depth monthly maps over sea ice are also available for the period 2013-2018 and is being extended up to 2019.

All these products are now progressively re-distributed via AVISO+, our new common platform with AVISO: <http://www.aviso.altimetry.fr/en/home.html>. More information can be found on the CTOH website <http://ctoh.legos.obs-mip.fr/>.

## **Corresponding author:**

**Sara Fleury (LEGOS, France),** [sara.fleury@legos.obs-mip.fr](mailto:sara.fleury@legos.obs-mip.fr)



# Multi-Scale Assimilation of Simulated SWOT Observations

**Joseph D'Addezio (Naval Research Laboratory, United States)**; Innocent Souopgui (University of New Orleans, USA); Clark Rowley (Naval Research Laboratory, USA); Scott Smith (Naval Research Laboratory, USA); Gregg Jacobs (Naval Research Laboratory, USA); Robert Helber (Naval Research Laboratory, USA); Max Yaremchuk (Naval Research Laboratory, USA)

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_001

## **Abstract:**

We demonstrate the successful assimilation of simulated Surface Water Ocean Topography (SWOT) observations into a high-resolution forecast model using a multi-step 3DVAR analysis procedure. The first analysis step seeks to correct the large-scale, while the second step seeks to correct for the smaller-scale features present in the SWOT observations. An Observing System Simulation Experiment (OSSE) is used to explicitly calculate errors produced by competing single- and multi-scale analysis procedures. The first analysis step is the standard exploitation of observations with a 5-day data analysis period, horizontal correlation scales, vertical structure, and background errors consistent with mesoscale corrections. Experimentation with the observation window length of the second analysis step shows that a shorter time window produces lower analysis errors. This is consistent with the larger mesoscale structures having a longer time period and submesoscale structures having short Eulerian times being advected by the mesoscale. Therefore, a 24-hour observation window with a first guess at appropriate time (FGAT) for the second step was selected and sequential analysis/forecast cycles were performed for an entire year. The multi-scale analysis produces less overall error than the single-scale analysis when analyzing both area-averaged errors and wavenumber spectral analysis. Therefore, the multi-scale assimilation is essential for most effectively utilizing the forthcoming SWOT observations, which resolve features across a much wider spectrum of horizontal scales than are observed by the current nadir altimeters.

## **Corresponding author:**

**Joseph D'Addezio (Naval Research Laboratory, United States)**, joseph.daddezio@nrlssc.navy.mil

# Wave Model Confidence Index: A metocean decision support tool.

**Chafih Skandrani (NOVELTIS, France); Eric Munesa (NOVELTIS, France); Léo Grignon (NOVELTIS, France)**

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_002

## **Abstract:**

WMCI is world first service designed and developed by NOVELTIS in the frame of the European NEPTUNE Innovation Support Program. WMCI provides a unique solution that addresses the following major need regularly expressed by maritime stakeholders:

« I need to know the accuracy of sea states forecasts in order to take a decision but do not have any easy/global solution ».

WMCI offers an online and integrated access to a very large reliable set of multi-source sea states information (buoys networks, satellite data...), along with easy to use comparison functionalities with the most relevant wave forecasting data (from Copernicus, NOAA...).

The information and functionalities provided by WMCI allows to prevent maritime risks and to save fuel and money for many maritime users. The service can be used to double check if there is a real need for operation cancellation/deviation and can avoid any operation cancellation/deviation due to false alerts, saving money, fuel, and tons of CO2 at the same time. WMCI solution faces the spread of near real-time observations concerning wave heights which is often one of the major parameters used by all the sea users. Users usually rely on models and forecasts, but by definition, models contain errors and users need to check the accuracy and the reliability of the models for making the right decisions.

As there are very few wave heights measurements (in situ data along the coasts only, missing of data in the ocean basins), and due to the heterogeneity (formats/sources) of wave heights and sea states measurement information, no solution gathering all open source available information in near real time (NRT) is available. All the data already exist but they are disseminated in many servers across different institutions, since these data come from models, satellites or buoys, each of them being managed by separated entities. WCMI tackles this challenge, providing access to all the available NRT information concerning wave heights and sea states as well as multi models forecasts.

The project involved two major representative end-users, CMA-CGM and COMPAGNIE MARITIME CHAMBON, who helped in the design and the validation of the WMCI service proposed by NOVELTIS.

## **Corresponding author:**

**Chafih Skandrani (NOVELTIS, France)**, [chafih.skandrani@noveltis.fr](mailto:chafih.skandrani@noveltis.fr)

# CMEMS Level-3 Near-Real-Time Significant Wave Height and Spectral Parameters derived from altimetry and SAR measurements

**Elodie Charles (CLS, France);** Romain Husson (CLS, France); Alexis Mouche (IFREMER, France); Nicolas Taburet (CLS, France); Guillaume Dodet (IFREMER, France)

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_003

## **Abstract:**

A near-real-time wave service started in July 2017 in the frame of the Copernicus Marine Environment Monitoring Service (CMEMS). Handled by the WAVE-TAC (Thematic Assembly Center), a partnership between CLS and IFREMER, it provides near-real-time wave products derived from altimetry and SAR measurements.

Based on the Level-2 products, significant wave heights (SWH) from altimetry Jason-3, Sentinel-3A and -3B, Saral/AltiKa and Cryosat-2 missions are processed and distributed on CMEMS catalogue approximately 3 hours after the measurements, for operational applications. The 1Hz along-track Level-3 product available for each mission is quality flagged, inter-calibrated between altimeter missions and with respect to in-situ measurements and noise-filtered. This product will soon be upgraded with a state-of-the-art denoising method described in Quilfen et al. 2018 and Quilfen and Chapron 2019. This method is based on Empirical Mode Decomposition and preserves the meso- and sub-mesoscale geophysical signal. The new Level-3 SWH product will include both filtered and unfiltered SWH and a new variable quantifying the uncertainty related to the level of noise. This product is validated against in-situ buoy measurements and between altimeters at cross-over points.

In addition to the altimeters SWH, Level-3 SAR wave products are produced using the Level-2 directional wave spectra processed using Sentinel-1A and -1B acquisitions in a specific Wave mode. From the integral parameters estimated for each wave partition (significant wave height, peak period and peak direction), wave observations whose SWH is larger than 30 cm and peak wavelength is larger than 200 m are gathered according to the swell field they belong to. This is based on back-propagation in space and time using great circle theory: wave measurements converge to their storm source. This association in swell fields enables filtering out wave observations inconsistent with respect to the overall swell distribution. The accuracy of the Level-3 propagated integral parameters is estimated statistically using numerical wave model WaveWatch3 and over a few swell fields of interest using also in-situ measurements.

This presentation will describe the processing, the characteristics and the validation of these different wave products, suitable for several applications such as near-real-time assimilation in numerical wave models.

## **Corresponding author:**

**Elodie Charles (CLS, France),** [echarles@groupcls.com](mailto:echarles@groupcls.com)

# Assimilation of high frequency altimeter wave data in regional wave model for the french coastal areas

**Alice Dalphinnet (Météo-France, France)**; Celia Louarn (Météo-France, France); Lotfi Aouf (Météo-France, France); Annabelle Ollivier (CLS, France); Salvatore Dinardo (He Space, Deutschland)

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_004

## **Abstract:**

1 Hz altimeter significant wave heights (Cryosat-2, Saral, Jason 3, Sentinel-3) are commonly used in the assimilation of operational wave model MFWAM at Météo-France for many years. This contributes to a significant improvement of the sea state forecast at the first time steps of the run. The regional configuration of the model MFWAM at 2,5 km for the French coasts did not benefit yet from the assimilation of altimeters. The goal of this work consists in implementing the assimilation of high frequency altimeters wave data in the operational regional wave model.

The 20Hz wave data are provided by Sentinel 3, through two datasets: SAMOSA+ reprocessing by GPOD SARvatore Service (Dinardo et al. 2017) and CNES S3PP products obtained with innovative LR-RMC processing (Boy et al, OSTST 2017, Tran et al OSTST 2019). First, the wave data have been filtered out from corrupted values and then smoothed to a resolution of roughly 1 km along track. Diagnostics on the product show a good quality of the signal.

Afterward the data have been assimilated in the model MFWAM dedicated to French coasts (2,5 km) during a several months period. The results are compared with the run with assimilation of the 1 Hz altimeter wave data. The validation of the results of both datasets is performed in comparison with coastal buoys and independent altimeters. We focused on some storm cases generating high sea state in the coastal area in the Mediterranean sea and in the channel. We also investigated the use of other altimeters wave data such Saral or CFOSAT missions. The processing in the ground segment of CFOSAT was designed to optimize the high frequency quality of significant wave height estimates.

The study explores the quality of high frequency wave height measurement and the interest of taking into account observations from 20 Hz altimeter data into regional wave model.

## **Corresponding author:**

**Alice Dalphinnet (Météo-France, France)**, [alice.dalphinnet@meteo.fr](mailto:alice.dalphinnet@meteo.fr)

# Maximizing the impact of altimetry measurements in data assimilation with a high resolution model

Zhijin Li (JPL, United States); Wang Jinbo (JPL, United States); Archer matthew (JPL, United States); Fu Lee-Lueng (JPL, United States)

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_005

## **Abstract:**

We examine the impact of assimilating multi-satellite altimetry data into a model that resolves submesoscale ocean circulation of order 10 km. To resolve submesoscales, the model must have a horizontal grid spacing of about 1 km. To maximize the impact of the satellite altimetry data on the model, we need to deal with a particular set of challenges: (1) map the model solution to altimetry measurements according to the footprint size; (2) retain the high resolution along track information and spread it across tracks; (3) deal with internal tide and gravity wave signals; and (4) incorporate multiscale dynamics. Using a multiscale three-dimensional variational data assimilation (MS-3DVAR) and forecasting system for the California Current System, we illustrate these challenges, address methodologies and formulations to deal with them, and characterize the impact that multi-satellite altimetry data has on the model representation of flows down into the submesoscale.

## **Corresponding author:**

**Zhijin Li (JPL, United States)**, zhijin.li@jpl.nasa.gov

# Impact of altimetry observations in the Mercator Ocean real time monitoring and forecasting systems

**Elisabeth Remy (Mercator Ocean International, France); Mathieu Hamon (Mercator Ocean International, France); Mounir Benkiran (Mercator Ocean International, France)**

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_006

## **Abstract:**

Ocean analysis and forecasts produced in real time by Mercator Ocean serve a wide range of applications, from marine safety to seasonal forecasts. The global 1/12° ocean forecasting system is operated in the framework of the Copernicus Marine Environment and Monitoring Service. The forecast accuracy is highly dependent on the availability and quality of in situ and satellite observations that are assimilated to constrain the ocean forecast. Along track altimetry data are key observations for those systems as they provide integrated information on the water column, with a regular and global coverage.

Dedicated experiments highlight the sensitivity of the global ocean analysis and forecasts to changes in the altimetry constellation and to the MDT used as a reference to assimilate SLA. Those impact experiments also give an insight on the data assimilation efficiency to ensure the best use of those observations.

The concept of wide swath altimetry is now emerging. Efforts are ongoing on adapting the system to ingest such data and estimate their ability to better constrain the ocean circulation than today with a nadir altimeter constellation. Next challenges, from the assimilation point of view, are now to take into account complex correlated errors within the swath, and control physical processes that are unconstrained today.

## **Corresponding author:**

**Elisabeth Remy (Mercator Ocean International, France), [eremy@mercator-ocean.fr](mailto:eremy@mercator-ocean.fr)**

# Improving DUACS Sea Level products with CFOSAT and HY2B

**Yannice Faugere (CLS Space Oceanography Division, France);** Isabelle Pujol (CLS, France); Guillaume Taburet (CLS, France); Annabelle Ollivier (CLS, France); Gerald Dibarboure (CNES, France); Nicolas Picot (CNES, France)

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_007

## **Abstract:**

The DUACS system produces, as part of the CNES/SALP project, and the Copernicus Marine Environment and Monitoring Service, high quality multi-mission altimetry Sea Level products for oceanographic applications, climate forecasting centers, geophysics and biology communities... These products consist in directly usable and easy to manipulate Level 3 (along-track cross-calibrated SLA), Level 4 products (multiple sensors merged as maps or time series) and derived value added products such as Eddy Atlas.

Since 1997, altimeter missions from all the Space Agencies have been successively integrated in the system as soon as the data have been made available and assessed. The NRT system currently ingests 4 to 6 missions: Jason-3, Sentinel3A & B Cryosat-2, Altika which has been deactivated in February 2019, hopefully temporarily, and Jason-2 which is only available on specific periods. Since October 2018, two new satellites can complement this constellation Hy2B and CFOSAT. Hy2B, carries a classic (Jason like) LRM altimeter on the same orbit as HY2A used several years in DUACS. The CFOSAT mission, though dedicated to the measurement of ocean waves directional spectra and surface wind velocities, is also capable to measure Sea Surface height. A specific study will be implemented to assess the quality of these new datasets, demonstrate the feasibility of ingesting them in the DUACS system and assess the impact in terms of products quality. The main outcomes of this study will be presented here.

## **Corresponding author:**

**Yannice Faugere (CLS Space Oceanography Division, France),** [yfaugere@cls.fr](mailto:yfaugere@cls.fr)

# NOAA's Jason Products

**David Donahue (NOAA/NESDIS, United States);** Deirdre Byrne (NOAA/NESDIS, United States); Richardson Donald (Columbus Technology, United States); Yongsheng Zhang (NOAA/NESDIS/NCEI, United States)

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_008

## **Abstract:**

NOAA's Jason Products

The interagency Jason-2 and Jason-3 Ocean Surface Topography Missions measure sea surface height, wind speed, and significant wave height to help track global sea level rise, ocean currents, and upper ocean heat content. Four partner agencies share mission responsibilities: the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL), the Centre National d'Etudes Spatiales (CNES), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). NOAA's roles include satellite command and control, operational data processing, operational data distribution, and archive of data and processing software. NOAA's Environmental Satellite Processing Center (ESPC) generates Jason-2 and Jason-3 Operational Geophysical Data Record (OGDR) products. ESPC distributes OGDRs in near real time (within 3-5 hours of observation) in NetCDF format via their Data Distribution Server, and in BUFR format via the World Meteorological Organization (WMO) gateway. All Jason-2 and Jason-3 mission data are archived by NOAA's National Centers for Environmental Information (NCEI) using its Comprehensive Large Array-data Stewardship System (CLASS). The OGDRs, CNES-derived interim Geophysical Data Records (IGDRs), and the final science-quality Geophysical Data Records (GDRs), all in NetCDF, are made available by traditional FTP as well as through modern interoperable data services (see <https://www.nodc.noaa.gov/SatelliteData/jason/> for more information). Jason-2 and Jason-3 geophysical data record products are used for ocean nowcasting and forecasting, assimilation into global and region models, hazard monitoring, and hurricane intensification forecasts. Additional product details and data access information are available at <http://www.ospo.noaa.gov/Products/ocean/ssheight.html>.

## **Corresponding author:**

**David Donahue (NOAA/NESDIS, United States),** [david.r.donahue@noaa.gov](mailto:david.r.donahue@noaa.gov)



# Jason-2 and Jason-3 Near-Real Time Products Latency over the Past Year

**Donald Richardson (Columbus Technology, United States);** David Donahue (NOAA/NESDIS, United States)

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_009

**Abstract:**

The latency of Jason-2 and Jason-3 near-real time Operational Geophysical Data Records (OGDR) over the past year is examined using timeliness statistics against the requirement that product distribution be less than 3 hours from data collection. Major gaps in the ODGR production will be addressed, as well as periods of large latencies.

Latency calculations have been automated using the ProPro-005 algorithm as outlined in "ALGORITHMS ABOUT JASON-3 TM DATA AVAILABILITY AND OGDR DATA LATENCY, TP4-J0- NT-86- CNES", 30-Mar-2011 by C. Juan (CNES) and J. Lillibridge (NOAA).

**Corresponding author:**

**Donald Richardson (Columbus Technology, United States),** donald.richardson@noaa.gov

# Satellite altimeter observations of extreme winds and waves, and special editing required for Jason-2 Geodetic Mission data

**Walter Smith (NOAA Lab for Satellite Altimetry, United States);** Frances Achorn (NOAA Ocean Prediction Center, USA); Alejandro Egido (NOAA Laboratory for Satellite Altimetry, USA); Eric Leuliette (NOAA Laboratory for Satellite Altimetry, USA); Graham Quartly (Plymouth Marine Laboratory, UK); Joseph Sienkiewicz (NOAA Ocean Prediction Center, USA)

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_010

## **Abstract:**

The U. S. National Oceanic and Atmospheric Administration (NOAA)'s Ocean Prediction Center (OPC) provides hazardous marine weather warnings and forecasts for much of the north Atlantic and Pacific Oceans. Satellite altimeters are one of the few ways to measure the extreme significant wave height (SWH) and near-surface wind speed (WS) values that may occur in tropical and extra-tropical cyclonic storms. Data from CryoSat-2, Jason-2, Jason-3, SARAL, Sentinel-3A and Sentinel-3B are routinely displayed on the workstations of OPC forecasters. Data with less than 2 hours latency are used to verify the performance of forecast models and to make decisions about issuing warnings. For this purpose, forecasters want to see extreme values, if they are reliable, and therefore the standard editing procedures applied to altimetric sea surface height for assimilation into ocean models are not used in forecasting marine weather.

We find that altimeters seem to be measuring extreme SWH reliably in a variety of storms we have observed. However, during the 2018 North Atlantic hurricane season, Hurricanes Florence and Michael occasionally caused the Jason-2 altimeter to estimate truly spurious wave heights exceeding 20 m SWH. Inspection of the altimeter's radar waveforms and derived retracking parameters seems to show Jason-2 losing track of the radar echo soon after the extreme SWH values are estimated. In the case of Michael, the altimeter data were close enough to shore that we can compare them with ground-based radar measurements of rain intensity. It appears that the extreme SWH values occur as the altimeter flies through extreme rainfalls.

During its primary mission Jason-2 flew an exact-repeat orbit along a known ground track, and its radar measurement was controlled by the DIODE/DEM ("open loop tracking") system. Since July 2017 Jason-2 has been on a geodetic mission orbit, over which it does not use DIODE/DEM but strives to follow the sea surface automatically ("closed loop tracking"). We think that extreme rain intensity causes the Jason-2 altimeter to lose track of the sea surface, producing the spurious SWH values. We are developing a new editing scheme specific to the Jason-2 GM data that will allow large but likely correct SWH values to pass through to OPC forecasters, while editing SWH values that are likely due to the altimeter's loss of track.

The contents of this abstract and presentation are solely the findings and opinions of the authors and should not be construed as a statement of official policy or position of NOAA or the United States Government.

## **Corresponding author:**

**Walter Smith (NOAA Lab for Satellite Altimetry, United States),** [Walter.HF.Smith@noaa.gov](mailto:Walter.HF.Smith@noaa.gov)

# New Developments for NOAA's operational upper Ocean Heat Content product suite

**Deirdre Byrne (NOAA, United States)**; Eileen Maturi (NOAA, United States); Jessica Burns (NOAA, United States); Eric Leuliette (NOAA, United States)

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_011

## **Abstract:**

The NOAA National Environmental Satellite, Data, and Information Service operational satellite-derived Ocean Heat Content product (in production since September 11, 2012) is used to improve NOAA's predictions of tropical cyclone intensification. Ocean Heat Content, in this context, is the amount of energy stored in the ocean at sea temperatures of 26C and above. The existing operational algorithm is a geographically-based one that incorporates sea level anomaly, sea surface temperature, and ocean climatological information. We discuss the proposed development of an improved operational algorithm that is parameterized primarily in terms of steric height relative to a deep reference level. This parameterization depends on the generally strong correlation between steric height and the absolute dynamic topography. Due to its formulation, this new parameterization is expected to be able to capitalize on the increased resolution of the upcoming high-rate delay-Doppler missions and SWOT. The correlation between observed steric height and existing near-real time sea level anomaly (SLA) products is also examined. This includes the one currently used in the operational OHC product – from the US Navy's operational Altimeter Products System (ALPS) - and the new optimally interpolated gridded SLA from the Radar Altimeter Database System (RADS). Preliminary results are shown for a testbed region, the Gulf of Mexico.

## **Corresponding author:**

**Deirdre Byrne (NOAA, United States)**, [deirdre.byrne@noaa.gov](mailto:deirdre.byrne@noaa.gov)

# A REAL-TIME PRODUCT TO HELP OCEAN CLEANUP OPERATIONS

**Nikolai Maximenko (IPRC/SOEST, University of Hawaii, United States); Jan Hafner (IPRC/SOEST, University of Hawaii, United States)**

**Session:** Application development for Operations

**Presentation type:** Poster

**Poster number:** APOP\_012

## **Abstract:**

Growing awareness of plastic pollution in the ocean results in increasing numbers of projects and ideas of the open ocean cleanup. The efficiency of such operations is severely limited by the absence of an observing system capable of detecting individual items of their dense groups.

To help coordinate the search of debris, we simulate patterns of old, low-windage debris. In these numerical experiments, model tracer is advected by the SCUD (Surface CUrrents from Diagnostic) model, derived from a synthesis of drifter and satellite data. A standard drifter is drogued at 15 meters depth that corresponds well to the vertical extent of such debris as derelict fishing nets or depth of mixing of microplastics. The model starts from 1993 (when satellite altimetry became available) and is run under continuous uniform source from all shorelines. Calculations are looped until the solution reaches saturation. This way we eliminate sensitivity to (usually unknown) distribution of debris sources and focus on the tracer patterns that are determined by the ocean dynamics. Panel A exemplifies the model tracer pattern that was tested and approved in several collaborative debris search operations.

One lesson from that experience was that wind plays a critical role in the success of the operation: wind ways block the view and mix debris down, removing it from the surface and making observations difficult. Even if debris is detected, it's retrieval in the rough sea may be also difficult. To account for the effect of the wind we use 10-day NOAA WFS output (B) and introduce functions (C), describing wind effects on visibility and operations. These functions are then used to mask tracer simulations (A). The final product, presented on panel D, visualizes a compromise between areas of high debris concentration and regions of acceptable forecasted sea state.

The North Pacific product is public and is currently being tested in operations.

Figure Caption. Real-time model tracer concentration (A), 10-day mean speed from the NOAA WFS (B), function describing effects of the wind on visibility of debris and feasibility of operations (C), and combined product quantifying success of the search & retrieval operation (D). Units are m/s in B and conventional elsewhere.

## **Corresponding author:**

**Nikolai Maximenko (IPRC/SOEST, University of Hawaii, United States), maximenk@hawaii.edu**

# Regional in situ CalVal of Sentinel-3 altimeter range at non-dedicated sites

**Mathilde Cancet (NOVELTIS, France);** Pascal Bonnefond (OBSPM/SYRTE, France); Christopher Watson (University of Tasmania, Australia); Bruce Haines (NASA/JPL, USA); Florent Lyard (LEGOS/OMP/CNRS, France); Olivier Laurain (OCA/GEOAZUR, France); Pierre Féménias (ESA/ESRIN, Italy)

**Session:** Regional and Global CALVAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_001

## **Abstract:**

In situ calibration ensures regular and long-term control of the altimeter sea surface height (SSH) time series through comparisons with independent records. Usually, in situ calibration of altimeter SSH is undertaken at specific CalVal sites through the direct comparison of the altimeter data with in situ data.

However, Noveltis has developed a regional CalVal technique, which aims at increasing the number and the repeatability of the altimeter bias assessments by determining the altimeter bias both on overflying passes and on satellite passes located far away from the calibration site. In principle this extends the single site approach to a wider regional scale, thus reinforcing the link between the local and the global CalVal analyses. It also provides a means to maintain a calibration time series through periods of data-outage at a specific dedicated calibration site.

The regional method was initially developed at the Corsican calibration sites of Senetosa and Ajaccio. It was then successfully implemented at the Californian site of Harvest and at the Australian site of Bass Strait, in close collaboration with JPL and the University of Tasmania, respectively. The method was used to compute the altimeter biases of Jason-1, Jason-2, Envisat and SARAL/AltiKa at all these sites.

These studies gave the first Envisat and SARAL/AltiKa absolute bias estimates at non-dedicated sites using the same method, and showed high consistency with the analyses of the global CalVal teams and the work of the in situ CalVal teams. The method is now used to monitor the Sentinel-3A&B missions and shows high potential for the monitoring of any future altimetry missions.

## **Corresponding author:**

**Mathilde Cancet (NOVELTIS, France),** [mathilde.cancet@noveltis.fr](mailto:mathilde.cancet@noveltis.fr)

# CWPIES, a shallow water current, waves and pressure inverted echo sounder for higher resolution satellite altimetry calibration and validation.

**Benoit LEGRESY (CSIRO, Australia); Christopher WATSON (University of Tasmania, Australia); Sam CARENTZ (CSIRO, Australia)**

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_002

## **Abstract:**

In view of the developing higher spatial resolution altimetry missions, we have been developing new in situ calibration/validation tools. In order to tackle the challenge of higher resolution radar altimeters, their sensitivity to wave or to sea surface height heterogeneity within the footprint, we develop instrumentation to investigate the more local and higher frequency SSH signals. The Bass Strait cal/val area is situated in the South West of the strait and is now equipped for the historical Jason site, but also for Sentinel-3A and Sentinel-3B. The classic method that was used in there over the past decades included, besides a reference coastal tide gauge, permanent moorings recording bottom pressure, temperature and salinity through the column. The accurate altitude reference is achieved by regular short-term occupation of the mooring sites with GPS buoys. This ensures both attaching the SSH measurements to the same reference frame as the satellite and also to correct for the bottom pressure sensor temporal drift. With time, current meters were added to the kit in order to validate the regional ocean dynamics.

Recently we added kits with bottom mounted 5 beam Acoustic Profilers. These measure current profiles, but also complete wave spectra and Sea Surface Height in addition to the bottom pressure, temperature and salinity.

In the first part of this presentation we show the results from the first years of development and operation of the system. The system was deployed at a Sentinel-3B crossover and includes the bottom pressure, temperature and salinity sensors on top of the ADCP. We analyze the ADCP data and its high frequency signals thanks to the high (>1Hz) sampling frequency. We also compare the measurements to the Bottom pressure and seawater density variations. We find that the acoustic system can track the surface at high frequency with cm accuracy. The drift of the bottom pressure sensor can be monitored. Changes in atmospheric pressure are also recorded by the system thanks to the inverse barometric effect difference between bottom pressure and acoustic surface ranging. Regular GPS buoy occupation is still needed to put the measurement in the satellite reference frame. The measurements are more accurate and much higher temporal frequency opens more possibility of usage numbers are given on the first months of Sentinel-3B operation in its nominal orbit.

We investigate the impact of various satellites sampling phases, from the 1-day repeat of the future SWOT-CAL/VAL phase to the 27-day repeat of Sentinel-3. For the SWOT fast sampling phase, we plan to have 2 to 3 of these within the swath in addition to a string of GNSS buoys.

We then investigate the impact this kit can have on the SWOT fast sampling phase analysis in Bass Strait by adding waves and currents fields. We particularly investigate the impact using a regional high resolution (400m) operational ocean model to test sampling strategies.

## **Corresponding author:**

**Benoit LEGRESY (CSIRO, Australia)**, benoit.legresy@csiro.au

# In Situ Measurements for Satellite Altimeter Calibration and Validation using LiDAR Systems

**Adam Dodge (University of Colorado Boulder, United States);** Robert Leben (University of Colorado Boulder, United States); Michael Shannon (University of Colorado Boulder, United States); Bruce Haines (NASA Jet Propulsion Laboratory, United States)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_003

## **Abstract:**

We explore the accuracy of data collected from University of Colorado Boulder (UCB) LiDAR systems installed at the offshore Harvest Oil Platform and at a pier in Fisherman's Cove on Catalina island. We also show the LiDAR systems' capability for use in the calibration/validation (CAL/VAL) of the Jason-3 altimetry measurements alongside other tide gauge measurements.

The NOAA Bubbler installed on the Harvest Oil Platform has historically been used for CAL/VAL of altimetry satellites, and NOAA has recently installed a radar system at Harvest as well. The Harvest LiDAR system has been used alongside these NOAA systems for in situ validation of Jason-3 overhead passes. An attempt to characterize and minimize the errors in all three tide gauges has been performed, validating the historic correction for the bubbler and allowing for new corrections for both the LiDAR and radar systems. These corrections and their respective tide gauge data enable more accurate CAL/VAL of Jason-3 altimetry using multiple competing in situ sea level measurements at Harvest.

The Catalina LiDAR sensor was installed on Catalina island, across the San Pedro channel from an acoustic tide gauge measurement system installed in the Los Angeles Harbor. The Catalina LiDAR measurements are compared and combined with the historic acoustic system measurements for validation of Jason-3 passes through the San Pedro channel. Issues with the Catalina LiDAR system have been identified, and in the upcoming months we look forward to improved measurement accuracy and further CAL/VAL of Jason-3 altimeter passes over the San Pedro channel.

## **Corresponding author:**

**Adam Dodge (University of Colorado Boulder, United States),** [Adam.Dodge@Colorado.edu](mailto:Adam.Dodge@Colorado.edu)

# Round robin assessment of radar altimeter LRM and SAR retracking algorithms for significant wave height.

**Florian Schlembach (Technische Universität München, Germany);** Marcello Passaro (Deutsches Geodätisches Forschungsinstitut, Technische Universität München, Germany); Graham Quartly (Plymouth Marine Laboratory (PML), UK); Francesco Nencioli (Plymouth Marine Laboratory (PML), UK); Andrey Kurekin (Plymouth Marine Laboratory (PML), UK); Guillaume Dodet (Laboratoire d'Océanographie Physique et Spatiale (LOPS), CNRS, IRD, Ifremer, IUEM, Univ. Brest, France); Jean François Piollé (Laboratoire d'Océanographie Physique et Spatiale (LOPS), CNRS, IRD, Ifremer, IUEM, Univ. Brest, France); Paolo Cipolini (Telespazio VEGA UK for ESA Climate Office, ESA-ECSAT, UK); Christian Schwatke (Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM), Germany); Denise Dettmering (Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM), Germany); Florian Seitz (Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM), Germany); Craig Donlon (European Space Agency, ESA-ESTEC/EOP-SME, The Netherlands)

**Session:** Regional and Global CALVAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_004

## **Abstract:**

In June 2018, the Sea State Climate Change Initiative (SeaState\_cci) was launched by the European Space Agency (ESA). The main goal of the project is the estimation and exploitation of consistent climate-quality time-series of significant wave height (SWH) across different missions.

The responsibility of the altimetry Algorithm Development (AD) team of the SeaState\_cci project is to improve and develop novel algorithms for estimating the SWH parameters yielding increased signal-to-noise ratio (SNR) and better performance in the coastal zone. Furthermore, the new estimation techniques shall generate consistent results in terms of precision and accuracy during the past 25 years of satellite altimetry data. The process of fitting a satellite radar waveform to a modelled waveform, from which the SWH and wind speed can be extracted, is called retracking. Two novel retracking algorithms with the best retracking performance shall be selected for production, one for each of the two main operational modes of satellite altimetry, i.e. low resolution mode (LRM) and synthetic aperture radar mode (SARM).

In accordance to other ESA CCI projects, a round robin (RR) exercise for algorithm evaluation and selection is being conducted and was open to both internal and external teams. Five groups have participated in the call. The objective of this abstract is to illustrate the selection procedure and present an overview of the results of the different candidate algorithms.

The RR is focused on test datasets of the two missions Jason-3 (J3) and Sentinel-3A (S3A) covering two years of data and spanning different sea state conditions. The type of open-ocean and coastal scenarios were carefully selected, such that the overall performance of the retracker algorithms can be evaluated. In this regard, a series of criteria, which have been discussed and agreed within the consortium, have been defined. These include criteria for both internal statistics and for a comparison against in-situ (buoys) and model data. The former covers an extensive outlier and noise analysis. In the evaluation process, a differentiation is made between open-ocean and coastal scenarios and also for average and extreme sea states, in order to identify the general applicability of the individual retracking algorithms. The evaluation algorithms (written in Python or MATLAB) will be made publicly available to establish an objective evaluation process. A common code base for evaluating the performance of a retracking algorithm will be highly beneficial to the satellite altimetry community.



The improved estimation of sea state has a strong impact on the understanding and forecasting of climate and its variability, particularly in key areas of interest such as the coastal zone and in high-impact scenarios such as weather extremes. The RR exercise of the ESA SeaState\_cci project is an excellent opportunity to harmonise the algorithm evaluation process for finding the best performing retracking algorithms and can be reused in other projects that involve satellite altimetry.

**Corresponding author:**

**Florian Schlembach (Technische Universität München, Germany), [florian.schlembach@tum.de](mailto:florian.schlembach@tum.de)**

# Improving Conventional Altimetry SSH observability: Global assessment of SSH datasets derived from innovative LRM retrackers

**Matthias Raynal (CLS, France)**; H el ene Roinard (CLS, FRANCE); Emeline Cadier (CLS, FRANCE); Sylvie Labroue (CLS, FRANCE); Pierre Thibault (CLS, FRANCE); Fanny Piras (CLS, FRANCE); Nicolas Picot (CNES, FRANCE); Fran ois Boy (CNES, FRANCE)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_005

## **Abstract:**

Since many years, altimetry constellation is delivering relevant measurements to monitor the ocean large scale surface topography. More recently, with our understanding of the oceanic structures, these needs have evolved toward a better characterization of the oceanic mesoscale and sub mesoscales dynamic, over open and coastal areas. To answer this problematic, many progresses were made in the instrumental design domain. Thanks to the new generation of Delay Doppler altimeters (first time onboard on Cryosat-2 mission), the instrumental noise and spectral bump error were significantly reduced. On the other hand, to continue exploiting the recent and past LRM datasets, a lot of work has been dedicated to improve the retracking methods.

Today, for ocean application, three main algorithms, approaches could be distinguished:

- The ALES (Adaptive Leading Edge Subwaveform) retracker (Passaro et al. Year)
- The two-passes retracker (Sandwell et al., 2005)
- The adaptive retracker (Thibault et al., OSTST 2018)

These three retrackers represent state of the art of research on this topic and they all have different strength and weaknesses depending on the considered application. Thus, this paper aims at reviewing and comparing their Sea Surface Height retrieval performances with the same metrics. The assessment will be done with classical metrics at 1 Hz at global scales to assess the improvement compared to the existing MLE4 operational datasets. This will complement the assessment done by Smith et al (OSTST 2017) that focused on performances of several retrackers at small spatial scales. We highlight improvements and limitations considering different fields of applications: mesoscale observability, climate applications, coastal approaches, continuity performances over different surface (estuaries, ocean to sea ice transitions).

## **Corresponding author:**

**Matthias Raynal (CLS, France)**, mraynal@cls.fr

# Assessment of Sentinel-3A/B ocean data sets: Recent results of DGFI-TUM's multi-mission cross- calibration

**Denise Dettmering (Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM), Germany); Christian Schwatke (DGFI-TUM, Germany)**

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_006

## **Abstract:**

The innovative satellite altimeters on board of the Copernicus missions Sentinel-3A and Sentinel-3B are providing data since 2016 and 2018. In order to assess the performance of the derived sea surface heights and to check their consistency with other altimetry missions such as Jason-3, a multi-mission cross-calibration is useful. Such a calibration is able to provide information on the quality of all missions included in the analysis and to reveal instrument drifts or differences in the center-of-origin realization of the satellites' orbits.

Moreover, a multi-mission cross-calibration forms the basis to derive a long-term and consistent satellite altimetry data set and to determine, monitor, and investigate the water stage of the open oceans as well as of inland water bodies. In order to integrate contemporaneous and former altimetry missions to a consistent long-term multi-mission data set, their observations must continuously be updated, harmonized, and calibrated to eliminate systematic differences between the missions. DGFI-TUM performs a global cross-calibration of all missions on a regular basis.

This contribution will use the DGFI-TUM extended multi-mission crossover analysis approach in order to assess the performance of Sentinel-3 altimetry data over open ocean. The analysis yields time series of radial errors of Sentinel-3A and Sentinel-3B, which are used to derive inter-mission biases, to identify potential altimeter drifts, as well as to extract information on the quality of precise orbit determination (POD) and geophysical corrections (e.g., wet tropospheric errors).

## **Corresponding author:**

**Denise Dettmering (Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM), Germany), [denise.dettmering@tum.de](mailto:denise.dettmering@tum.de)**

# Results from Independent and Inter-Satellite Calibration and Validation of Jason-3 and Jason-2

**Matthieu Talpe (Jet Propulsion Laboratory, United States)**; Jean-Damien Desjonquères (Jet Propulsion Laboratory, USA); Shailen Desai (Jet Propulsion Laboratory, USA); Bruce Haines (Jet Propulsion Laboratory, USA)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_007

## **Abstract:**

The Jason-3 mission has been collecting sea level measurements along the reference 10-d repeat groundtrack, while the Jason-2 mission has been operating in its interleaved long-repeat orbit (iLRO) since July 2018, after a year spent in the long-repeat orbit (LRO). In this poster, we present a summary of calibration and validation results, which indicate that both missions continue to perform nominally.

Altimeter parameters (e.g., significant wave height,  $\sigma_0$ , relative sea surface height biases) from both missions correspond well to each other in spite of maneuvers and safe hold events. Furthermore, sea surface height anomaly (SSHA) crossovers and radiometer-derived parameters are stable. The standard deviations of 10-day windows of SSHA for Jason-2 are similar to Jason-3 over the iLRO time-span, but contrasts with the Jason-2 LRO time span when Jason-2 SSHA standard deviations were lower by ~4 mm.

## **Corresponding author:**

**Matthieu Talpe (Jet Propulsion Laboratory, United States)**, [matthieu.j.talpe@jpl.nasa.gov](mailto:matthieu.j.talpe@jpl.nasa.gov)

# Jason-2 mission performance

Hélène Roinard (CLS, France); Laure MICHAUD (CLS, FRANCE); François BIGNALET-CAZALET (CNES, FRANCE); Nicolas PICOT (CNES, FRANCE)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_008

## **Abstract:**

Jason-2 is the reference mission on TOPEX/Poseidon historical ground track for mean sea level applications from 2008 to 2016. It is also used to observe mesoscale ocean dynamics. Over the last 3 years many events occurred on Jason-2 mission. As for Jason-1 and TOPEX/Poseidon before it, Jason-2 was first moved to an interleaved but at the same altitude orbit in October 2016. Due to several gyro anomalies, system Safe Hold Modes (SHM) occurred and Jason-2 was moved to a Long Repeat Orbit (LRO) in July 2017. This orbit is approximately 27 km below the previous orbit still used by Jason-3. Thanks to this first year flying over Long Repeat Orbit, along-track data are available following an 8km resolution grid. During this period SHM occurred twice (in September 2017 and February 2018). Since its move in July 2018 to an interleaved LRO (i-LRO) SHMs have again occurred by four times (in oct-18, dec-18 and twice in feb-19). In addition to data from first year on LRO, this i-LRO will allow to provide data on a 4km resolution grid thanks to a complete second year of measurements, which is of great interest for geodesic community. It was so decided to enter a hibernation phase for about 3 months, and to develop and then apply a strategy to switch between operational and healthy gyros, in order to reduce the SHM events risk.

Since 22nd May 2019, Jason-2 has been re-operating, and has provided telemetry measurements. Data are analyzed and monitored in order to assess the quality of the products and how the system performance and data quality are affected (or not) by these events. The objective of this presentation consists in giving an overview of Jason-2 data coverage and data quality concerning altimeter and radiometer parameters, but also the performance of products at mono-mission crossovers and along-track.

## **Corresponding author:**

Hélène Roinard (CLS, France), [hroinard@groupcls.com](mailto:hroinard@groupcls.com)

# Jason-3 mission performance towards GDR-F

Hélène Roinard (CLS, France); Laure MICHAUD (CLS, FRANCE); Marine LIEVIN (CLS, FRANCE); François BIGNALET-CAZALET (CNES, FRANCE); Nicolas PICOT (CNES, FRANCE)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_009

## **Abstract:**

TOPEX/Poseidon, Jason-1, Jason-2, and then Jason-3 have allowed to build a high-precision ocean altimetry data record on historical ground track and will be followed in few years by Jason-CS/Sentinel-6.

A precise knowledge of Jason-3 data quality and errors is a key activity to ensure a reliable service to scientists involved in climate change studies as well as operational oceanography. As Jason-3 is the reference mission used in operational applications or for delayed time studies and especially for monitoring of the Global Mean Sea Level, the assessment of Jason-3 data quality is particularly important and we pay special attention to the long-term stability of Jason Global Mean Sea Level (GMSL). Long-term monitoring of the Jason altimetric system is routinely performed at CLS, as part of the CNES SALP (Système d'Altimétrie et Localisation Précise) project. The main objective of this activity is to provide an estimation of the mission performances for oceanic applications such as mesoscale or climate studies.

The monitoring of all altimeter and radiometer parameters is also routinely performed in order to detect jumps or drifts. After three years in orbit as a precise altimeter mission, two successive Jason-3 Safe Hold Modes occurred at the beginning of 2019. In this presentation we will give an overview of Jason-3 data coverage and data quality concerning altimeter and radiometer parameters, but also the performance of delayed and real time products (GDR, IGDR, OGDR/OSDR) at mono-mission crossovers and along-track.

Finally, in order to prepare Jason-CS/Sentinel-6 launch, reprocessing of Jason-3 GDR in standard F will begin in few months. We aim at presenting the overall performance of Jason-3 through different metrics highlighting the high-level accuracy of this mission and we will also focus on the way the future reprocessing would impact Jason-3 dataset.

## **Corresponding author:**

Hélène Roinard (CLS, France), hroinard@groupcls.com

# Assessment of the last TOPEX SideB reprocessing

Hélène Roinard (CLS, France); Laure MICHAUD (CLS, FRANCE); François BIGNALET-CAZALET (CNES, FRANCE); Nicolas PICOT (CNES, FRANCE)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_010

## Abstract:

The reference Mean Sea Level (MSL) record strongly relies on four missions: TOPEX/Poseidon and its successors Jason-1, Jason-2 and Jason-3 on the same historical orbit. The global trend uncertainty has been estimated close to 0.5 mm/yr (Ablain et al., 2015) over the whole altimetry period (1993-2013). However, this uncertainty rises (0.8 mm/yr) only considering the TOPEX period (1993-2002) (Ablain et al., 2013). In order to better understand TOPEX errors, JPL and CNES have been working together for several years in order to provide a reprocessed TOPEX altimeter dataset for users.

The TOPEX/Poseidon mission was the first precise altimeter mission specially designed for studying the circulation of the world's oceans. The TOPEX/Poseidon mission furnished altimetry data for 13 years (1992 – 2005). Equipped with a redundant main altimeter (TOPEX) and an experimental altimeter (Poseidon-1, which was operated roughly one cycle in ten), altimeter data were first furnished by the TOPEX-sideA instrument. Nevertheless changes in the sideA Point Target Response (PTR) degraded (from mid-1996 onwards) progressively the altimeter measurements [Hayne and Hancock, 1998]. The main impacts were an increase of Significant Wave Height (SWH), an increase of range rms, and an error on range estimate. Sea State Bias (SSB) was also impacted as it is based on SWH. In February 1999, TOPEX side-A was turned off and TOPEX side-B was turned on.

In order to correct for this PTR drift of TOPEX-A a retracking of the data is necessary. Several retracking releases have been computed over the last years, those analysis have been presented in previous OSTST sessions. For the last two years, CNES and NASA have worked on the reprocessing of the new TOPEX release of Geophysical Data Records. The latest retracking release include results from MLE4, MLE3 and gaussian methods. In addition, this new version of reprocessed dataset will include the best geophysical corrections available during this period (provided by CNES in 2018).

In this study, we propose to analyze the impact of this new TOPEX retracking over sideB at a first step. Therefore parameters from the retracking (range, SWH) or based on retracked parameters (SSB) are compared with previous data version. The reference parameters are non retracked data used in CMEMS2018 products (which are based on MGDR products concerning altimeter parameters) and updated geophysical and orbit standards. The new solutions are also compared with Jason-1 data. Furthermore mesoscale performances (SSH differences at crossovers) and global mean sea level are also computed and compared to CMEMS2018 standards.

## Corresponding author:

Hélène Roinard (CLS, France), hroinard@groupcls.com

# CryoSat-2 Long-term Ocean Data Analysis and validation

**Marc Naeije (TU Delft, Netherlands); Ernst Schrama (TU Delft, Netherlands); Jerome Bouffard (ESRIN-ESA, Italy)**

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_011

## **Abstract:**

The ESA's Earth Explorer CryoSat-2 mission is dedicated to precise measurement of the changes in the thickness of marine ice floating on the polar oceans and variations in the thickness of the vast ice sheets that overlie Greenland and Antarctica. With the effects of a fast-changing climate becoming apparent, particularly in the Polar Regions, it is increasingly important to understand exactly how Earth's ice fields are responding. Diminishing ice cover is frequently cited as an early casualty of global warming and since ice plays an important role regulating climate and sea level, the consequences of change are far-reaching. To understand fully how climate change is affecting these remote but sensitive regions, there remains an urgent need to determine exactly how the thickness of the ice, both on land and floating in the sea, is changing. By addressing this challenge, the data delivered by the CryoSat-2 mission completes the picture and leads to a better understanding of the ice role in the Earth system. In order to achieve this, the quality of the orbit, the measurements of the altimeter, and all required corrections have to meet the highest performance, and this not only over the ice caps and sea-ice surface but also over the oceans.

The objective of our research is the long-term analysis and validation of the CryoSat-2 ocean data. This entails assessing the long-term quality and stability of Level-2 GOP parameters when compared to concurrent in situ data from e.g. tide gauges, when compared to relevant numerical ocean models and when compared to other altimeter data sets through the use of RADS. It also entails assessing the impact of using alternative orbit solutions in terms of long-term quality, stability and consistency of Level-2 GOP geophysical parameters when compared to other reference altimeter data sets and Fiducial Reference measurements. We will present preliminary results of this research.

## **Corresponding author:**

**Marc Naeije (TU Delft, Netherlands), m.c.naeije@tudelft.nl**



# The Altimeter Sea Level Climate Data Record in the Copernicus Climate Service (C3S)

**Jean-Francois Legeais (CLS, France);** Guillaume Taburet (CLS, France); Pierre Prandi (CLS, France); Antoine Delepoulle (CLS, France); Yannice Faugere (CLS, France); Isabelle Pujol (CLS, France)

**Session:** Regional and Global CAL/VAL for Assembling a Climate Data Record

**Presentation type:** Poster

**Poster number:** CVL\_012

## **Abstract:**

Sea level is a key indicator of climate change and variability. Sea level integrates the ocean warming, mountain glaciers and ice sheets melting. Accurate monitoring of the sea level is required to better understand its variability and changes as well as the exchanges between ocean, land, cryosphere, and atmosphere. It is also fundamental for policymakers as it allows to better characterize the social and economic consequences of the sea level rise affecting coastal populations and all low-lying areas.

The satellite altimeter sea level has been measured by different successive missions since 1993. More than 70 cumulated years of measurements have now been reprocessed with the DUACS (Data Unification and Altimeter Combination System) production system.

In addition of the altimeter instrument, the sea level estimation strongly relies on other complex systems such as orbit solutions, reference fields and oceanic/atmospheric geophysical corrections. During the recent years, the ESA Sea Level Climate Change Initiative has been the opportunity to improve the homogeneity and stability of the altimeter sea level record.

Today, the altimeter sea level is used for two main kinds of applications: (i) The monitoring of the long-term evolution of the sea level for climate applications and the analysis of Ocean/Climate Index (such as the global and regional Mean Sea Level evolution). This requires a homogeneous and stable sea level record. Such dataset is produced within the Copernicus Climate Service (C3S). (ii) The retrieval of mesoscale signals in the context of ocean modeling and analysis of the ocean circulation at global or regional scale. This requires the most accurate sea level estimation at each time step with the best spatial sampling of the ocean. Such dataset is produced within the Copernicus Marine Service (CMEMS) (previously distributed by AVISO).

The main steps of the altimeter production system will be presented. Then, the characteristics and limits of the different products described above (C3S, CMEMS) will be presented in order to help the ocean and climate community on their optimal use for validation, assimilation activities as well as scientific studies.

## **Corresponding author:**

**Jean-Francois Legeais (CLS, France),** [jlegeais@groupcls.com](mailto:jlegeais@groupcls.com)

# A RIP-based SAR Retracker and its application in North East Atlantic with Sentinel-3

**Salvatore Dinardo (HeSPACE, Italy);** Luciana Fenoglio-Marc (University of Bonn, Germany); Matthias Becker (TU Darmstadt, Germany); Remko Scharroo (EUMETSAT, Germany); Maria Joana Fernandes (University of Porto, Portugal); Joanna Staneva (Helmholz Zentrum Geesthacht, Germany); Jérôme Benveniste (ESA, Italy)

**Session:** Coastal Altimetry

**Presentation type:** Poster

**Poster number:** COAST\_001

## **Abstract:**

Just as CryoSat-2, Sentinel-3 embarks on board a radar altimeter (SRAL) with the novel Synthetic Aperture Radar (SAR) mode that enables higher resolution and more accurate altimeter-derived parameters in the coastal zone, thanks to the reduced along-track footprint. Exploiting the SAR data in the recent years, many researchers have already proven that the performance of SAR altimetry with specific coastal retracker is superior to collocated Pseudo-Low Resolution Mode (PLRM) coastal altimetry algorithms but they also pointed out that residual errors due to land contamination are still present in the very proximity of the land (0-3 km).

The objective of this work is to further improve these results by exploiting extra information provided by SAR altimeters, namely the so-called Range Integrated Power (RIP), the new waveform built by a simple integration of the Doppler beams in the range direction. The RIP characterizes the backscattering state of the ground cell, where to all the Doppler beams are steered.

These developments led to a new retracker, here coined SAMOSA++, in which the RIP, as computed from the L1B-S data, is converted into a surface backscattering profile and directly integrated in the SAMOSA retracker as part of the model formulation itself. In this way, the modified SAMOSA model is automatically and autonomously able to cope with the different return waveform shapes from different surface types: either diffusive or specular. The mean square slope computed from the RIP is also estimated, representing a new output of the retracker.

The performance of the new retracker has been cross-compared against its previous version, SAMOSA+, and with the standard Sentinel-3 marine PDGS (Payload Data Ground Segment) SAR retracker (SAMOSA2) in the coastal zone and in open ocean in order to ensure a seamless transition between these zones.

The new retracker SAMOSA++ has been validated in the region of the North East Atlantic, where appropriate in situ validation data are available. The retrievals from the new retracker have been cross-compared against the network of tide gauges and buoys in the German Bight and versus the output of the GCOAST Helmholtz-Zentrum Geesthacht (HZG) regional circulation and wave model. In addition, sea level estimates derived with different geophysical correction models for ocean tide and wet path delay were compared. Results indicate that in this region the best geophysical correction models are the FES2014b tide model and the GPD+ wet tropospheric correction that incorporates data from the Sentinel-3 on-board radiometer.

Analyses show that both SAMOSA+ and SAMOSA++ ensure the continuity of the PDGS SAR Marine retracker in the open ocean, leading to clear improvements in the coastal zone, larger for SAMOSA++ than SAMOSA+. In summary, the new SAMOSA++retracker retrieves more accurate altimetric parameters in the coastal zone, with a better consistency with respect to regional ocean models and in situ data

## **Corresponding author:**

**Salvatore Dinardo (HeSPACE, Italy),** salvatore.dinardo@eumetsat.int

# The new generation of high-resolution X-TRACK/ALES regional altimetry product

**Fabien LEGER (LEGOS / CTOH, France)**; Florence Birol (LEGOS / CTOH, France); Fernando Niño (LEGOS / CTOH, France); Marcello Passaro (DGFI-TUM, Germany); Christian Schwatke (DGFI-TUM, Germany)

**Session:** Coastal Altimetry

**Presentation type:** Poster

**Poster number:** COAST\_002

## **Abstract:**

Sea level variation is one of the major threats for coastal zones; its observation is essential to better understand and predict the behavior of the coastal ocean. Altimetry provides unique long term and almost global observational dataset to characterize how sea level variability evolves from the open ocean to the coastal ocean.

More than 10 years ago, the CTOH and LEGOS started to develop the X-TRACK processing chain in order to recover as more as possible coastal sea level observations from the GDR altimetry products. Now, X-TRACK is a mature multi-mission along-track altimetry 1-Hz product and as well a along-track empirical tidal constants product, covering all the coastal ocean, produced by the CTOH/LEGOS and freely distributed by the operational AVISO+ service.

The new version of the processing chain we present, integrates progress made by the altimetry community in the last years, both in terms of the retracker and the geophysical corrections applied. The ALES retracker has proven its efficiency in retrieving more coastal sea level observations than other retrackers, particularly when using high-rate (i.e. 20 Hz) altimeter measurements instead of the standard (1 Hz) data. On the other hand, geophysical corrections wet tropospheric and tidal corrections in particular, have also improved in the coastal domain. In the context of the bridging phase of the ESA's climate change initiative sea-level project (SL\_cci) and acknowledging user needs, we develop a new X-TRACK L3 multi-mission product combining the better spatial resolution provided by high-rate data (20-Hz), the post-processing strategy of X-TRACK and the advantage of the ALES retracker. This product increases the number of useful near shore sea level data available and provides then new informations that opens new fields of applications.

## **Corresponding author:**

**Fabien LEGER (LEGOS / CTOH, France)**, [fabien.leger@legos.obs-mip.fr](mailto:fabien.leger@legos.obs-mip.fr)

# Spaceborne coastal altimetry for monitoring slope current intrusion events into the Gulf of Lion .

**Daniele Casella (ISAC-CNR, Italy);** Marco Meloni (Serco-ESA, Italy); Anne Petrenko (MIO - Institut Méditerranéen d, France); Andrea M. Doglioli (MIO - Institut Méditerranéen d, France); Jerome Bouffard (ESA-ESRIN, Italy)

**Session:** Coastal Altimetry

**Presentation type:** Poster

**Poster number:** COAST\_003

## **Abstract:**

The space-time variability of slope currents plays a key role on the across-shore transport of natural and anthropogenic elements. The Northern Mediterranean Current is the northern branch of the cyclonic circulation of the northwestern Mediterranean Sea. Under particular wind and stratification conditions the Northern Current can penetrate on the Gulf of Lion shelf, with strong impact for the local biogeochemistry and consequently the primary production. Monitoring the positions of these hydrodynamical features in a synoptic way is therefore of critical importance. Satellite-based altimetric observations data can be an essential resource for monitoring the long-term behaviour of slope currents. The use of altimetric-derived currents for monitoring intense but small in size current features especially near to the coast is still an issue..

Our approach for monitoring such current intrusions has been developed combining i) the output of a numerical simulation performed with the model SYPHONIE with a 3 km resolution spanning from 2001 to 2011, ii) coastal oriented optimized along-track altimetry dataset and iii) in-situ measurements acquired by a bottom-moored ADCP (RDI Ocean Sentinel, 300 kHz) positioned at the JULIO (JUDicious Location for Intrusion Observation) station on the eastern side of the Gulf of Lion.

## **Corresponding author:**

**Daniele Casella (ISAC-CNR, Italy),** [daniele.casella@artov.isac.cnr.it](mailto:daniele.casella@artov.isac.cnr.it)

# Sea level anomalies using altimetry, model and tide gauge along the African coasts in the Eastern Tropical Atlantic Ocean: inter-comparison and temporal variability

**Habib Boubacar Dieng (LEGOS: CNRS/CNES/IRD/UT3-PS, France);** Isabelle Dadou (LEGOS: CNRS/CNES/IRD/UT3-PS, France); Fabien Léger (LEGOS: CNRS/CNES/IRD/UT3-PS, France); Julien Jouanno (LEGOS: CNRS/CNES/IRD/UT3-PS, France); Yves Morel (LEGOS: CNRS/CNES/IRD/UT3-PS, France)

**Session:** Coastal Altimetry

**Presentation type:** Poster

**Poster number:** COAST\_004

## **Abstract:**

Because of sparse in situ measurements, the use of altimeter and ocean models are currently the only options to understand the coastal variability of sea level anomalies (SLA) near the African coasts of the Eastern Tropical Atlantic Ocean (ETAO: 35°S–25°N; 25°W–African coasts). In this study, SLA products derived from altimetry (X-TRACK and CMEMS) and from a regional ocean model (NEMO) are validated near the coast using the 14 tide gauges (TGs) available in the region. We used statistical criteria (correlation, standard deviation and root mean square) to inter-compare our three different products with the TG. We then analyzed the sub-seasonal to inter-annual variability of SLAs (i.e. from 20 days up to 2 years) over the period January 2008 – December 2014.

We found a very good agreement between altimetry, model and TGs near the coasts of Senegal (10°N – 25°N) and Gulf of Guinea (10°S – 10°N). This is not the case near the coast of Benguela region (south of 10°S) and is mainly explained by the combined effects of the position of TGs (located in semi-enclosed bays), the geophysical corrections used in the computations of the SLA derived from altimetry (i.e. tide, dynamical atmospheric correction -DAC- and sea state bias -SSB-) and the still low spatial resolution of the CMEMS and model data in connection with the greater oceanic and atmospheric variability in the Benguela upwelling system. We also show, with all products, that the time signal of SLA is mainly seasonal (annual and semi-annual) throughout the ETAO region. The altimetry data also show some inter-annual (15 to 24 months) variability in the equatorial band, which can be related to the equatorial Kelvin waves very present in this zone. This is less marked with the NEMO model and does not appear on the whole equatorial band.

We show that high spatial resolution and improved altimeter geophysical corrections near the coast can reduce near-shore data errors by up to 10% for each improvement. However, despite these improvements, agreements between SLA products are still weak in the Benguela region, suggesting that efforts need to be intensified on geophysical corrections and in increasing the temporal and spatial resolution of data near the coast. Moreover, the TGs network should be completed where measurement gaps remain along the West African coast, especially outside the bays for the Benguela region.

## **Corresponding author:**

**Habib Boubacar Dieng (LEGOS: CNRS/CNES/IRD/UT3-PS, France),** [habib.dieng@legos.obs-mip.fr](mailto:habib.dieng@legos.obs-mip.fr)

# Variability of Coastal circulation in the Gulf of Guinea using altimetry data

**Kouacou BOSSON (Felix Houphouet-Boigny University, Cote d'Ivoire/ LOCEAN/IPSL Université Pierre et Marie Curie, France, Côte d'Ivoire); Sabine ARNAULT (LOCEAN/IPSL Université Pierre et Marie Curie, France); Aman ANGORA (Felix Houphouet-Boigny University, Cote d'Ivoire, Côte d'Ivoire); Elisée TOUALY (Felix Houphouet-Boigny University, Cote d'Ivoire, Cote d'Ivoire)**

**Session:** Coastal Altimetry

**Presentation type:** Poster

**Poster number:** COAST\_005

## **Abstract:**

The Gulf of Guinea (GG) in the Tropical Atlantic Ocean is characterized by a strong seasonal variability of oceanic surface conditions. The open ocean surface circulation is predominantly zonal with the presence of the South Equatorial Current (SEC) flowing westward. Along the northern coast, an intense eastward coastal current is observed: the Guinea Current. Due to the paucity of in situ measurements, the time and space variability of this surface circulation in the GG remains poorly documented. The link between this variability and other oceanic phenomena (such as upwelling) has also not been clearly established, as well as its impact on the West African Monsoon. The aim of this study is to provide a synoptic view of the seasonal and interannual variability of this surface circulation in the GG and to highlight the different connections with other oceanic and atmospheric features if any. The approach is mainly based on altimetry data using either gridded multi-satellite products or coastal along-track products available over the period 1993-2015. In situ measurements such as Acoustic Doppler Current Profiler measurements obtained during oceanographic campaigns (Equalant 1999, Equalant 2000, EGEE2, PIRATA 2012 and PIRATA 2014), satellite Sea Surface Temperature (SST) information, and tide gauge data complete our data sets.

## **Corresponding author:**

**Kouacou BOSSON (Felix Houphouet-Boigny University, Cote d'Ivoire/ LOCEAN/IPSL Université Pierre et Marie Curie, France, Côte d'Ivoire), [bossonmarcel@yahoo.fr](mailto:bossonmarcel@yahoo.fr)**

# A new coastal tidal model for Australia

**Madeleine Cahill (CSIRO, Australia);** Mike Herzfeld (CSIRO, Australia); Mark Hemer (CSIRO, Australia); David Griffin (CSIRO, Australia); Benoit Legresy (CSIRO , Australia)

**Session:** Coastal Altimetry

**Presentation type:** Poster

**Poster number:** COAST\_006

## **Abstract:**

Being able to predict the tides – both height and velocity – is a high priority for all users of the marine estate, and an essential component of a coastal oceanographer's toolbox. It is also a key requirement for successfully exploiting altimetry, especially over the continental shelf where de-tiding errors are a first-order problem. This will be especially true for SWOT. With all these factors in mind, CSIRO has developed a new regional tidal model on an unstructured grid with 183810 cells down to 400m in places. Australia has a very diverse tidal regime, with amplitudes ranging from >1m in the NW to near zero in the SW. Tidal current amplitudes in excess of 1m/s occur in places. The model is nested within OTPS and to date has only been tested in barotropic mode. The development cycle included comparisons with observed harmonic constituents from 132 tide gauge sites and 69 current meter sites, with results ranging from excellent to unsatisfactory, for reasons we are still to discover.

## **Corresponding author:**

**Madeleine Cahill (CSIRO, Australia),** [madeleine.cahill@csiro.au](mailto:madeleine.cahill@csiro.au)

# Improvements in the Validation Techniques Applied to Tide Gauge and Altimetry Observations of Coastal Sea Level Rates

**Andrew Shaw (SKYMAT Ltd, United Kingdom);** Francisco Mir Calafat (National Oceanography Centre, United Kingdom); Chris Banks (National Oceanography Centre, United Kingdom); Nadim Dayoub (National Oceanography Centre, United Kingdom); Christine Gommenginger (National Oceanography Centre, United Kingdom); Jérôme Benveniste (ESA-ESRIN, Italy)

**Session:** Coastal Altimetry

**Presentation type:** Poster

**Poster number:** COAST\_007

## **Abstract:**

The validation of coastal altimetry sea level products against in situ tide gauge measurements is an essential part of verifying altimetric sea level observations and characterising their errors. The recent introduction of specialised retracers, such as the Adaptive Leading-Edge SubWaveform (ALES), has raised the possibility of retrieving good-quality altimetry data closer to the coast. One way to assess these new data is via altimetry-tide gauge comparisons, but this is complicated by the fact that altimetry measurements are rarely collocated with tide gauge stations, which gives rise to discrepancies between the two due to spatial separation. These discrepancies will be necessarily smaller in regions where sea level signals vary coherently over long length scales and so tide gauges located in such regions will provide a more reliable assessment of altimeter sea level data performance. Here, as part of a study conducted within the framework of the ESA Sea Level Climate Change Initiative (SL\_cci), we identify regions of long sea level trend length scales using data from both the high-resolution NEMO (1/12 degree) global ocean model and altimetry in order to improve the validation technique for assessing the performance of coastal altimetry sea level rates. To this aim, the tide gauges are sorted into groups according to their decorrelation values. The performance of the coastal altimetry observations is then assessed for each group of tide gauges separately. We report on the methodology and the outcome of these results in three selected regions in the North Sea, the Mediterranean Sea and coast of West Africa.

## **Corresponding author:**

**Andrew Shaw (SKYMAT Ltd, United Kingdom),** [agps@skymat.co.uk](mailto:agps@skymat.co.uk)



# On denoising satellite altimeter measurements for high-resolution geophysical signal analysis

Yves Quilfen (IFREMER, France); Bertrand Chapron (IFREMER, France)

**Session:** Quantifying Errors and Uncertainties in Altimetry data

**Presentation type:** Poster

**Poster number:** ERR\_001

## **Abstract:**

Satellite radar altimeter observations are key to advance studies in ocean dynamics, with a particular focus on mesoscale processes. To resolve scales less than about 100 km, altimeter measurements are often characterized by low signal-to-noise ratio (SNR), and low-pass filtering or least-square curve fitting is generally applied to smooth the data before analysis. An alternative method is presented. It is based on Empirical Mode Decomposition (EMD) developed to analyze non-stationary and non-linear processes, which adaptively projects a signal on a basis of empirical AM / FM functions, called Intrinsic Modulation Functions (IMFs). Applied to a Gaussian noise signal, EMD provides a set of IMFs with a predictable distribution of noise energy, to be exploited by wavelet-inspired threshold methods for an efficient data denoising approach. The EMD method ensures a local SNR analysis, does not require a priori assumptions about the underlying geophysical signal, e.g. its degree of smoothness or its compliance with a particular mathematical framework. The signal is simply assumed to be the sum of a piecewise-smooth deterministic part and a stochastic part. The proposed EMD-based denoising approach is thus well suited for mapping non-linear features, such as strong gradients, and extreme values without significant smoothing. Using Jason-2, Cryosat-2, and Saral/AltiKa significant wave height measurements, the proposed method provides efficient means to map overlooked geophysical sea state variability at scales much below 100 km, i.e. a range of scales largely impacted by low SNRs. Furthermore, it further provides a consistent approach for long-term noise analysis and monitoring over global and local conditions. The proposed methodology is a step forward to better exploit the unique set of altimeter observations which now covers more than 25 years.

## **Corresponding author:**

Yves Quilfen (IFREMER, France), [yquilfen@ifremer.fr](mailto:yquilfen@ifremer.fr)

# Daily harmonics of ionospheric Total Electron Content and implications for single-frequency altimeters

Richard Ray (NASA/GSFC, United States)

**Session:** Quantifying Errors and Uncertainties in Altimetry data

**Presentation type:** Poster

**Poster number:** ERR\_002

## **Abstract:**

An invaluable time series of the ionosphere's Total Electron Content (TEC) is available thanks to the Topex/Poseidon and Jason missions. Unlike sun-synchronous altimeters, these missions can be used to map daily harmonics of TEC, much like is done for ocean tides. Of special interest is TEC variability at  $n$  cycles/day, their seasonal variability, and their dependence on solar fluxes. A recent comprehensive paper by Lean et al. (2016) explored much of this material by using TEC data determined from the global network of GNSS stations. I discuss the kinds of high-wavenumber errors that occur in these GPS products, which nadir altimeters are particularly good at highlighting. The implications of relying on GNSS-based TEC data to correct for path delay -- now done routinely for single-frequency altimeters -- will be explored. Errors directly impacting determination of ocean tides are most obvious.

## **Corresponding author:**

Richard Ray (NASA/GSFC, United States), richard.ray@nasa.gov

# Using observations of SSH, SST and air-sea turbulent flux of heat to find the depth of the ocean that interact with the atmosphere

LuAnne Thompson (University of Washington, United States); Cristian Proitosescu (University of Washington, United States)

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Poster

**Poster number:** SC2\_001

## **Abstract:**

The canonical view of air-sea interaction in the mid-latitudes is that atmospherically driven turbulent fluxes of heat drive SST changes and that these SST (sea surface temperature) anomalies are then damped by the atmosphere. With a focus on the North Atlantic, we examine the lagged correlations between monthly and interannual SST from OISST with OAFLUX turbulent flux to assess where this paradigm holds. We cluster the structure of the lagged correlations using Kmeans clustering and find three regimes, one near the Gulf Stream, one in the subtropical gyre interior, and one in the subpolar gyre. Repeating the analysis using SSH, we find similar classification regions.

We use two different idealized one-dimensional models to understand the physical processes that control the lagged correlation structures found in the cluster analysis. The regime found within the Gulf Stream peaks near zero lag (with positive surface flux indicating cooling of the ocean) and shows locations where ocean heat transport anomalies control SST and air-sea interaction. In the subtropical interior, the lagged correlations are asymmetric about zero lag, with positive correlations when Q leads and negative correlations when SST leads; atmospheric forcing dominates following the canonical view of air-sea interaction. In the subpolar gyre, the atmosphere forces changes in SST with no significant correlation when Q leads, and a negative correlation when SST leads. In this case, the atmosphere forces SST anomalies, with little feedback to the atmosphere.

Using the lagged correlation structures, we define a feedback parameter that quantifies the strength of the surface flux anomaly for a given SST anomaly with units of Watts/m<sup>2</sup>/degree C. The results are consistent with studies using in situ based data sets, although within the western boundary current regions, the feedback is up to twice as big as in earlier analyses. We also perform the same feedback analysis using SSH (sea surface height) to define a feedback with units of Watts/m<sup>2</sup>/cm.

We find the ocean depth that interacts with the atmosphere by assuming that SSH anomalies result from thermal expansion over a depth H with thermal expansion coefficient given by the climatological SST. H is found by taking the ratio of the SST feedback to the SSH feedback divided by the thermal expansion coefficient. This results in an H that is larger than the mixed-layer depth in many regions, particularly in the North Atlantic Current, and in the return flows of the Northern and Southern Recirculation gyres. In these regions, heat must be converged from the side to feed the heat released to the atmosphere.

## **Corresponding author:**

LuAnne Thompson (University of Washington, United States), luanne@uw.edu

# Twenty-five years of Mercator ocean reanalysis GLORYS12 at Drake Passage: performance and volume transport.

**Camila Artana (UMPC LOCEAN, France);** Ramiro Ferrari (CIMA/CONICET-UBA and UMI IFAECI-3351, Buenos Aires, Argentina); Clément Bricaud (MERCATOR-OCEAN, Parc Technologique du Canal, Ramonville St. Agne, France); Jean-Michel Lellouche (MERCATOR-OCEAN, Parc Technologique du Canal, Ramonville St. Agne, France); Giles Garric (MERCATOR-OCEAN, Parc Technologique du Canal, Ramonville St. Agne, France); Nathalie Sennécahel (Laboratoire LOCEAN-IPSL, Sorbonne Université, (UPMC, Université Paris 6), CNRS, IRD, MNHN, Paris, France); Jae Hak Lee (KIOST, Korea Institute of Science and Technology, South Korea); Young-Hyang Park (Laboratoire LOCEAN-IPSL, Sorbonne Université, (UPMC, Université Paris 6), CNRS, IRD, MNHN, Paris, France); Christine Provost (Laboratoire LOCEAN-IPSL, Sorbonne Université, (UPMC, Université Paris 6), CNRS, IRD, MNHN, Paris, France)

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Poster

**Poster number:** SC2\_002

## **Abstract:**

The velocities in the Drake Passage from the 25-year GLORYS12 Mercator Ocean reanalysis were compared with satellite altimetry-derived surface velocities and independent in-situ velocity measurements from the DRAKE (2006-2009) and cDrake (2007-2011) experiments. GLORYS12 model velocities compared well with the current-meter data from the DRAKE (in the water column) and cDrake (at 50 m above seafloor) experiments in terms of means and standard deviations; most correlations between the model-derived and directly measured velocities time series were significant (above 99% confidence level). We then used the model to examine the Antarctic Circumpolar Current (ACC) volume transport across three sections in Drake Passage. The model provides a mean volume transport of  $155 \pm 3$  Sv over the 25 years of the reanalysis (1993-2017) with a mean standard deviation of 6.7 Sv. Annual mean values span over a range of 12 Sv. The DRAKE and cDrake experiments took place in low transport years, with their annual mean transports being smaller than the 25-yearlong average. GLORYS12 transport time series shows significant energy at the intraseasonal, semi-annual and annual periods with no significant low-frequency variation (beyond 2 years) or trend, in agreement with previous studies. This first assessment of GLORYS12 velocities in the Drake Passage is very encouraging and suggests that GLORYS12 can provide further insight into the complex circulation in the Drake Passage at synoptic to interannual time scales.

Figure caption:

Comparison of GLORYS12 to Drake current-meter data.

a) Time-mean velocity vectors and velocity standard deviation ellipses from the current meters, collocated GLORYS12 outputs and the differences in black, green and red respectively from January 2006 to April 2008

b) Same as a) from April 2008 to March 2009.

c) Location of the Drake current meter moorings and upward-looking ADCP (black and red dots). Black dotted line corresponds to Jason ground-track # 104.

d) Time-mean velocity vectors and velocity standard deviation ellipses obtained from the ADCP (M1 and M3), collocated GLORYS12 outputs and the differences from January 2006 to April 2008

e) Same for deployment from April 2008 to March 2009.

A clockwise (anticlockwise) rotation of the mean velocity vector with decreasing depth indicates mean downwelling (upwelling). The bottom topography is indicated in solid gray. Velocity scale is indicated in the upper right corner.

**Corresponding author:**

**Camila Artana (UMPC LOCEAN, France), [camila.artana@locean-ipsl.upmc.fr](mailto:camila.artana@locean-ipsl.upmc.fr)**

# Salinity advection and Rossby waves in northern Indian Ocean

**Xiaosu Xie (Jet Propulsion Laboratory, United States); W Timothy Liu (Jet Propulsion Laboratory, United States)**

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Poster

**Poster number:** SC2\_003

## **Abstract:**

The hydrodynamics of the northern Indian ocean is dominated by the annual reversal of salinity advection between the more saline Arabian Sea and the Bay of Bengal freshened by river discharge. The advection is supposedly driven by the seasonal change of monsoon, but there is slight phase difference between change of surface current and local wind. There are hypotheses that the current is remotely forced through Kelvin and Rossby Waves. The westward propagation of sea level anomalies and geostrophic current as manifestation of Rossby Waves in the north Indian Ocean has been well observed by the radar altimeters. We have also developed statistical models, with which we have mapped ocean surface carbon parameters using satellite observations. We found ocean surface salinity, partial pressure of carbon dioxide, and total alkalinity, exhibit westward propagation, with sea level, albeit at different speeds in different seasons. The underlying reasons of these differences in term of monsoon influence, local and remote, are being explored.

## **Corresponding author:**

**Xiaosu Xie (Jet Propulsion Laboratory, United States), [xiaosu.xie@jpl.nasa.gov](mailto:xiaosu.xie@jpl.nasa.gov)**

# Observations of the Antarctic Circumpolar Current over the Udintsev Fracture Zone, the narrowest choke point in the Southern Ocean

**Young-Hyang Park (Laboratoire LOCEAN-IPSL, Sorbonne Université (UPMC, Univ. Paris 6)-CNRS-IRD-MNHN, France); T. Park (Korea Polar Research Institute, Korea); T.-W Kim (Korea Polar Research Institute, Korea); S.-H. Lee (Korea Polar Research Institute, Korea); C.-S. Hong (Korea Institute of Ocean Science and Technology, Korea); J.-H. Lee (Korea Institute of Ocean Science and Technology, Korea); M.H. Rio (Collect Localisation Satellites, France); I. Pujol (Collect Localisation Satellites, France); M. Ballarotta (Collect Localisation Satellites, France); I. Durand (Laboratoire LOCEAN-IPSL, Sorbonne Université (UPMC, Univ. Paris 6)-CNRS-IRD-MNHN, France); C. Provost (Laboratoire LOCEAN-IPSL, Sorbonne Université (UPMC, Univ. Paris 6)-CNRS-IRD-MNHN, France)**

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Poster

**Poster number:** SC2\_004

## **Abstract:**

An up-to-date map of the Antarctic Circumpolar Current (ACC) fronts is constructed from the latest version of mean dynamic topography from satellite altimetry, and reveals the narrowest ACC width in the Udintsev Fracture Zone (UFZ), with the strongest concentration of the three major ACC fronts within a limited distance as short as 170 km, about 40% narrower than that at Drake Passage. At 144°W, at the entrance of the UFZ, which lies between the Pacific-Antarctic Ridge (PAR) and its eastwardly-offset segment (offset PAR segment), there is a triple confluence of the Subantarctic Front (SAF), Polar Front (PF), and Southern ACC Front. Downstream of this longitude, the SAF progressively meanders northward over the relatively shallow offset PAR segment before channeling through the Eltanin Fracture Zone, thus diverging from the PF which proceeds through the UFZ. In-situ observations from two recent cruises at 144°W confirm the satellite altimetry-derived frontal circulation in the UFZ region, and yield a baroclinic transport relative to the bottom of  $113 \times 10^6 \text{ m}^3 \text{ s}^{-1}$ , comparable to that through Drake Passage. The hydrographic sections show no Antarctic bottom water colder than 0.2°C. Characteristics of major water masses are described and the implications for their potential downstream modifications at Drake Passage are discussed in terms of the meridional overturning circulation across the ACC. Mesoscale eddy activity with periods shorter than 90 days is predominantly concentrated in the immediate downstream area of the offset PAR segment, suggesting a substantial poleward eddy heat flux there.

Figure caption: (a) Altimetry-derived five ACC fronts with topography. Big five choke points are indicated, from the west: UFZ = Udintsev Fracture Zone; DP = Drake Passage; SWIR = Southwest Indian Ridge; KP = Kerguelen Plateau; TAS = Tasmania. (b) Meridional distance (y-axis, degree in latitude) of each front from the PF as a function of longitude (x-axis).

## **Corresponding author:**

**Young-Hyang Park (Laboratoire LOCEAN-IPSL, Sorbonne Université (UPMC, Univ. Paris 6)-CNRS-IRD-MNHN, France), [young-hyang.park@mnhn.fr](mailto:young-hyang.park@mnhn.fr)**

# Forcings of the west African costal upwelling by ocean and atmosphere intraseasonal waves

alban lazar (LOCEAN-IPSL-UPMC, France); Badara Sane (LPAOSF-ESP, UCAD, Senegal); Malick Wade (UGB, Senegal)

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Poster

**Poster number:** SC2\_005

## **Abstract:**

Competition between local and remote forcing of the variability has been a long-standing issue, especially when one search for sources of predictability. In several eastern boundary upwelling systems, it has been shown that coastally trapped waves are a key forcing, with decreasing intensity for increasing distance to the equator.

In this study we tackle the remote versus local forcing of SSH at the intraseasonal scale in the Senegalese part of the Canary coastal upwelling, using satellite and model data, and a new costal ocean-atmosphere buoy dataset.

Despite errors at the coast of the Altimetry derived signal, we evidence the frequent and clear occurrence of costal wind anomalies synchronous with the arrival of costal oceanic waves. We present an investigation of the possible mechanisms to explain this phenomenon, and in particular the role of atmosphere African easterly waves and their successive interactions with the west African coasts and the equatorial oceanic band.

## **Corresponding author:**

alban lazar (LOCEAN-IPSL-UPMC, France), [alban.lazar@upmc.fr](mailto:alban.lazar@upmc.fr)



# A western tropical Atlantic dynamics analysis using statistics and satellite data

**Sabine Arnault (LOCEAN UMR CNRS/IRD/UPMC/MNHN, France);** François Kaly (Laboratoire de Traitement de l'Information (LTI), Senegal); Sylvie Thiria (LOCEAN UMR CNRS/IRD/UPMC/MNHN, France)

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Poster

**Poster number:** SC2\_006

## **Abstract:**

The western tropical Atlantic ocean is a very energetic and highly variable region. It is one of the main contributors to the inter-hemispheric mass and heat transports. The aim of this study is to give a new picture of the space and time variability of this region using statistical tools applied to satellite measurements such as radar altimeters (TOPEX/Poséidon/Jason series...), Soil Moisture and Ocean Salinity (SMOS) radiometer, the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) products and the European Center for Medium Range Weather Forecasts (ECMWF) wind stresses. The investigated variables are thus the Sea Surface Temperature (SST), the Sea Level Anomalies (SLA), the Sea Surface Salinity (SSS) and the wind stresses between 70°W-30°W, 0°N-15°N, from 2010 to 2016. The Self-Organizing Maps (SOM) approach, a clustering methodology based on non-linear artificial neural network, is combined with a Hierarchical Ascendant Classification to classify the different phenomena located in that area and to identify their characteristics. Three classes are identified and allowed us to focus on the dynamics of the North Brazil Current, and the North Equatorial CounterCurrent, respectively, and their links with the InterTropical Convergence Zone and the Amazon and Orinocco river runs off.

## **Corresponding author:**

**Sabine Arnault (LOCEAN UMR CNRS/IRD/UPMC/MNHN, France),** [sa@locean-ipsl.upmc.fr](mailto:sa@locean-ipsl.upmc.fr)

# Effect of regional water cycle on meridional sea level gradient along the Makassar Strait

**Tong Lee (JPL, United States)**; Severine Fouriner (JPL, USA); Arnold Gordon (Columbia University, USA); Janet Sprintall (University of California San Diego, USA); Jacqueline Boutin (Sorbonne University, France)

**Session:** Science II: Large Scale Ocean Circulation Variability and Change

**Presentation type:** Poster

**Poster number:** SC2\_007

## **Abstract:**

The Indonesian throughflow (ITF) is the only tropical connection of the global ocean circulation, influencing Indo-Pacific oceanic exchanges, climate, biogeochemistry, and Indian Ocean sea level. Meridional sea level gradient along the main channel of the ITF, the Makassar Strait in the Indonesian Seas, is indicative of the pressure gradient that drives the ITF. Effect of regional water cycle on the meridional sea level gradient along this strait is not well understood. Using ocean-atmosphere-land satellite measurements, we found that (1) seasonal variation of upper-layer salinity variation has a major contribution to meridional sea level gradient along the strait, and (2) the seasonal variation of upper-layer salinity is primarily caused by the regional water cycle associated with monsoon-induced precipitation and runoff. We further assess the relation of water cycle, upper-layer salinity, and sea level gradient on interannual time scales.

## **Corresponding author:**

**Tong Lee (JPL, United States)**, [tlee@jpl.nasa.gov](mailto:tlee@jpl.nasa.gov)

# Nonlocal effects of an unstable ocean current

**Tom Farrar (Woods Hole Oceanographic Institution, United States)**; Theodore Durland (Oregon State University, United States); Steven Jayne (Woods Hole Oceanographic Institution, United States); James Price (Woods Hole Oceanographic Institution, United States)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_001

## **Abstract:**

We analyze sea-surface height (SSH) anomalies from satellite altimetry to show that the instability of the Pacific equatorial current system trigger oceanic Rossby waves that affect the variability in distant regions. SSH variability throughout much of the North Pacific is coherent with the SSH signal of tropical instability waves (TIWs) near the equator that result from instabilities of the swift equatorial current system. This variability has regular phase patterns that are consistent with barotropic Rossby waves radiating energy away from the unstable equatorial currents, and the waves can be clearly seen to propagate from the equatorial region to at least 30°N. Comparisons with numerical simulations further support this interpretation. North of 40°N, more than 6000 km from the unstable equatorial currents, the SSH field remains coherent with the near-equatorial SSH variability, but it is not as clear whether the variability at the higher latitudes is a simple result of barotropic wave radiation from the tropical instability waves. There are even more distant regions, as far north as the Aleutian Islands off of Alaska, where the SSH variability is significantly coherent with the near-equatorial instabilities. In the period band associated with tropical instability waves, a surprisingly large amount of the geostrophic eddy kinetic energy at distant midlatitude locations can be ascribed to the remote effects of the unstable equatorial currents. The fact that instabilities of strong ocean currents can radiate waves that affect mesoscale variability at distant locations poses an important challenge for parameterization of mesoscale variability in climate models.

## **Corresponding author:**

**Tom Farrar (Woods Hole Oceanographic Institution, United States)**, [jfarrar@whoi.edu](mailto:jfarrar@whoi.edu)

# On the Agulhas Bank Circulation

**Ricardo Matano (CEOAS, Oregon State University, United States);** Vincent Combes (CEOAS, Oregon State University, USA); P. Ted Strub (CEOAS, Oregon State University, USA)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_002

**Abstract:**

This presentation focuses on the oceanic circulation over the Agulhas Bank, which is the continental shelf region located at the southern tip of the African continent. Model and observations are used to characterize the time mean circulation its seasonal evolution and its interannual variability. Model results are compared with in-situ and satellite observations. A suite of process-oriented experiments evaluates the relative contributions of local wind forcing, tides and the Agulhas Current on the shelf dynamics and on the shelf/deep-ocean exchanges.

**Corresponding author:**

**Ricardo Matano (CEOAS, Oregon State University, United States),** [rmatano@coas.oregonstate.edu](mailto:rmatano@coas.oregonstate.edu)

# Forced vs Intrinsic variability of the Agulhas Bank circulation

**vincent combes (Oregon State University, United States);** Ricardo Matano (Oregon State University, United States); Ted Strub (Oregon State University, United States)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_003

## **Abstract:**

The Agulhas Bank, a broad shelf at the southern tip of Africa, is bound by the Agulhas Current to the south and by the Benguela Current to the west. In the present study, we assess the driving mechanisms of the sea surface height and circulation variability over the Agulhas Bank using the altimetry and model experiments. Forced variability includes variability driven by local wind stress, tides and by remotely generated equatorial Kelvin waves propagating along the Atlantic coast. Intrinsic variability is principally found at the southern Agulhas Bank triggered by the passage of mesoscale eddies/pulses of the Agulhas current.

## **Corresponding author:**

**vincent combes (Oregon State University, United States),** [vcombes@coas.oregonstate.edu](mailto:vcombes@coas.oregonstate.edu)

# Understanding Regional Trends in Southern Ocean Eddy Kinetic Energy

**Don Chambers (University of South Florida, United States);** Yang Zhang (University of South Florida, United States); Xinfeng Liang (University of South Florida, United States)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_004

## **Abstract:**

According to the eddy-saturation theory, changing winds in the Southern Ocean will primarily increase turbulence and not overall transport. Many studies using high-resolution models have demonstrated this, but observational evidence is limited. One study recent by Hogg et al. (JGR, 2015) demonstrated a 20-year trend in eddy kinetic energy (EKE), computed from satellite altimetry data, but only after averaging over large spatial areas.

In this study, we examine this problem further. First, we demonstrate altimetry tracks (and crossovers) are sufficient to sample the full EKE variability of the Southern Ocean. This is done sampling a high-resolution state estimate that resolves mesoscale eddies to altimetry tracks and crossover points. We then examine the average EKE from 1993-2018 over smaller regions than used in Hogg et al. (JGR, 2015). We use regions approximately 30° in longitude between northern and southern boundaries that encompass the primary high EKE regions of the Southern Ocean and the principal fronts of the Antarctic Circumpolar Current (ACC).

Our results suggest the conclusions reached by Hogg et al. (JGR, 2015) of observational support for the eddy-saturation theory may be premature. Although there are significant positive trends in EKE in one region of the Southern Ocean, this is primarily downstream of the Kerguelen Plateau, which is known to be an area of high EKE. In other regions where there is no interaction of the ACC jets with bathymetry, EKE does not change significantly. This one region alone can explain the broad Indian Ocean and Pacific Ocean estimates that Hogg et al calculated, suggesting those estimates were biased by regional extremes, and not an overall increase in EKE over the entire Southern Ocean.

## **Corresponding author:**

**Don Chambers (University of South Florida, United States),** donc@usf.edu

# PRELIMINARY RESULTS OF FLOATECO: EXPERIMENTAL STUDY OF PHYSICAL AND BIOLOGICAL PROCESSES MAINTAINING THE FLOATING PELAGIC ECOSYSTEM

**Nikolai Maximenko (IPRC/SOEST, University of Hawaii, United States);** Luca Centurioni (Scripps Institution of Oceanography, United States); Andrey Shcherbina (Applied Physics Laboratory, University of Washington, United States); Gregory Ruiz (Smithsonian Environmental Research Center, United States); Linsey Haram (Smithsonian Environmental Research Center, United States); Mary Crowley (Ocean Voyages Institute, United States); James Carlton (Williams College, United States); Cathryn C Murray (Fisheries and Oceans Canada, Canada); Jan Halfner (IPRC/SOEST, University of Hawaii, United States)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_005

## **Abstract:**

Converging surface currents create in subtropical oceans areas of high-concentration of floating artificial debris ("garbage patches"). This debris can carry marine biota over long distances and provides a substrate for a new type of pelagic ecosystem, in which coastal species can survive and establish. To study the oceanic processes, responsible for the formation of such marine debris accumulation areas, the multi-institutional team of the interdisciplinary project FloatEco deployed in 2018 a set of Lagrangian tools, including nine drifting buoys with drogues attached between 2 and 20 meters and trackers attached to real debris objects. Preliminary analysis of the trajectories showed that after deployment drifters spread consistently with the vertical shear of Ekman currents, sampled by different drifters at different depths. However, after the initial dispersion, drifters remain in a relatively small area, filled with mesoscale and submesoscale eddies, and their highly fractal trajectories (see Figure) reflect strong horizontal eddy mixing without any significant difference between the drifters of different geometry.

Two pairs of drifters were trapped for several weeks in cyclonic submesoscale eddies and converged to a distance of only 100 meters. Characteristics of the drifters suggest that the vertical scale of the submesoscale circulations was comparable to the mixed layer depth. High vertical coherence of such eddies may be homogenizing the ocean momentum, stratified by the wind stress.

Remarkably, real debris tagged with satellite trackers demonstrated a similar behavior and was wandering in the same area as drifters. Type and size of debris object as well as change with time of the debris geometry, derived from their observed responses to the local wind and from interruptions in satellite transmissions, did not have strong effect on debris residence in the garbage patch.

Preliminary results of FloatEco suggest that mesoscale and submesoscale turbulence reduces effects of the wind-induced vertical shear on the horizontal mixing. Physical mechanisms of this reduction is under investigation.

Figure Caption. Trajectories of 9 drifters with varying drogue depths, deployed in the eastern North Pacific November 2, 2018. Streamlines in the background are real time currents diagnosed with the SCUD model. Units are cm/s.

**Corresponding author:**

**Nikolai Maximenko (IPRC/SOEST, University of Hawaii, United States), [maximenk@hawaii.edu](mailto:maximenk@hawaii.edu)**



# Particle dispersion in a multiple migrating quasi-zonal jet regime: A case study in the eastern North Pacific

Oleg Melnichenko (University of Hawaii, United States)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_006

## **Abstract:**

Low-frequency motions in the interiors of the subtropical gyres include distinct multiple, alternating quasi-zonal jet-like features (striations) which slowly, at a speed of about 0.3-0.5 km/day, propagate toward the equator. In their presence, the space-time distribution of mesoscale eddies is not completely random but organized into some sort of “storm tracks”, elongated along the jets and moving with them. Transient quasi-zonal jets and their associated “storm tracks” represent a marked mode of oceanic low-frequency variability and may play an important role in the ocean component of the Earth’ climate system.

The effect of the jets and eddy organization on the horizontal transport and mixing of tracers is investigated using Lagrangian particle trajectories. Numerical experiments with “virtual” particles are conducted in the eastern North Pacific and utilize altimetry-derived velocity fields. To separate the effects of the large-scale flow, quasi-zonal jets and eddies, three different experiments are conducted, using (1) total velocity fields (include large-scale and mesoscale), (2) high-pass filtered velocity fields to retain only mesoscale phenomena (include zonal jets and eddies) and (3) synthetic eddy velocity fields composed of contributions of perfectly isotropic Gaussian eddies, but distributed in space and time as the observed mesoscale eddies in the eddy dataset. The results demonstrate that, in all three cases, spreading rates in the zonal direction systematically exceed spreading rates in the meridional direction. The zonal anisotropy is mainly due to quasi-zonal jets. The secondary and generally weaker effect is due to eddy organization. This effect is not negligible, however. Despite the fact that the jets are weak relative to mesoscale eddies, their role in localizing eddy pathways can be important for mixing contributions. Quantitative analysis of the dispersion curves also reveals significant deviations from the diffusive regime even on scales longer than half a year. These deviations are particularly pronounced in the synthetic eddy-only case, where the dispersion curves show super-diffusive regime at longer time lags. This is qualitatively consistent with the eddy organization into persistent “storm tracks”, localized on the jets, which results in the long-time Lagrangian velocity correlations.

## **Corresponding author:**

**Oleg Melnichenko (University of Hawaii, United States)**, oleg@hawaii.edu

# High-wavenumber variability in the eastern tropical Pacific from ADCP, altimetry, and a high-resolution numerical model

**Saulo Soares (Scripps Institution of Oceanography UCSD, United States);** Teresa Chereskin (Scripps Institution of Oceanography UCSD, United States); Sarah Gille (Scripps Institution of Oceanography UCSD, United States)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_007

## **Abstract:**

Recent studies have shown that inertia-gravity waves (IGWs) contribute significantly to the oceanic variability at spatial scales smaller than 20-100 km, while geostrophic flows govern variability at larger scales. Results from a high-resolution model suggest that the length scale of the transition from IGWs to geostrophic flow varies regionally and seasonally. Shipboard Acoustic Doppler Current Profiler (ADCP) lines can be useful for evaluating this transition but have been geographically limited. A concentrated effort to recover previously unprocessed ADCP transits from the eastern Pacific has expanded the volume and geographic range of available data records. From these expanded ADCP records, we compute one-dimensional wavenumber spectra and decompose them into rotational and divergent components (roughly proportional to vortex and wave components). We compare results with high-resolution model output from the MITgcm and with high-resolution along-track nadir altimetry. Our analysis focuses primarily on the eastern tropical Pacific upper thermocline. Over similar latitudes in opposing hemispheres, the model predicts that the transition from predominantly rotational to divergent spectra occurs at longer length scales in the southeast tropical Pacific than in the northeast. The ADCP observations cannot confirm this pattern and differ from the model in a number of details. Generally, transition scales in the observations show depth dependency and are shorter nearer the surface. The transition scales, when averaged in the upper ocean and between different sonars, are longer in the southeast than in the northeast tropical Pacific. These scales, ranging from 40 to 200 km, and the inferred dynamics contrast to the ~70 km transition scales at midlatitudes that we studied previously in the southern California Current.

## **Corresponding author:**

**Saulo Soares (Scripps Institution of Oceanography UCSD, United States),** saulo@ucsd.edu

# Monitoring open sea and coastal ocean dynamics in the Baltic Sea and North East Atlantic

**Luciana Fenoglio (University of Bonn, Germany);** Johanna Staneva (Helmholtz-Zentrum Geesthach, Germany); Johannes Karstensen (GEOMAR, Germany); Antonio Bonaduce (Helmholtz-Zentrum Geesthach, Germany); Hermann Bange (GEOMAR, Germany); Sebastian Grayek (Helmholtz-Zentrum Geesthacht, Germany); Jürgen Kusche (University of Bonn, Germany)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_008

## **Abstract:**

The proposed activity investigates the ocean processes at different scales in coastal and estuarine regions. The approach includes assessing the quality of real observations against model and in-situ data and performing SWOT simulations at selected locations in preparation to the SWOT data analysis. Along-track altimeter data are from Delay Doppler Altimetry and conventional altimetry missions for the interval 2010-2018.

The modelling system used is based on the regional coupled, ocean, wave and atmosphere model system, which is part of the Geesthacht COAstal model SysTem (GCOAST). implemented in the Atlantic, North Sea, Baltic Sea and Danish Straits, given by structured (NEMO-WAM) and unstructured (SCHISM-WWM) grid coupled models capable to resolve the complex ocean dynamics at the regional and coastal scales. The focus of the coupled system is on the nonlinear feedback (e.g. between the ocean circulation and wind-waves), which can no longer be ignored, in particular in the coastal zone where its role seems to be dominant. The synergy of the GCOAST coastal modelling system with both in-situ and remote sensing observations will be demonstrated.

First investigations will focus mesoscale structures and upwelling event in the Danish Straits and Southern-Western Baltic Sea. Two long term observational sites (Fehmarn Belt, Boknis Eck) located in the cal/val SWOT Pass 3 provide time series of full depth water currents and sea level/bottom pressure records. Wind (local, central Baltic), seiches, run-off variability, and tides all impact the sea-level at different spatial and temporal scales. The topography is characterized by a central ridge that levels out towards the coasts and can act as an amplifier for sea level signals. Additionally, observational data from the Copernicus Marine Environment Monitoring System (CMEMS) over the area of interest will be utilized.

Other potential sites along SWOT Pass 3 will be investigated in order to determine an optimal sampling during the cal/val mission. A second target will be most likely the Elbe estuary, looking at the time variability of hydrodynamics in an estuarine macrotidal system.

The study is part of the SWOT Early Adopter activities at Uni-Bonn and HZG. This region of study will be covered by SWOT in the 1 day repeat phase.

## **Corresponding author:**

**Luciana Fenoglio (University of Bonn, Germany),** fenoglio@geod.uni-bonn.de

# Analysis of Second-Order Transverse Structure Functions of Velocity in the Southern Ocean

**Don Chambers (University of South Florida, United States)**; Jessica Caggiano (University of South Florida, United States); Boris Galperin (University of South Florida, United States); Greg King (University of South Florida, United States)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_009

## **Abstract:**

Transverse structure functions sort transverse velocity differences as a function of separation distance. The slope of the function from small distances to longer distances will change depending on the level of turbulence and sub-mesoscale energy in the velocity field. Here, we compare structure functions computed from along-track TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3 data throughout the Southern Ocean with acoustic doppler current profiler (ADCP) data primarily in the Drake Passage. Both are also tested against a new theory that can explain why structure functions and spectra of velocity data change as a function of latitude related to Coriolis force.

## **Corresponding author:**

**Don Chambers (University of South Florida, United States)**, donc@usf.edu

# A New NRT Mesoscale Eddy Trajectory Atlas on AVISO

**Antoine Delepouille (cls, France);** Yannice Faugere (CLS, France); Evan Mason (APL, UW; IMEDEA, CSIC, Spain)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_010

## **Abstract:**

A new Near Real Time "Mesoscale Eddy Trajectory Atlas" is to be released in 2019 on the AVISO altimetry portal. This dataset will be produced with the "py-eddy-tracker" software in collaboration with E. Mason from IMEDEA, using daily altimetry maps based on the full altimeter constellation (CMEMS SEALEVEL GLO product formerly known as the AVISO all-sat maps). This new algorithm will provide eddy contours and speed profiles. A delayed time method of tracking will also be used in the NRT product. In addition to the locations of detected eddies along their trajectories, the atlas will include additional information about the amplitude, rotational speed, radius, eddy type (cyclonic/anticyclonic), contour, and speed profile, as well as a flag which stores missing detections. Here we present the methodology and assessment results for these new NRT product lines.

## **Corresponding author:**

**Antoine Delepouille (cls, France),** [adelepouille@groupcls.com](mailto:adelepouille@groupcls.com)

# Improvements of Sentinel-3A altimetry data in the retrieval of sea level variability in the coastal region of the European Seas

**Antonio Sánchez Román (IMEDEA (CSIC-UIB), Spain);** Yannice Faugère (CLS, Toulouse, France); Isabelle Pujol (CLS, Toulouse, France); Guillaume Taburet (CLS, Toulouse, France); Marta Marcos (IMEDEA (CSIC-UIB), Spain); Ananda Pascual (IMEDEA (CSIC-UIB), Spain)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_011

## **Abstract:**

Altimeter missions have been providing accurate measurements of sea surface height (SSH) for the last 25 years. The quality assessment of altimetry data can be conducted by analysing their internal consistency and the cross-comparison between all missions. Moreover, in-situ measurements are also used as an external, independent reference.

In this work, we assess Sea Level Thematic Centre (SL-TAC) operational products in the European Seas using in-situ tide gauges from the Copernicus Marine Environment Monitoring Service (CMEMS) catalogue. Namely, we conduct an inter-comparison of delayed mode along-track sea level anomaly (SLA) from Sentinel-3A and Jason-3 satellite missions with SSH provided by in-situ tide gauges located in the European coasts of the North Atlantic Ocean, and in the Mediterranean Sea.

The processing of the tide gauge data includes corrections of (i) oceanic tidal effects by filtering high frequency diurnal and semidiurnal tides, (ii) long-period tide waves by using an algorithm based on well-balanced tide tables, (iii) atmospheric effects by subtracting the high frequency dynamical atmospheric correction, and (iv) vertical land movements associated to GIA. The comparison consists in co-locating altimetry and tide-gauge data. The method is based on a criterion of maximal correlation between tide gauge time series and altimeter L3 products. Then, statistics of sea level differences (correlation coefficient, root mean square error, variance) are computed. Results show a better performance of Sentinel-3A time series with respect to Jason-3 data in the coastal region of Europe. Similar results are obtained for the different sub-regions investigated.

## **Corresponding author:**

**Antonio Sánchez Román (IMEDEA (CSIC-UIB), Spain),** [asanchez@imedea.uib-csic.es](mailto:asanchez@imedea.uib-csic.es)

# Meso to sub-mesoscale variability observed by Sentinel-3A

Oscar Vergara (CLS, France); Rosemary Morrow (LEGOS, France); Isabelle Pujol (CLS, France); Gérald Dibarboure (CNES, France); Clément Ubelmann (CLS, France)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_012

## **Abstract:**

Recent evidence from along-track Sea Surface Height observations (1 Hz) has demonstrated the capabilities of current generation altimeters to tease out the oceanic variability in the meso to sub-mesoscale wavelength range.

In the present work, we update previous results on the submesoscale wavelength range ( $\lambda < 100$  km) using two years of Sentinel-3A SSH observations (20 Hz), reprocessed using a novel waveform stacking method developed by CNES (SAR/LR-RMC). The main objective is to diagnose the characteristic scale that marks the shift from balanced-motion (eddy) dominated towards unbalanced-motion (wave) dominated in the SSH spectrum (Transition Scale; Lt). Higher signal to noise ratio is obtained due to the LR-RMC reprocessing, improving the observability of fine scale variability. This materializes as an improvement in our estimates of Lt and its comparisons against modeling results.

Our estimates of average Lt and its spatial distribution at global scale are in agreement with the values predicted by global models. The lowest values ( $Lt < 50$  km) are found at the highly energetic western boundary current systems, marking a clear asymmetry with the eastern boundaries in all the ocean basins ( $Lt \sim 100-150$  km). Lt values progressively increase from the mid-latitudes ( $\sim 150$  km) towards the equatorial ocean ( $Lt > 250$  km), consistent with the increased dominance of unbalanced over balanced motions in the SSH variability that is observed at low latitudes. We also observe a seasonal cycle of Lt, showing the same phase as the one predicted by global models, and reported by in situ measurements. However, the amplitude of the altimetry-derived seasonal cycle of Lt is below that computed from numerical simulations. Limitations of our methodology and implications for the future wide-swath observations from SWOT are discussed.

## **Corresponding author:**

Oscar Vergara (CLS, France), [overgara@groupcls.com](mailto:overgara@groupcls.com)

# Spectral content of nadir altimetry at regional scales: a case study in the Bay of Biscay and New Caledonia region

**Mei-Ling Dabat (LEGOS, France);** Nadia Ayoub (LEGOS, France); Lionel Gourdeau (LEGOS, France); Frederic Marin (LEGOS, France); Fabien Léger (LEGOS, France); Isabelle Pujol (CLS, France); Rosemary Morrow (LEGOS, France)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_013

## **Abstract:**

Recent studies have investigated the spectral content of conventional altimetry data at low resolution (1 Hz) in order to characterize the seasonal and spatial variability of the nature of the surface dynamics (balanced vs unbalanced motions), of the noise level and of the data resolution among others (e.g. Fu et al., 2012; Zhou et al., 2015; Dufau et al., 2016; Vergara et al., 2019). All these studies were performed at global scale based on spectra representative of large areas ( $\sim 10^\circ$  square boxes).

In the present work, we propose to revisit such spectral analysis using high-resolution data (20 Hz/40 Hz) of the most recent satellite missions such as Jason 2, Saral/Altika and Sentinel 3A. The motivation is to extend the previous analysis to finer scales with regard to the next SWOT mission. We first summarize different available data sets and options in the processing: geophysical corrections, editing of data and corrections, smoothing. The extra information provided by high-resolution data is then explored in different datasets.

We focus on two specific regions: a subtropical area around New Caledonia in the western tropical Pacific and a middle latitude area which is the abyssal plain of the Bay of Biscay in the north-east Atlantic not investigated in the aforementioned papers. These regions have contrasted dynamics, but are both characterized by the presence of strong internal tides. The averaged spectra over these areas are first discussed in terms of the local dynamics, and their representativeness of the local dynamics is discussed in comparison with individual along track spectra. Indeed, anisotropic motions such as internal tides may induce different signatures in the different spectra.

## **Corresponding author:**

**Mei-Ling Dabat (LEGOS, France),** mei-ling.dabat@legos.obs-mip.fr



# High-Resolution Maps of Sea Surface Height: A new method applied to the California Current system

**Matthew Archer (JPL, United States);** Zhijin Li (JPL, USA); Lee-Lueng Fu (JPL, USA)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_014

## **Abstract:**

We present a new method to optimize mapping of along-track measurements of sea surface height (SSH) from multiple satellites onto a regular space-time grid. Motivated by the upcoming SWOT Cal/Val in the California Current system, our goal has been to investigate how much of the fine-scale ocean variability resolved by along-track observations can be retained in the interpolated 2D maps, while avoiding spurious off-track variance. To objectively map the SSH, we apply a variational interpolation technique, optimize the correlation scales for the region, and incorporate a new 'representation error' term in the observational error covariance matrix. Initial results indicate a significant improvement over AVISO in terms of the spatial and temporal resolution of the maps, which we validate with independent remote and in-situ datasets.

## **Corresponding author:**

**Matthew Archer (JPL, United States),** [archer@jpl.nasa.gov](mailto:archer@jpl.nasa.gov)

# Multiscale Data Assimilation for SWOT Ocean Application

Jinbo Wang (JPL, United States); Zhijin Li (JPL, United States); Lee-Lueng Fu (JPL, United States)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_015

## **Abstract:**

The Surface Water and Ocean Topography mission will launch its satellite in 2021 to measure the sea surface height with two wide swaths at a high resolution (down to 15km in some regions). The 2D aspect and the high resolution of SWOT SSH measurements will improve our understanding of the mesoscale eddies and low mode internal tides, and unveil the eddies and higher mode internal tides at smaller mesoscale and even submesoscale. The mission is unprecedented in producing 2D SSH measurements at such a high resolution. It also presents us with great challenges as follows. (1) Building an in-situ observing system to reconstruct the ground truth for validation purpose becomes unconventional. (2) The high resolution measurement was done at the cost of temporal resolution. Mapping/assimilating the wide swaths data with large temporal gaps (21 day cycle) becomes a challenge especially for fast evolving small-scale processes. In this study, a multi-scale data assimilation system is built to address these challenges. Here we focus on challenge (1) and present an observational system simulation experiment (OSSE) to demonstrate the design of an in situ observing system for the SWOT post-launch validation.

## **Corresponding author:**

Jinbo Wang (JPL, United States), Jinbo.Wang@jpl.nasa.gov

# Nested data assimilative modeling of submesoscale variability at the Mid Atlantic Bight Pioneer Coastal Array

**John Wilkin (Rutgers University, United States)**; Andrew Moore (University of California Santa Cruz, United States); Julia Levin (Rutgers University, United States); Hernan Arango (Rutgers University, United States)

**Session:** Science III: Mesoscale and sub-mesoscale oceanography

**Presentation type:** Poster

**Poster number:** SC3\_016

## **Abstract:**

Using a hierarchy of three 1-way nested grids (7 km: 2.3 km: 700 m resolution) with data assimilation at each successive level of grid refinement, we capture event wise correspondence of modeled and observed features at the ocean submesoscale in the vicinity of the NSF Ocean Observatories Initiative (OOI) Pioneer Coastal Array in the Mid Atlantic Bight of the northeast U.S. We use 4-dimensional variational (4D-Var) data assimilation in the Regional Ocean Modeling System (ROMS). All available data from altimeter and temperature satellites, coastal HF-radar, and in situ platforms (moorings, gliders, Argo, drifters and vessels) are assimilated. Results focus on processes at the shelf-break where the impingement of Gulf Stream warm core ring waters drives exchange between coastal and deep-ocean water masses.

## **Corresponding author:**

**John Wilkin (Rutgers University, United States)**, [jwilkin@rutgers.edu](mailto:jwilkin@rutgers.edu)

# GOCE User Toolbox and Tutorial

Per Knudsen (DTU Space, Denmark); Jerome Benveniste (ESA, Italy)

**Session:** The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

**Presentation type:** Poster

**Poster number:** GEO\_001

## **Abstract:**

The GOCE User Toolbox GUT is a compilation of tools for the utilisation and analysis of GOCE Level 2 products. GUT support applications in Geodesy, Oceanography and Solid Earth Physics. The GUT Tutorial provides information and guidance in how to use the toolbox for a variety of applications. GUT consists of a series of advanced computer routines that carry out the required computations. It may be used on Windows PCs, UNIX/Linux Workstations, and Mac. The toolbox is supported by The GUT Algorithm Description and User Guide and The GUT Install Guide. A set of a-priori data and models are made available as well. Without any doubt the development of the GOCE user toolbox have played a major role in paving the way to successful use of the GOCE data for oceanography.

The GUT version 2.2 was released in April 2014 and beside some bug-fixes it adds the capability for the computation of Simple Bouguer Anomaly (Solid-Earth). During this fall a new GUT version 3 has been released. GUTv3 was further developed through a collaborative effort where the scientific communities participate aiming on an implementation of remaining functionalities facilitating a wider span of research in the fields of Geodesy, Oceanography and Solid earth studies. Accordingly, the GUT version 3 has:

- An attractive and easy to use Graphic User Interface (GUI) for the toolbox,
- Enhance the toolbox with some further software functionalities such as to facilitate the use of gradients, anisotropic diffusive filtering and computation of Bouguer and isostatic gravity anomalies.
- An associated GUT VCM tool for analysing the GOCE variance covariance matrices.

## **Corresponding author:**

**Per Knudsen (DTU Space, Denmark)**, [pk@space.dtu.dk](mailto:pk@space.dtu.dk)

# NEW CNES CLS 2019 MEAN SEA SURFACE: FIRST VALIDATION.

**Philippe Schaeffer (CLS, France);** Isabelle Pujol (CLS, France); Yannice Faugere (CLS, France); Quentin Dagneaux (CELAD, France); Gerald Dibarboure (CNES, France); Nicolas Picot (CNES, France)

**Session:** The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

**Presentation type:** Poster

**Poster number:** GEO\_002

## **Abstract:**

A new Mean Sea Surface model, the CNES\_cls\_2019 MSS, has been determined. It is based on the integration of more than 25 years of altimetric data, using more than 10 altimeters from the historical Topex/Poseidon to the in-flight Sentinel-3A mission, including repetitives and geodetic/drifted orbits. Like the previous 2015 version this new determination is focused on the following points of improvement which remains a permanent challenge:

- the correction of ocean variability, especially for wavelengths between 50 and 200 km.
- the accuracy of altimetric data and therefore of the MSS near the coast, particularly since MSS can serve as a reference for studying the coastal vulnerability.
- a fine-tuned determination of the Arctic zone, which is a major indicator of climate change.
- a most accurate mapping of the finest topographic structures for wavelengths shorter than 50 km, in preparation of a new reference for the upcoming SWOT mission.

We therefore propose a synthesis of analyzes of these different aspects in order to quantify the improvements of this new MSS compared to the other existing models.

## **Corresponding author:**

**Philippe Schaeffer (CLS, France)**, pschaeffer@cls.fr

# THE NEW CNES-CLS 2019 MARINE GRAVITY ANOMALY MODEL: FIRST VALIDATION IN THE MEDITERRANEAN.

**Philippe Schaeffer (CLS, France);** Sean Bruinsma (CNES, France); Frank Reinquin (CNES, France)

**Session:** The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

**Presentation type:** Poster

**Poster number:** GEO\_003

**Abstract:**

A new model of marine free-air gravity anomalies has been determined. It is based on the same data set used in the CNES CLS 2019 Mean Sea Surface determination. Particular attention is paid to the shortest wavelength of the geoid of less than 30 km. Furthermore, data sampling at 1 Hz (~7km) along track is not sufficient in this context. It is necessary to focus this new determination on the use of 20 Hz (~350m) data that are provided by a new generation of altimeter, such as the Jason-1/2, Cryosat-2, and also SARAL missions in the geodetic phase. However, at this rate, observations are too noisy. They are resampled at 5 Hz cadence after application of a dedicated optimal filter.

We will present the validation of this new marine gravity field by means of comparing with existing models like UCSD V27 and DTU15, and the high-resolution GEOMED2 (ship) gravity database of the Mediterranean in particular.

**Corresponding author:**

**Philippe Schaeffer (CLS, France),** [pschaeffer@cls.fr](mailto:pschaeffer@cls.fr)

# Geomed2: High-Resolution Geoid Models of the Mediterranean

Sean Bruinsma (CNES, France)

**Session:** The Geoid, Mean Sea Surfaces and Mean Dynamic Topography

**Presentation type:** Poster

**Poster number:** GEO\_004

## Abstract:

The GEOMED2 project started in 2014 with the aim of estimating the geoid of the Mediterranean. In this work, an overall view on the GEOMED2 project is presented and the different steps in managing the project are revised and commented. The way gravity data has been checked for possible outliers and biases is discussed and a comparison among Global Geopotential Models (GGM) used for reducing the low frequency component of the gravity signal is given. The different methods for terrain effect computation (RTC) and the outcomes of the applied geoid estimation methods, i.e. Collocation, Stokes-Wong&Gore and the KTH methods are presented and commented.

Marine gravity data is not available for large parts of the Mediterranean and consequently the gravimetric geoid solution is significantly less accurate there. Gravity inferred from altimetry data can be used to fill the gaps. However, ocean dynamic signal may contaminate the derived gravity or geoid, which is why a pure gravimetric solution is preferred in an ideal world.

Geoid solutions using altimeter-inferred data only, such as DTU15 and DTU17 and UCSD V24 and V27 gravity, were computed too. These solutions were computed using the Stokes-Wong&Gore method. By interpolating the altimeter-inferred data on the ship measurements' positions, i.e. replacing ship data, and then computing the geoid solution allowed drawing surprising solutions on the quality of both datasets.

All models are compared with a marine geoid constructed with models for the MSS and the MDT (based on drifter data), which is our benchmark. The difference in geoid quality due to geoid estimation method is rather small, fortunately, but the impact of the GGM used in the remove-restore procedure is very big. The RTC method equally has a big impact, and best results are obtained with the Kuehn-Hirt model.

Comparing model-inferred to drifter-inferred current velocities constitutes an independent quality evaluation. This type of evaluation leads to a very detailed quality assessment of the models, notably as a function of spatial scale.

## Corresponding author:

Sean Bruinsma (CNES, France), sean.bruinsma@cnes.fr

# Bathymetry improvement and tidal modeling in the North East Atlantic Ocean and in the Mediterranean Sea

**Mathilde Cancet (NOVELTIS, France)**; Florence Toublanc (NOVELTIS, France); Florent Lyard (LEGOS/OMP/CNRS, France); Gérald Dibarboure (CNES, France); Nicolas Picot (CNES, France); Thierry Guinle (CNES, France)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Poster

**Poster number:** TID\_001

## **Abstract:**

Coastal processes (tidal currents, storm surges, waves) are highly dependent on bathymetry and directly impact offshore and coastal activities and studies. Many studies and applications lie on a growing modelling effort of the ocean and the limited accuracy of bathymetry, especially on the continental shelves, contributes to degrade numerical model performance despite significant use of in-situ and satellite measurements assimilation. In particular, the tidal models are very sensitive to the bathymetry accuracy on the shelves, where the ocean tides show the largest amplitudes and are strongly non-linear.

The increase in the grid resolution, combined with local model tuning, is one of the means to improve the tidal model performance in the coastal regions and large improvements have been achieved thanks to this approach. However, increasing the resolution of the model grid implies consistent bathymetry quality and accuracy, which is today the main limiting factor to accurate high-resolution tidal modelling.

In particular this has a direct impact on the quality of the altimetry sea surface heights as the tide correction is one of the largest corrections on the shelves, ranging from several centimetres to several metres. It is of prime importance for the current and future satellite altimetry missions that already or will enable to retrieve high-resolution coastal observations of the sea surface height, such as Sentinel-3, SWOT and Sentinel-6/Jason-CS.

Various sources of bathymetry data exist but many regions remain not well known because of too sparse measurements, data access limitation or large temporal variability of the seabed dynamics. In this context, CNES funds a project that aims to improve the bathymetry and the tides in the North-East Atlantic Ocean and in the Mediterranean Sea.

The work is divided in several steps: 1) an inventory of the existing bathymetry datasets in the regions of interest; 2) the integration of the collected datasets into a reference global bathymetry dataset; 3) the evaluation of this new bathymetry dataset through hydrodynamic modelling; 4) the assimilation of tidal observations into the model and the production of high resolution regional tidal atlases.

This paper presents the most recent results obtained within this project.

## **Corresponding author:**

**Mathilde Cancet (NOVELTIS, France)**, mathilde.cancet@noveltis.fr



# Coastal tides and sea level variations at high latitudes from GNSS-R and satellite altimetry

**Ole Baltazar Andersen (Prof, Denmark)**; Karina Nielsen (DTU Space, Denmark); Simon Williams (NOC Liverpool, UK); Michael Kern (ESA ESTEC, The Netherlands)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Poster

**Poster number:** TID\_002

## **Abstract:**

The ability to determine ocean tides are still limited in coastal regions due to the limited space-time sampling and ocean tide errors remain the largest source of range error in satellite altimetry today in the coastal zone. SAR altimetry from Cryosat-2 and Sentinel 3A/B is capable of providing altimetry closer to the coast than conventional altimetry and in this presentation we aim at presenting result from the ESA GOCE++ project which looks at the ability to add information about sea level and tides from GPS reflectometry in high latitude regions where tide gauges are sparse and where GPS reflectometry is a promising alternative to measure sea level close to the GPS stations. We have currently identified some high latitude stations on Greenland where tide gauges are sparse, but where the Danish GNET system of coastal GNSS stations operated and have identified and processed the GNSS data to determine sea level variation. We will present results from these co-located GPS reflectometry data and Cryosat-2 and Sentinel 3A SAR altimetry with respect to both sea level variations and estimation of the residual tide signal at those locations

## **Corresponding author:**

**Ole Baltazar Andersen (Prof, Denmark)**, oa@space.dtu.dk

# The effect of horizontal resolution and wave drag on tidal baroclinic mode waves in realistic global ocean simulations

**Maarten Buijsman (Division of Marine Science, The University of Southern Mississippi, Stennis Space Center, MS, United States);** Brian Arbic (Department of Earth and Environmental Sciences, University of Michigan, Ann Arbor, MI, USA); Jay Shriver (Oceanography Division, Naval Research Laboratory, Stennis Space Center, MS, USA); Gordon Stephenson (Division of Marine Science, The University of Southern Mississippi, Stennis Space Center, MS, USA); Zhongxiang Zhao (Applied Physics Laboratory, University of Washington, Seattle, WA, USA)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Poster

**Poster number:** TID\_003

## **Abstract:**

The M2 tidal energetics are studied for two realistically forced global ocean HYCOM simulations with horizontal resolutions of 8 km (H12) and 4 km (H25) and 41 layers. In both simulations the M2 SSH RMS error with TPXO is 2.7 cm. To optimize the tidal accuracy, the wave drag is tuned differently: in H12 the wave drag scale is 0.5, while in H25 it is 0.3. In HYCOM, the wave drag dampens both the barotropic and baroclinic tidal waves. The M2 baroclinic fields are decomposed into the first 5 vertical modes. In H12 the first 2 modes are resolved, while in H25 the first 5 modes are resolved. From H12 to H25, the M2 barotropic energy conversion to the resolved baroclinic wave modes increases by 47%, mainly due to the increased resolution in H25. At the same time, the barotropic energy lost to the wave drag decreases in H25 due to the reduction in drag scale. In both simulations, the sum of the resolved conversion and wave-drag dissipation, which represents the unresolved high-mode conversion, is the same (about 1 TW), in accordance with both simulations having identical tidal accuracy. The M2 barotropic energy conversion to the first 5 modes agrees with analytical models based on Bell's theory. The reduction in wave drag scale also reduces the damping on the resolved baroclinic modes in H25, which are too energetic when compared to satellite altimetry and altimetry-inferred fluxes. The resolved, low-mode, internal tide dissipation rates in H25 are in agreement in magnitude and spatial distribution with dissipation rates inferred from Argo and Mirco- and Finestructure data. However, when the parameterized high-mode dissipation is included, the tidal internal tide dissipation is larger than the rates inferred from Argo and Fine/Microstructure. These findings suggest that HYCOM needs barotropic and baroclinic wave damping terms that can be tuned separately.

## **Corresponding author:**

**Maarten Buijsman (Division of Marine Science, The University of Southern Mississippi, Stennis Space Center, MS, United States),** maarten.buijsman@usm.edu

# Using Complex-Demodulation to Identify Non-Phase-Locked Tides from Reference-Mission Altimetry

Edward Zaron (Portland State University, United States)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Poster

**Poster number:** TID\_004

## **Abstract:**

Modulations of the internal tide are caused by both large-scale, seasonal-to-interannual, changes in ocean stratification and also by smaller-scale mesoscale currents and stratification. The magnitude and frequency spectrum of the tidal modulations is hardly known, but it is clear that this information may be crucial to the interpretation of ocean topography measured by SWOT and it may provide a useful record of climate statistics which are currently poorly measured by direct means. Complex-demodulation, which may be implemented with short-term harmonic analysis or other techniques, can be combined with spatial analyses of along-track altimetry data to reveal changes in internal tides and distinguish them from broadband mesoscale variability. In this talk I will show examples of these kinds of analysis which identify seasonal-to-interannual variability of internal tides. By looking at variability as a function of the demodulation window, it is possible to infer the total variance associated with the non-phase-locked internal tide. These results provide a view of internal tide variability which complements previous approaches based on analysis of the wavenumber spectrum.

## **Corresponding author:**

Edward Zaron (Portland State University, United States), ezaron@pdx.edu

# De-aliasing of tidal signals using wide-swath sun synchronous orbits

**Loren Carrere (CLS, France)**; Florent Lyard (LEGOS, France); Clement Busche (CLS, France); Mathilde Cancet (NOVELTIS, France); Nicolas Picot (CNES, France)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Poster

**Poster number:** TID\_005

## **Abstract:**

Thanks to its current accuracy and maturity, altimetry is considered as a fully operational observing system dedicated to scientific and operational applications. In order to access the targeted ocean signal, altimeter measurements are corrected for several geophysical parameters among which the ocean tide correction is one of the most critical. The accuracy of tidal models has been much improved during the last 20 years, and in this context, a new global tidal model, FES 2014, has been developed and finalized in 2016 and it is now available on AVISO website :

<https://www.aviso.altimetry.fr/en/data/products/auxiliary-products/global-tide-fes.html>.

Some errors still remain mainly in shelf seas and in polar regions where availability of new databases is still worful for the development of future tide models.

In this context and knowing that the tides and tidal currents are a predominant signal in shallow and shelf regions which have critical applications and societal interests, we analyse the interest of new satellite missions for the observation of tidal signals.

It is well-known that sun-synchronous orbits (SSO) do not sample properly the tidal signal, leading to bad aliasing frequencies of most tidal waves, and some solar waves are not even observable (S1 and S2).

As some of future SSO will benefit from wide-swath measurements of SSH or even surface currents (WISA, SKIM), we propose an estimation of the observability of tidal signals while taking into account the local multiple sampling allowed by the wide-swath of those new missions. The WISA constellation flying context is also taken into account.

The analysis is based on OSSE experiments using the IBI36 regional simulation of the North-East Atlantic Ocean (provided by Mercator-Ocean), which includes the tidal signal as well as other oceanic variability which can prevent a proper tide estimation from satellite measurement due to crossed aliasing issues. Results of this tidal desaliasing analysis are presented here.

## **Corresponding author:**

**Loren Carrere (CLS, France)**, [lcarrere@groupcls.com](mailto:lcarrere@groupcls.com)

# Last TUGO model simulations and perspectives of evolution of the Dynamic Atmospheric Correction for altimetry

**Loren Carrere (CLS, France)**; Damien Allain (CLS/LEGOS, France); Florent Lyard (LEGOS, France); Yannice Faugere (cls, France); Nicolas Picot (CNES, France)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Poster

**Poster number:** TID\_006

## **Abstract:**

Given its current accuracy and maturity, altimetry is considered a fully operational observing system dedicated to various applications such as operational oceanography and climate studies. Altimeter measurements are corrected for several geophysical effects in order to isolate the oceanic variability, and the Dynamic Atmospheric Correction (DAC) is the second most important one after the tide correction. This DAC correction allows for the removal of high frequency ocean variability induced by the atmospheric forcing and aliased by the altimetric measurements.

The accuracy of the DAC has been much improved over the last 25 years leading to centimetric accuracy in open ocean. However significant errors still remain mainly in shallow waters and in polar regions, due to bathymetric errors, to atmospheric forcing errors, to local lack of resolution of the grid, or even to sea ice effects ...

In this context and taking into account the new challenges of dynamic atmospheric correction for the coming high-resolution altimetry missions, several ways of improvements are being tested, including: replacing the barotropic model MOG2D by TUGO-M version, using higher frequency temporal sampling provided by the new ERA-5 ECMWF meteorological database, using a higher resolution mesh, or generating higher frequency maps of DAC to take into account a better propagation of the high frequency surge signal. Including the gravitational tide forcing within the barotropic model used to compute the DAC is also investigated to try to improve the bottom friction dissipation in the simulations. Preliminary results are interesting and show significant improvement in some regions of interest. We will describe the tests performed and some validation results and we will present an implementation plan for a new version of the operational DAC for altimetry in 2020.

## **Corresponding author:**

**Loren Carrere (CLS, France)**, lcarrere@groupcls.com

# Mapping Internal Tides from Satellite Altimetry without Blind Spots

Zhongxiang Zhao (University of Washington, United States)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Poster

**Poster number:** TID\_007

## **Abstract:**

Satellite altimetry may be the only practical technique for observing internal tides on the global scale. However, it is a challenge to mapping the global complicated internal tide field using satellite altimeter data, mainly due to the low spatiotemporal sampling rate of nadir-looking satellite altimetry. The next-generation wide-swath altimetry will also have low temporal resolution. Therefore, it is important to develop new techniques for better mapping internal tides from the current- and next-generation satellite altimetry. This study addresses a problem caused by along-track high-pass filtering in previous studies, which is used to remove long-wavelength nontidal noise and barotropic tidal residual. However, the filter removes internal tides having large angles with respect to satellite ground tracks and thus causes blind spots in the resultant internal tide field. Satellite ground tracks are generally in south-north direction at low latitudes; therefore, westbound and eastbound internal tides are either underestimated or totally missed. This study presents a new technique that replaces the one-dimensional (1D) along-track high-pass filter with a two-dimensional (2D) bandpass filter. The latter extracts internal tides in all directions without blind spots. Westbound and eastbound internal tides can be retrieved by the new technique. The new internal tide models are presented and compared with previous models. The improvement is shown by SSH variance reduction explained by applying different models to independent Cryosat-2 altimeter data. However, the new technique makes no improvement in boundary current systems or energetic equatorial zones. The application of this new technique to other observational and modeled datasets are also demonstrated.

## **Corresponding author:**

**Zhongxiang Zhao (University of Washington, United States)**, [zzhao@apl.washington.edu](mailto:zzhao@apl.washington.edu)

# Temporal variability of the mode-1 M2 internal tide

Zhongxiang Zhao (University of Washington, United States); Peter Rhines (School of Oceanography, University of Washington, United States)

**Session:** Tides, internal tides and high-frequency processes

**Presentation type:** Poster

**Poster number:** TID\_008

## **Abstract:**

This work aims to (1) construct time-variable internal tide models accounting for the incoherent component and (2) monitor ocean heat change in the upper ocean over various time scales. For these goals, seasonal, annual and decadal variations of the mode-1 M2 internal tide are studied using 25 years of multisatellite altimeter data from 1992–2017. A series of global internal tide maps are constructed using subsetted altimeter data. A new mapping technique is employed to better suppress nontidal noise and retrieve westbound/eastbound internal tides. The resultant maps enable us to explore the temporal and spatial variability of internal tides (1- and 2-order derivatives). By dividing the data into two decades: 1992–2004 and 2005–2017, we construct two global internal tide fields that have almost identical spatial patterns. Interestingly, global statistical analysis reveals that there is a 6-degree phase difference between them (about 10 minutes in time), suggesting that the ocean stratification strengthened from the first to the second decade, which is mainly attributed to upper ocean warming. However, the phase difference is very complicated in space. In addition, four seasonal internal tide maps are constructed and all have similar spatial patterns. Systematic phase differences mainly occur in equatorial zones and marginal seas, consistent with the seasonal speed change of internal tides estimated from World Ocean Atlas 2013. We also construct global internal tides using yearly subsetted data. Due to limited data length and thus large uncertainties, annual variations are mainly studied in regions of strong internal tides. Significant phase changes are observed to be associated with numerous long-range internal tidal beams in different years.

## **Corresponding author:**

**Zhongxiang Zhao (University of Washington, United States)**, [zzhao@apl.washington.edu](mailto:zzhao@apl.washington.edu)

# Initial Analysis of CFOSAT SCAT and SWIM Data using Relative and Cross Calibration Technique.

**Suchandra Bhowmick (Space application centre isro, India); Seemanth M (Space application centre, india); Rashmi Sharma (Space application centre isro, India)**

**Session:** CFOSAT

**Presentation type:** Poster

**Poster number:** CFOSAT\_001

## **Abstract:**

CFOSAT (the China France Oceanography Satellite) is a joint China and France mission, dedicated to the simultaneous observation ocean surface wind and surface gravity waves. This mission is unique in the sense that it would have a synergistic realization of both wind and waves at the same time. It aims to improve NWP and ocean state forecast for operational marine meteorology, advanced ocean state forecast, ocean process studies and modelling ocean dynamics, prediction of climate variability and will suffice to fundamental understanding the surface processes. The CFOSAT has two payloads Ku-Band radars. One is the wave scatterometer known as Surface Waves Investigation and Monitoring instrument (SWIM) and the other one is a wind scatterometer (SCAT). These two instruments are indeed very unique. SCAT is implementation of a new type of Rotating Fan-Beam Scatterometer. On the other hand, SWIM is a new space-borne instrument with technological innovations having Rotating antenna, on-board advanced digital processing. SWIM is conceived at a frequency of 13.5 Ghz in Ku band and operates in the VV polarization. It has 6 incidence angles at 0 2 4 6 8 and 10 degrees respectively on ground. The wind and integrated wave parameter like SWH is provided at nadir while at 6 8 and 10 degrees it would provide the essential wave spectra information. CFOSAT would therefore bring to us simultaneous and in the same zone, the directional spectra of ocean waves and the wind vector. The initial relative calibration of CFOSAT scat has been planned from India using the global land targets over Amazon, Greenland and Antarctica and Runn of Katch respectively. A decent cross calibration is also planned using the Indian scatterometers SCATSAT-1. The initial phase of SWIM spectra would be matched using the 2-dimensional wave model spectra from Wave watch-3 and SWAN.

## **Corresponding author:**

**Suchandra Bhowmick (Space application centre isro, India), suchandra81@yahoo.com**



# First results of multi-incidence radar at Ku-band analysis over land surfaces

**Frédéric Frappart (Observatoire Midi-Pyrénées, France)**; Fabien Blarel (LEGOS, France); Eric Mougin (GET, France); Philippe Paillou (LAB, France); Fabrice Papa (LEGOS, France); Catherine Prigent (LERMA, France); Frédérique Rémy (LEGOS, France); Jean-Pierre Wigneron (ISPA, France); Mehrez Zribi (CESBIO, France)

**Session:** CFOSAT

**Presentation type:** Poster

**Poster number:** CFOSAT\_002

## **Abstract:**

Earth observation using active microwave sensors offers an all-weather global monitoring of every type of surface (ocean, land and ice-caps) in a wide range of frequencies, spatio-temporal resolutions, incidence angles and polarizations. Over land, backscattering coefficients from radar scatterometers, Synthetic Aperture Radar (SAR) and radar altimetry provide useful information on land surface characteristics related to land cover, vegetation density, surface soil moisture (SSM), salinity or detection of flooded areas, and the temporal dynamics of these key environmental variables.

The CFOSAT payload is composed of two sensors: SWIM (Surface Wave Investigation and Monitoring) a near-nadir (0 to 10° incidence) real-aperture Ku-Band azimuthally scanning radar and SCAT a radar scatterometer operating at Ku-Band aiming at moderate incidence angles (26° to 46°) with a rotating fan-beam antenna. These two innovative instruments will provide new and complementary information on the characteristics of land surfaces.

Here we propose to analyze the response of land surfaces and ice sheets using the first data acquired by SWIM and SCAT over of backscattering from SWIM and CFOSAT over three types of environments presenting stable backscattering at Ku and C bands from both altimetry and scatterometry: semi-arid areas, tropical rainforests and Vistok lake in Antarctica. Results will be compared to the results obtained satellite radar altimetry at Ku-band from Jason-3 and Sentinel-3A.

## **Corresponding author:**

**Frédéric Frappart (Observatoire Midi-Pyrénées, France)**, frederic.frappart@legos.obs-mip.fr

# Combined wave and wind products based on CFOSAT multi-instrument observations

**Alexey Mironov (OceanDataLab, France)**; Yves Quilfen (LOPS, IFREMER, France); Jean-Francois Piolle (LOPS, IFREMER, France); Gilles Guitton (OceanDataLab, France); Fabrice Collard (OceanDataLab, France); Antoine Grouazel (LOPS, IFREMER, France); Frederic Nouguier (LOPS, IFREMER, France); Alexis Mouche (LOPS, IFREMER, France); Bertrand Chapron (LOPS, IFREMER, France)

**Session:** CFOSAT

**Presentation type:** Poster

**Poster number:** CFOSAT\_003

## **Abstract:**

The CFOSAT is the innovative space mission dedicated to the observation of the ocean sea state and the sea surface winds. Recently launched in October 2018, CFOSAT operates two Ku-band rotating radars: the nadir and near-nadir Ku-band wave scatterometer (SWIM) and the dual-polarization, moderate incidence angle, Ku-band wind scatterometer (SCAT). This unique configuration of two sensors operating at two different incidence angle ranges provides regular measurements of sea state parameters, including directional wave spectrum, together with simultaneous wind speed and direction. From timely collocated wave and wind measurements, each single instrument data by its own can benefit from the other one. Such multi-modal observations require to develop new methods and approaches to realize the full expected potential of the mission.

IFREMER and OceanDataLab in cooperation with CNES implement and operate Wind and Wave Operation Center (IWWOC) dedicated to analysis and processing of combined observations from SWIM and SCAT sensors. It will process, archive and disseminate to the ocean user community delayed mode products from level 2 to level 4. Particularly, combined Level 2 (L2S) products are aimed to provide a consistent and homogeneous time series of wave and wind data through reprocessing activities.

In the L2S SWIM, one of the main objectives is to handle complex cases (heterogeneous seas and coastal areas) using ancillary data and alternative methodologies. This is an opportunity to revisit common wave inversion tasks spatial and spectral processing, computation of the modulation transfer function and partitioning.

The benefit of the synergistic approach will be demonstrated in application to SCAT wind vector retrieval which is improved by using SWIM nadir observations (L2S SCAT). The standard scatterometer wind vector inversion procedure based on the Maximum Likelihood Estimator (MLE) is extended to accommodate the SWIM collocated measurements.

The application of combined L2S products will be shown during the conference on the example of the analysis of selected use cases related to different oceanographic tasks.

## **Corresponding author:**

**Alexey Mironov (OceanDataLab, France)**, alexey.s.mironov@gmail.com

# Standardization for Time and Coordinates in Satellite Altimetry

**Stelios Mertikas (Technical University of Crete, Greece);** Craig Donlon (European Space Agency, The Netherlands); Demetrios Matsakis (Formerly with the US Naval Observatory, Time Reference, USA); Constantin Mavrocordatos (European Space Agency, The Netherlands); Zuheir Altamimi (IGN (National Geographic Institute) Geodesy Research Laboratory, France); Costas Kokolakis (Technical University of Crete, Greece); Achilles Tripolitsiotis (Space Geomatica, Greece)

**Session:** The Future of Altimetry

**Presentation type:** Poster

**Poster number:** FOA\_001

## **Abstract:**

Time is the fundamental measurement in satellite altimetry and the key parameter in building and keeping up a long-term, consistent, and reliable record for monitoring changes in sea level. Over the years, different time scales, although interconnected, have been used in altimetry but also in satellite positioning. This leads to unclear and sometimes ambiguous definitions of time and orbit coordinates as well as of their transformations between various reference and measuring systems.

Altimetry satellites, like Sentinel-3, CryoSat-2, Jason-3, HY-2A/-2B/-2C, IceSat-2, etc., observe and practically realize ranges by measuring time differences between transmission and reception of an electromagnetic wave (either radar or laser at present). Similar principles apply for global navigation satellite systems and for their terrestrial reference systems (TRS) on which all are linked and tied together. Yet, the “meter” (scale) of any TRS is also defined by time.

This work seeks to establish a standard reference system for the parameter “time” and for the “coordinates” in satellite altimetry. A new strategy of Fiducial Reference Measurements for Altimetry has been thus introduced to achieve reliable, long-term, consistent and undisputable satellite altimetry observations and products via calibration based upon metrology standards. The new strategy is also to include reference systems of coordinates, precise orbit determination, time tagging and range measurements in satellite altimetry. It has been carried out by the European Space Agency in an effort to reach uniform and absolute standardization for satellite altimetry. This principle delivers a common language of communication (1) for building trust on the scientific data we produce, (2) for presenting the correct information to the public, and (3) for supporting us to make the right decisions for Policies regarding the Earth and its Oceans.

## **Corresponding author:**

**Stelios Mertikas (Technical University of Crete, Greece),** mertikas@mred.tuc.gr

# Effect of spatio-temporal sampling of altimeter observations in the north Indian Ocean: A synthetic study using ocean model and SWOT simulator

Neeraj Agarwal (ISRO, India); Aditya Chaudhary (ISRO, India); Rashmi Sharma (ISRO, India); Raj Kumar (ISRO, India)

**Session:** The Future of Altimetry

**Presentation type:** Poster

**Poster number:** FOA\_002

## **Abstract:**

Surface water and ocean topography (SWOT) mission, which is proposed to be launched in 2022, will provide synoptic coverage of oceanic mesoscale and sub-mesoscale features that are not seen in conventional nadir altimeter observations. These observations are expected to enrich the existing knowledge of the ocean dynamics and fill the gaps in the conventional measurements. In addition, it is also expected that the simulations from numerical ocean models would improve when observations from SWOT will be used to constrain these models.

In this paper, an attempt has been made to comment on the optimum number and type (nadir or/and SWOT) of altimeter based space borne instruments to correct a high-resolution ocean model for the north Indian ocean by means of data assimilation. Synthetic observations are generated for SWOT and nadir altimeter tracks in different combinations (single, two or more nadir and SWOT combined) using sea level anomaly fields from a data assimilative, state-of-the-art numerical ocean model and SWOT simulator. The noise levels similar to those of existing Ka band altimeters such as Jason-2, 3, sentinel and Ku band SARAL/AltiKa and upcoming SWOT mission are added while generating these synthetic observations. These observations are then assimilated in a high resolution numerical ocean model for the north Indian ocean. Several assimilation experiments are performed wherein observations from single, multiple nadir altimeters in combination with SWOT observations are used. A hypothetical scenario with two SWOT mission type instruments separated by a gap of 10 days is also generated and the observations are assimilated in the model. The simulated state variables (Temperature, salinity, sea level and currents) from these experiments are then compared with the fields obtained from the same model using which the pseudo-observations were generated. It is expected that these experiments will provide an insight on how many nadir/SWOT altimeters would be required in future to constrain numerical ocean models for accurate ocean state estimation.

## **Corresponding author:**

Neeraj Agarwal (ISRO, India), neeraj@sac.isro.gov.in

# MISSION REQUIREMENTS FOR KU/KA-BAND SIGNALS OF OPPORTUNITY ALTIMETRY

James Garrison (Purdue University, United States)

**Session:** The Future of Altimetry

**Presentation type:** Poster

**Poster number:** FOA\_003

## **Abstract:**

Over the last two decades, ocean altimetry using signals of opportunity (SoOp) has been demonstrated using transmissions from the Global Navigation Satellite System (GNSS). Recently, techniques first developed for GNSS have been expanded to digital communication signals with the promise that the wider bandwidth and higher power would enable sea surface height (SSH) retrievals at a scientifically useful precision.

Analysis has shown that utilizing a 400 MHz direct broadcast SoOp, a SSH precision of 5.3 cm height precision can be achieved from a typical altimetry orbit of 1380 km and 4.1 cm can be achieved from a 500 km orbit. An error model first developed for GNSS-R was used to make these predictions after being validated by tower-based experiments. In addition to the tracking error model, a mission error budget must incorporate uncertainty in both transmitter and receiver orbits, as well as propagation effects of the ionosphere and troposphere. Transmitter orbit knowledge is the one part of this error budget that is not present in conventional altimetry. By definition, SoOp sources are not under control of the science mission, and orbit determination must be performed on these non-cooperative transmitters independently of the receiver. We will present an assessment of the impact of transmitter orbit knowledge on the altimetry error budget and a review of preliminary approaches for passive orbit determination.

Requirements for a high-gain (>20 dB) antenna and the more complex and variable bistatic scattering geometry impose some antenna design challenges as well. This is particularly true in using constellations of small satellites. We will present results from coverage simulations which can be used to define working antenna requirements.

## **Corresponding author:**

James Garrison (Purdue University, United States), [jgarriso@ecn.purdue.edu](mailto:jgarriso@ecn.purdue.edu)

# WiSA : a Wide Swath Altimetry Mission for Operational Oceanography and Hydrology - A good candidate for of Copernicus-NG Sentinel 3-Top Program

**Cecile CHEYMOL (CNES, France)**; Sophie Coutin-Faye (CNES, France); Pierre-Yves Le Traon (Mercator-Ocean, France); Sylvain Biancamaria (CNRS/LEGOS, France)

**Session:** The Future of Altimetry

**Presentation type:** Poster

**Poster number:** FOA\_004

## **Abstract:**

In order to provide continuity to the highly valuable spatial measurements that will be performed by the Surface Water and Ocean Topography (SWOT) wide-swath altimetry mission on a demonstration basis, CNES has started a 2-year study called WiSA, focused on defining an innovative concept of altimetry system to provide new measurements for both oceanography and hydrology on an operational basis. This will lead to improved estimates of deep-ocean and near-coastal marine circulation as well as the dynamics of open water stored on the land surface. The targeted programmatic framework is the Sentinel-3 Topo altimetry mission (~2030), follow-up of Sentinel-3, which will answer the expected evolution of the Copernicus Space Component.

The primary focus of the next generation of altimeters should be to extend the observing capability of the current altimeter constellation, and to observe smaller scales of the ocean surface topography. The objective is to resolve ocean scales of 50 km and 5 days, i.e. ocean features that are approximately twice as small and twice as fast as what is resolved today with altimetry. The secondary mission objective of the constellation should be to monitor the medium to large rivers (> 100 m width) and lakes/reservoirs (areas above 250 m x 250 m) with a time resolution from ~10 days and a height accuracy around 10 cm, at basin scale. In collaboration with expert scientists from the ocean and inland waters communities, a WiSA Users Requirement Document will be written to serve as reference input for future Copernicus studies.

CNES is involved with NASA/UKSA/CSA in SWOT mission which embarks KaRIn, the first Ka-band interferometric altimeter instrument operating in space. Alternative concepts have been proposed in the past by Thales Alenia Space. They rely on simpler antenna subsystem than for SWOT to moderate the complexity and the cost of the mission.

In the frame of WiSA study, several topics will be addressed such as Preliminary Definition of the Wide Swath Instrument and its mission performances, orbit analysis in hybrid altimetry (nadir+swath) satellite constellation context, swath altimetry system error budget, oceanography and hydrology processing chains definition (including on-board processing demonstrator for ocean topography mission).

This Poster will present an overview of mission objectives and the preliminary definition of the swath altimeters mission based on-going WiSA activities, which are led in coordination with ESA related activities (Swath Altimeter for Operational Oceanography - Feasibility Study, TRP Feasibility Study into Multibeam Swath Altimetry,...).

## **Corresponding author:**

**Cecile CHEYMOL (CNES, France)**, cecile.cheymol@cnes.fr

# SMASH: a Constellation of Small Altimetry Satellites Dedicated to Hydrology

**Denis BLUMSTEIN (CNES/LEGOS, France);** Alexandre Guérin (CNES, France); Alain Lamy (CNES, France); Alexandre Couhert (CNES, France); Alexandre Piquereau (CNES, France); Baptiste Palacin (CNES, France); Florian Rouzies (CNES, France); Alain Mallet (CNES, France); Sylvain Biancamaria (LEGOS, France); Sophie Le Gac (CNES, France); Thierry Amiot (CNES, France); Eric Boussarie (CNES, France); Philippe Maisongrande (CNES, France); Selma Cherchali (CNES, France); Sophie Coutin-Faye (CNES, France)

**Session:** The Future of Altimetry

**Presentation type:** Poster

**Poster number:** FOA\_005

## **Abstract:**

The monitoring of water resources at the global scale is already a major challenge whose importance will increase in the next years. Continental waters are essential components of the water, energy and carbon cycles. The rivers and lakes water levels are identified as essential climate variables by the GCOS which recommends daily measurements of these variables. Traditionally, this information was provided by gage data. However, the availability of these in situ measurements is very heterogeneous and is declining (GDRC).

For the last twenty years, numerous research teams have demonstrated that measurements from space altimeters could be used to mitigate this lack of in situ measurements even if these instruments were mainly designed for measurements over the oceans. However, all the historic and current altimetry missions, based on repeat track orbits with cycle durations of 10 days (T/P, Jason), 27 days (Sentinel3), 35 days (ERS2, ENVISAT, AltiKa) and more (CryoSat) cannot provide these daily measurements.

As the performance of altimetry missions applied to inland water surfaces improves constantly, the next frontier is to increase the frequency of temporal revisit. A “flash” study was performed by CNES to propose altimetry missions which could provide this daily revisit. The constellation of Small Altimetry Satellites for Hydrology (SMASH) is the result of this study.

This is a constellation of ten small satellites of the class 50 kg / 50 W / 27 U put on a Sun Synchronous Orbit. Each satellite carries a nadir altimeter and a precise orbit determination subsystem which provide the targeted end to end altimetric performance of 10 centimeters. The payload will allow us to monitor rivers as narrow as 50 meters wide and lakes as small as 100 meters x 100 meters and the orbit provides a latitude coverage that is largely sufficient to monitor inland waters. The constellation provides a daily revisit for each point on the earth overflight by a satellite. The altimetry products should be provided with a short time latency in order to make full use of the high temporal frequency of the measurements.

The SMASH constellation is very complimentary to the Wide Swath altimetry missions like SWOT (launch planned in 2021) and WiSA (ongoing phase A) which provide almost complete spatial coverage at a lower temporal frequency.

The presentation will provide more details on the SMASH study and its continuation in CNES.

## **Corresponding author:**

**Denis BLUMSTEIN (CNES/LEGOS, France),** [denis.blumstein@cnes.fr](mailto:denis.blumstein@cnes.fr)

# Altimetry over inland waters: current achievements thanks to the Open-Loop Tracking Command (OLTC) and perspectives for future missions

**Sophie Le Gac (CNES, France)**; Denis Blumstein (CNES/LEGOS, France); Léa Lasson (LEGOS/OceanNext, France); Simon Boitard (NOVELTIS, France); Lionel Zawadzki (CLS, France); Maxime Vayre (CLS, France); Nicolas Taburet (CLS, France); François Boy (CNES, France); Amandine Guillot (CNES, France); Etienne Berthier (LEGOS/Univ.Toulouse/CNES/CNRS/IRD, France); Liam Taylor (School of Geography, University of Leeds, UK); Pierre Féménias (ESA/ESRIN, Italy); Nicolas Picot (CNES, France)

**Session:** The Future of Altimetry

**Presentation type:** Poster

**Poster number:** FOA\_006

## **Abstract:**

In times of ever decreasing amount of in-situ data for hydrology, altimetry becomes key to provide global and continuous datasets of water surface height. Indeed, studying lakes, reservoirs and rivers water level at global scale is of prime importance for the hydrology community to assess the Earth's global resources of fresh water.

Much progress has been made in altimeters capability to acquire quality measurements over inland waters. In particular, the Open-Loop Tracking Command (OLTC) represents a major evolution of the tracking function. This tracking mode's efficiency has been proven on past missions and it is now stated as operational mode for current Sentinel-3 and Jason-3 missions. It has recently benefited from improvements brought to onboard tables contents.

We show how Jason-3 and Sentinel-3 altimetry missions are now able to observe and monitor tens of thousands of lakes and rivers all over the globe and how it is contributing in building a global dataset of inland waters level, in preparation for future missions such as Sentinel-6 and SWOT nadir. For that matter users are also invited to contribute to the definition of onboard tables through a dedicated website.

OLTC can also be used over more challenging surfaces, such as continental glaciers. In particular, one of the challenges of continental ice observation is the glaciers surface slope, so this optimization must be performed carefully. We show early results of a tentative exercise run for Sentinel-3 over a dozen glaciers in Europe (French Pyrenees and Alps), Asia (Pamir and Himalaya) and South America (Peru and Patagonia).

Finally, we present the numerous perspectives foreseen by CNES for innovative data processing techniques and ground validation campaigns.

## **Corresponding author:**

**Sophie Le Gac (CNES, France)**, [sophie.legac@cnes.fr](mailto:sophie.legac@cnes.fr)



# Combining Fully Focused and Swath Processing for Glacier applications

**Albert Garcia-Mondejar (isardSAT Ltd., United Kingdom); Ferran Gibert (isardSAT, Catalonia); Mònica Roca (isardSAT, Catalonia); Michele Scagliola (ARESYS s.r.l., Italy); Lisa Recchia (ARESYS s.r.l., Italy); Noel Gourmelen (University of Edinburgh, Scotland)**

**Session:** The Future of Altimetry

**Presentation type:** Poster

**Poster number:** FOA\_007

## **Abstract:**

High PRF altimeters transmit pulses at a high pulse repetition frequency thus making the received echoes suitable for coherent processing on-ground.

Conventional delay-Doppler processing (DDP, commonly called SAR or High Resolution) coherently integrates echoes in a burst-by-burst basis to provide single look waveforms referred to a specific ground location, which after being correctly aligned (compensating for the slant-range migration, among others) can be incoherently averaged, increasing the performance in terms of the speckle reduction and the along-track resolution compared with the traditional Low Resolution Mode and in turns in terms of geophysical retrieval.

The Fully Focused delay-Doppler processing (FF-DDP, also known as Fully Focused SAR) moves one step ahead and intends to coherently integrate the echoes over a time longer than a burst to get an even higher along-track resolution with an improved speckle reduction with respect to (unfocused) DDP.

The Open Burst (or interleaved) transmission mode to be implemented in Sentinel 6 and the Copernicus polar Ice and Snow Topography Altimeter (CRISTAL) missions makes more suitable the exploitation of the FF-SAR thanks to the uniform along-track sampling of the scene. However, in the conventional Closed Burst mode (like in CryoSat-2), replicas induced by the non-uniform sampling of the Doppler spectrum will be mixed with the main echo and, in most cases, won't be able to be filtered out.

Swath mode processing has been used to monitor elevation of areas with complex topography such as over ice sheet margins, ice caps and mountain glaciers, improving upon the resolution of conventional radar altimetry. Swath mode relies on an accurate angle of arrival of the measured echo, this is obtained from the SAR Interferometric mode of CryoSat-2 and CRISTAL and post-processing strategies resolving the ambiguous nature of the phase measurement.

The CRISTAL Mission will include Open Burst and Interferometric capabilities. It will be the first altimeter to be able to combine both methodologies to increase both the along and across-track resolutions improving the current performances of CryoSat-2 over small glaciers that can't be observed properly.

In this paper, we are the benefits that the combination of these methods will bring into the glacier monitoring by comparing results obtained after processing CRISTAL simulated data with the classical DDP retrievals, DDP+Swath retrievals and FF+Swath.

**Corresponding author:**

**Albert Garcia-Mondejar (isardSAT Ltd., United Kingdom), [albert.garcia@isardsat.co.uk](mailto:albert.garcia@isardsat.co.uk)**

# ALTIS: a new tool for processing along-track altimetry data

**Fabien Blarel (LEGOS, France)**; Frédéric Frappart (LEGOS, France); Vincent Marieu (EPOC, France);  
Fernando Niño (LEGOS, France); Denis Blumstein (LEGOS, France)

**Session:** Others (poster only)

**Presentation type:** Poster

**Poster number:** OTH\_001

## **Abstract:**

Analysis of along-track information contained in radar altimetry GDR could present some difficulties when dealing with long-term records over wide region. The new ALTimetry Time Series (ALTIS) software offers new opportunities to end-users for processing along-track altimetry data. This software operates in two modes. One with a Graphical User Interface (GUI) which could be mostly used for the definition of altimetry virtual stations over inland water bodies that requires a very specific processing composed of a refined selection of valid data for estimating water levels and eventually the correction of hooking effect. Inheriting from the Multi-mission Altimetry Processing Software (MAPS), it offers the possibility to end-users to define their own virtual stations using the altimetry data contained in the Geophysical Data Records (GDRs) for the most recent nadir-looking altimetry missions (i.e., Envisat, Jason-1, Jason-2, and Saral). Once achieved a coarse selection of the altimetry measurements present in the study area, altimetry heights are computed using the geophysical and environmental corrections for different type of surface (rivers and small lakes, great lakes, ocean, and coastal areas). A graphical user interface allows to visualize not only the altimetry heights derived from the different retracked ranges available for each mission (e.g., Ocean, Ice-1, Ice-2, Sea Ice, MLE-3) inside the study area, but also any corrections used and other parameters (e.g., backscattering coefficients) that can be useful for selecting the valid altimeter heights. Correction of the hooking effects can be performed on the selected or a part of the selected data at any cycle. The selection of the valid data can be saved at any time and reloaded. Time-series of altimeter heights are then computed based on the user's selection of the valid data and can be exported. The second mode allows the reconditionning of the altimetry data using the normalized tracks defined at CTOH. These normalized tracks were defined to order the altimetry data using an along-track grid allowing an easier handling of the altimetry data especially for the statistical analysis. This software will be soon available on the CTOH website: <http://ctoh.legos.obs-mip.fr>.

## **Corresponding author:**

**Fabien Blarel (LEGOS, France)**, [fabien.blarel@legos.obs-mip.fr](mailto:fabien.blarel@legos.obs-mip.fr)

# Monitoring marine litter with ocean current products in the North Atlantic Ocean

**Muriel Lux (NOVELTIS, France);** Etienne Sahuc (NOVELTIS, France); Mathilde Cancet (NOVELTIS, France);  
Matthieu Denisselle (NOVELTIS, France)

**Session:** Others (poster only)

**Presentation type:** Poster

**Poster number:** OTH\_002

## **Abstract:**

With an increasing rate of production, plastic management has become a global concern. As a majority of plastic items are single-use products, mismanagement of waste leads to a lot of items ending up at sea. Monitoring plastic litter has become of great importance for the protection of the ocean and water quality. The IFADO (Innovation in the Framework of the Atlantic Deep Ocean) project aims to create new marine services to support the Marine Strategy Framework Directive implementation with the North Atlantic Ocean as a study case. One of the objectives of this project is to use Earth Observation products in order to characterize marine litter convergence zones, pathways and main sources in the North Atlantic Ocean. This information is essential in the perspective of preventive and cleaning actions.

We used the Lagrangian particle modelling tool Opendrift, developed at the Norwegian Meteorological Institute, to evidence convergence areas in the North Atlantic Ocean. The Opendrift tool was fed with global ocean current maps derived from satellite observations (GlobCurrent products) or computed by an ocean circulation model (CMEMS analyses). Different scenarios of marine litter release were considered in order to understand the fate of plastic particles released from land (80% of marine litter ending up in the ocean) and the trajectories of particles floating offshore (shipping and fishing litter). Indicators were developed to highlight the preferential residence zones and pathways for plastic particles.

This presentation highlights the capabilities of ocean current products derived from satellite observations and models to simulate plastic particles trajectories at a basin scale. Comparison of the results shows a good consistency between both products.

## **Corresponding author:**

**Muriel Lux (NOVELTIS, France),** [muriel.lux@noveltis.fr](mailto:muriel.lux@noveltis.fr)

# Operational ocean data assimilation/prediction system for the western North Pacific at JMA

**Kotaro Mine (Japan Meteorological Agency, Japan);** Mikitoshi Hirabara (Japan Meteorological Agency, Japan); Hiroaki Asai (Japan Meteorological Agency, Japan); Hiromu Kobayashi (Japan Meteorological Agency, Japan); Toshiyuki Sakurai (Japan Meteorological Agency, Japan)

**Session:** Others (poster only)

**Presentation type:** Poster

**Poster number:** OTH\_003

## **Abstract:**

Japan Meteorological Agency (JMA) has been routinely operating an ocean data assimilation and prediction system for the western North Pacific (MOVE/MRI.COM-WNP\*) developed by the Meteorological Research Institute (JMA/MRI) since March 2008. The operational system assimilates Jason-3, SARAL/AltiKa and CryoSat-2 along-track sea level anomaly (SLA) data from CMEMS, in addition to in situ temperature and salinity observations, and daily SST analysis (MGDSST\*\*).

This poster will show the outline of MOVE/MRI.COM-WNP system and the impact of using additional SLA data (Sentinel-3A/B).

\* Multivariate Ocean Variational Estimation system / Meteorological Research Institute Community Ocean Model for the Western North Pacific, Usui et al. 2006

\*\* Merged satellite and in-situ data Global Daily SST

## **Corresponding author:**

**Kotaro Mine (Japan Meteorological Agency, Japan),** mine@met.kishou.go.jp

# Fundamental Data Records For Altimetry: a reprocessing of ERS-1, ERS-2 and ENVISAT altimeter and radiometer dataset oriented towards dedicated Level 1 and Level 2+ products

**Pierre Thibaut (CLS, France)**; Andrew Shepherd (University of Leeds, United Kingdom); Malcolm McMillan (University of Lancaster, United Kingdom); Eero Rinne (FMI, Finland); Frank Fell (Informus, Germany); Florence Birol (Legos, France); Sara Fleury (Legos, France); Angelica Tarpanelli (CNR/IRPI, Italy); Emma Woolliams (NPL, United Kingdom); Mathilde Cancet (Noveltis, France); Pierre Féménias (ESA/ESRIN, Italy)

**Session:** Others (poster only)

**Presentation type:** Poster

**Poster number:** OTH\_004

## **Abstract:**

In the framework of the European Long Term Data Preservation Program (LTDP+) which aim is to generate innovative Earth system data records named Fundamental Data Records (basically level 1 altimeter and radiometer data) and Thematic Data Records (basically level 2+ geophysical products), ESA/ESRIN has launched a reprocessing activity of ERS-1, ERS-2 and ENVISAT altimeter and radiometer dataset. A large consortium of thematic experts has been formed to take in charge these activities which are 1) to define products including the long, harmonized record of uncertainty-quantified observations, 2) to define the most appropriate level 1 and level 2 processing, 3) to reprocess the whole times series according to the predefined processing and, 4) to validate the different products and provide them to large communities of users focused on the observation of the atmosphere, ocean, coastal, hydrology, sea ice, ice sheet regions.

The objective of this poster is to inform the OSTST members of this initiative and to explain what the main guidelines, constraints and calendar of this project will be. Its objective is also to announce that an user consultation poll will be organized at the beginning of the project (September 2019) aiming at gathering the different expectations and recommendations expressed by the various communities.

## **Corresponding author:**

**Pierre Thibaut (CLS, France)**, [pthibaut@groupcls.com](mailto:pthibaut@groupcls.com)

# Quality Assessment of the new CryoSat Ice Baseline-D over the Cryosphere

Marco Meloni (Serco c/o ESA, Italy); Jerome Bouffard (ESA, Italy); Tommaso Parrinello (ESA, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_001

## **Abstract:**

The ESA Earth Explorer CryoSat-2 was launched on 8 April 2010 and from an altitude of just over 700 km and reaching latitudes of 88 degrees, monitors precise changes in the thickness of terrestrial ice sheets and marine ice. The aim of the CryoSat-2 mission is to determine variations in the thickness of the Earth's marine ice cover and understand the extent to which the Antarctic and Greenland ice sheets are contributing global sea level rise. CryoSat new Baseline-D ice data operational since May 2019 includes several evolutions as well as a new data format (NetCDF) compliant with other space-based observations. This paper provides one of the first detailed quantitative and qualitative analysis of the CryoSat ice Baseline-D data over the land ice and sea ice domains, covering all relevant mode-dependent Level-2 geophysical parameters (e.g. freeboard, ice sheet elevations, Polar sea level anomaly) and their comparisons with previous Baseline products and other source of ground and/or space-based observations. The Baseline-D upgrades will bring significant improvements to the quality of Level-1B and Level-2 products relative to the previous baseline products, which in turn are expected to have a strong positive impact on the scientific exploitation of the CryoSat mission over the cryosphere.

## **Corresponding author:**

Marco Meloni (Serco c/o ESA, Italy), marco.meloni@esa.int

# An interactive website for enhancing the Open-Loop Tracking Command (OLTC) of conventional altimeters for inland waters observation

**Sophie Le Gac (CNES, France)**; François Boy (CNES, France); Nicolas Picot (CNES, France); Denis Blumstein (CNES/LEGOS, France); Sylvain Biancamaria (LEGOS/Univ. Toulouse/CNES/CNRS/IRD, France); Jean-François Crétaux (LEGOS/Univ. Toulouse/CNES/CNRS/IRD, France); Stéphane Calmant (IRD, France); Simon Boitard (NOVELTIS, France); Franck Borde (ESA/ESTEC, The Netherlands); Pierre Féménias (ESA/ESRIN, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_002

## **Abstract:**

The Open-Loop Tracking Command (OLTC) mode represents a major evolution of the altimeter tracking function that was first developed for Jason-2 and SARAL/Altika missions as probative mode (called Diode/DEM mode). Taking into account this experience, this tracking mode's efficiency has been proven and it is now stated as operational mode for Jason-3 and Sentinel-3 missions.

On Sentinel-3, areas of interest define where SRAL is operated in OLTC mode. Outside these areas, SRAL altimeters operate in Close-Loop mode (a.k.a. autonomous tracking mode), with no a priori elevation information used to set the echo reception window.

When operated in OLTC mode, the SRAL altimeter computes the distance between its antenna and the on-ground surface by combining the satellite altitude provided by DIODE navigator of DORIS instrument with the on-ground elevation available in the OLTC tables. These tables are uploaded onboard the altimeter memory. It is a static file that can only be updated by telecommand operation.

That is why it is of high importance to define the most accurate and enriched contents of the OLTC onboard tables.

A new website (<https://www.altimetry-hydro.eu>), developed by Noveltis for ESA, offers the possibility to display OLTC elevation tables onboard ESA Sentinel-3 SRAL altimeters.

An interactive map allows visitors to view elevations defined onboard Sentinel-3 altimeters and navigate over inland water targets worldwide. Several visualization tools have been added to enhance the OLTC website experience: choice of map layout, display of satellite ground tracks and areas of interest.

Users wishing to further contribute to OLTC contents may sign up and have access to additional functionalities: once logged in, they have the possibility to submit modifications of existing elevations as well as requesting targets that may not yet be defined in the onboard OLTC tables. For example, adding a virtual station over a river or a lake, in order to enhance the OLTC contents and make sure that the altimeter will acquire quality echoes over the defined targets. Requests may be submitted directly using the "Contribute" tool or by sending a list of targets to the OLTC database management Committee.

We encourage scientists and Sentinel-3 users to visit the website and contribute to OLTC contents in order to enhance the altimeter's capability over inland waters.



**Corresponding author:**

**Sophie Le Gac (CNES, France), [sophie.legac@cnes.fr](mailto:sophie.legac@cnes.fr)**

# Performance of the Sentinel-3 STM constellation over Inland Waters

**Nicolas TABURET (CLS, France);** Matthias Raynal (CLS, France); Labroue Sylvie (CLS, France); Manon Rousseau (CLS, France); Maxime Vayre (CLS, France); Lionel Zawadzki (CLS, France); Pierre Féménias (ESA-ESRIN, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_003

## **Abstract:**

The main objective of the Copernicus Sentinel-3 Surface Topography Mission (STM) constellation over inland waters is to provide accurate measurements of water surface heights to support the monitoring of freshwater stocks for drinking water and agriculture, reduce risks for navigation, floods, and droughts. In order to provide the Copernicus Core Services as well as the end users with simple and reliable diagnoses on the L2 PDGS land products quality, the S3 Mission Performance Centre (MPC) team operationally monitors the STM data quality. This talk aims at presenting an overview of the Sentinel-3 A and B STM performances over inland waters.

The Sentinel Radar Altimeter (SRAL) sensors on-board Sentinel-3 missions differ from previous conventional pulse limited altimeters by providing observations within 300m along track bands using the Synthetic Aperture Radar Mode (SARM). The SARM measurements performances are assessed over a large set of lakes and rivers worldwide: statistical analyses between the two satellites data are performed as well as inter comparisons with the Jason-3 data over inland waters.

The S3 SRAL sensor also benefits from on-board enhanced Digital Elevation Model (DEM), tuned for inland water monitoring, allowing a precise Open Loop Tracking Command (OLTC) which is also an important asset to improve the precision of the measurements over inland waters. Comparisons of the Open Loop mode performances with respect to the conventional Close Loop (CL) mode will be shown, benefiting from data acquired during the tandem phase between Sentinel-3A and B when the altimeters recorded measurements over the same targets in the two different acquisition modes.

Performances of the two Sentinel-3 missions over the last cycles will be presented and compared to the previous ones. The global improvement of the products performance over land following the Sentinel-3 OLTC last updates will also be discussed.

## **Corresponding author:**

**Nicolas TABURET (CLS, France),** ntaburet@groupcls.com

# Sea ice thickness estimates impact temperature and heat flux estimates in the Arctic Ocean

James Carton (University of Maryland, United States); Gennady Chepurin (University of Maryland, United States)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_004

## **Abstract:**

Many environmental variables of interest are poorly constrained in the Arctic, including ice thickness, ocean temperature, and net surface heat flux. In addition to improving sea ice thickness estimates the recent development of altimeter freeboard techniques also offers the potential to improve ocean temperature and net surface heat flux. We begin discussing the energy budget of the Arctic Ocean/sea ice system, pointing out that the high thermal diffusivity of sea ice affects the amount of heat the Arctic Ocean receives (independent of its impact on albedo). Improving estimates of sea ice thickness within an ocean/sea ice reanalysis system alters the geographic and seasonal input and loss of heat from the ocean causing potentially large changes in upper ocean temperature estimates.

In the second part of the presentation we present a series of experiments carried out with a coupled ocean/sea ice model and a sequential data assimilation system, an example of which is shown in Fig. 1. The upper two panels present the ten year (1991-1999) mean (left) net surface heat flux and (right) 0/75m average temperature for a reanalysis forced by ERA-Interim surface variables (winds, downwelling radiation,  $T_a$ ,  $q_a$ , SLP, and precipitation). The righthand panel also has time mean ice thickness in black contours superimposed (solid contours show isolines of 1m and 2m thickness). All historical temperature and salinity observations are assimilated. The lower two panels present the ten year (1991-1999) mean (left) net surface heat flux and (right) 0/75m average temperature for a reanalysis experiment that only differs in that sea ice thickness is constrained (using an enthalpy-based assimilation algorithm) to match, in this example, the thicker PIOMAS analysis of Zhang et al. (2004). The increased thickness of the sea ice is evident by comparing the distribution of contours in the righthand panels.

Even though the only aspect of the reanalysis data that has changed is sea ice thickness, both net surface heat flux and upper ocean temperature are considerably altered. The changes to net surface heat flux are most evident in locations where the sea ice has gotten thicker such as the Chukchi Sea north of Bering Strait (compare lefthand panels). There the increase in ice thickness reduces net surface heat loss by more than  $30\text{Wm}^{-2}$  with much of this heat loss occurring in fall and early winter. On the Atlantic side of the Arctic increases in sea ice thickness reduce wintertime heat loss in the Nordic Seas. In some regions such as the Chukchi Sea these increases in sea ice cover lead, counter-intuitively, to lower ocean temperatures because of their effects on reduction in absorption of sunlight in summer (compare righthand panels).

## **Corresponding author:**

James Carton (University of Maryland, United States), carton@atmos.umd.edu

# Validation of Lake Water Level from altimetry with in-situ measurements.

**Beatriz CALMETTES (CLS, France);** Crétaux Jean-François (LEGOS, France); Vuglinsky Valery (Hidrolare, Russia); Zawadzki Lionel (CLS, France)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_005

## **Abstract:**

The validation of lake water levels with in-situ data, needs the installation of permanent instruments over a large period. By using the lake water level data generated by several in-situ databases from a long-term monitoring (from 1992 to present), we determined the accuracy of lake water level estimated in Hydroweb from a wide spectrum of mission such as T/P, ENVISAT, SARAL, Jason-1, Jason-2 and Jason3 and Sentinel-3A. Some of them as the Jason missions operate in a Low Resolution Mode (LRM) and Sentinel-3A in a Synthetic Aperture Radar (SAR) mode. In-situ data is evaluated by averaging data over multiple fixed stations on a monthly basis. Altimeter data is performed averaging data along the track when the satellite overpass the lake. For this study, three indicators were estimated: Bias, RMS and Pearson coefficient. For all lakes the Pearson coefficient is higher than 0.9. In some cases, the bias is high an suggest that, even if the precision is good, the accuracy of the LWL products should be considered carefully by users. The data from Hydroweb is also compared to dataset from other altimetric based datasets as G-Realm and Dahiti.

## **Corresponding author:**

**Beatriz CALMETTES (CLS, France),** bcalmettes@cls.fr

# Validation of the database of hydrology targets for DEM onboard altimeters (Jason3, Sentinel-3A and Sentinel-3B)

**Léa Lasson (Ocean Next, LEGOS, France);** Denis Blumstein (Centre National d'Etudes Spatiales, LEGOS, France); Sylvain Biancamaria (LEGOS, France); Jean-François Cretaux (Centre National d'Etudes Spatiales, LEGOS, France); Stéphane Calmant (LEGOS, France); Sophie Le Gac (Centre National d'Etudes Spatiales, France); François Boy (Centre National d'Etudes Spatiales, France); Nicolas Picot (Centre National d'Etudes Spatiales, France)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_006

## **Abstract:**

Initially designed to observe the oceans, the satellites radar altimetry are used now to measure river and lake water levels with large successes for the last 20 years. Despite this, it is well known that the altimeters have difficulties to track the surface of the water bodies especially in cases where the surrounding topography is rugged. To overcome this issue, recent radar altimeters can be operated in two tracking modes: the Close Loop mode (CL) and the Open Loop mode (OL). In OL mode the position of tracking window is not defined autonomously by the altimeter but is imposed by internal tables that are built from a database of Hydrology Targets (HT). This database provides position, approximate width and elevation of the water bodies. Many times the Open Loop mode has shown its benefits for inland water bodies, it now remains to enrich the database in order to still increase the amount of valid data.

A first validation on Jason3 was carried out on French rivers (around 100 targets) and has already shown good results. For 2 years now Jason3 had a new global dem with more than 4300 HT. During this time, many methods of validation have been developed or improved in order to automatically validate a large number of HT. Now, after 2 years of data with the update, we can validate the HT with these new tools.

Recently, the number of available HT has increased thanks to new automatic method of HT definition, especially for Sentinel-3A (33000 HT) and Sentinel-3B (32500 HT). We are very interested about Sentinel satellites for its complementarity with Jason, especially because Jason is limited at 66° of latitude while Sentinel can acquire data until latitude of 82°.

Therefore, all of the methods developed for the validation have been tested and validated for the first time on Sentinel 3B. Effectively, it was crucial to have an automatic method to validate this large number of Hydrology Targets. The process of validation is based on several criteria mainly based on two raw data produced by the altimeter: the Automatic Gain Control and the waveforms. These criteria have been defined to classify the overpasses for which the altimeter tracks a waterbody and those where it fails to do that.

We currently have a first encouraging result of validation for Sentinel-3B: 97 % of HT set has been classified as water by our process. This first validation was done this winter, so there was a risk of snow on waterbodies and that can skew the results. Consequently, we created a snow mask to reduce the number of HT that could be on snow, finally we have practically removed half of the targets for this first validation. That's why, it is crucial today to wait for the summer to renew validation on all HT.

In the poster, we will show the results of the validation obtained after the summer period which should be quite similar for Sentinel 3B and we will do the same validation process and show the results for Sentinel 3A and Jason 3 worldwide.

**Corresponding author:**

**Léa Lasson (Ocean Next, LEGOS, France)**, [lea.lasson@legos.obs-mip.fr](mailto:lea.lasson@legos.obs-mip.fr)

# A remotely-sensed/modeling approach to monitor the the hydro-climatology of the Ogooué River Basin

**Sakaros Bogning (LEGOS, France);** Frédéric Frappart (LEGOS, France); Adrien Paris (CLS, France); Fabien Blarel (LEGOS, France); Fernando Niño (LEGOS, France); Stéphane Saux-Picard (CNRM, France); Pauline Lanet (CNRM, France); Frédérique Seyler (ESPACE-DEV, France); Gil Mahé (IRD, France); Raphaël Onguéné (Université de Douala, Cameroun); Jean-Pierre Bricquet (IRD, France); Jacques Etame (Université de Douala, Cameroun); Marie-Claire Paiz (TNC, Gabon); Jean-Jacques Braun (GET, France)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_007

## **Abstract:**

Hydrological models are crucial tools for the simulation of hydrological storage and fluxes in large basins and complex river systems to compensate for reduction in watershed monitoring around the world in recent decades. In this study, the hydrological model of large basins (MGB) is used to evaluate the hydrological processes of the Ogooué River Basin (ORB), which has been mostly unmonitored for about three decades. Simulations were carried out over an 18-year period from 1998 to 2015 using TRMM 3B42 daily rainfall data from the Tropical Rainfall Measurement Mission (TRMM) as forcing and in situ and altimetry-based river discharges from ENVISAT, SARAL and Jason-2 for calibration and validation. The results of the model were in good agreement with the flows measured at stations upstream and downstream of the Ogooué basin (Nash-Sutcliffe Efficiency (NSE) > 0.56 for all calibration gauges). The MGB model efficiently describes the seasonal and interannual variations of the flow in the Ogooué River and its major tributaries which were found to be highly correlated to the rainfall (R ranging from 0.84 to 0.95 and 0.60 to 0.88 at seasonal and interannual time-scales respectively). Interannual variations of precipitation and therefore of river discharge of the ORB are linked to the El Niño Southern Oscillation (ENSO) in the tropical eastern Pacific Ocean and southeastern tropical Atlantic Niño. Also, the Ogooué river discharge was found to be strongly correlated with Sea Surface Temperature (SST) at annual and semi-annual time-scales.

**Corresponding author:**

**Sakros Bogning (LEGOS, France)**, [Sakros.bogning@legos.osb-mip.fr](mailto:Sakros.bogning@legos.osb-mip.fr)



# Assimilating SWOT virtual discharge and water levels into a large scale hydrological model

**Vanessa Pedinotti (Magellium, France); Rémi Jugier (Magellium, France); Michaël Ablain (Magellium, France); Marielle Gosset (GET, France); Cécile Dardel (GET, France); Sylvain Biancamaria (LEGOS, France); Nicolas Picot (CNES, France); Alice Andral (CNES, France); Sly Correa Wongchuig (Federal University of Rio Grande do Sul, Institute of Hydraulic Research, Brazil)**

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_008

## **Abstract:**

Modelling continental waters at global scale is a crucial issue for water resources management in a continuously changing climate. In this scope, satellite measurements provide relevant information, especially in regions where in situ measurements are not readily available. The future Surface Water and Ocean Topography (SWOT) satellite mission will deliver maps of water surface elevation (WSE), discharge and slope with an unprecedented resolution for rivers wider than 100 m and water surface areas above 250 x 250 m<sup>2</sup> over continental surfaces between 78°S and 78°N.

In this study, we investigate the potential contribution of SWOT observations to improve discharge forecasts from a hydrological modeling platform. To this aim, we use an ensemble Kalman filter (EnKF), which is a stochastic or Monte Carlo approach of the classic Extended Kalman Filter (EKF) to correct several state variables in a hydrological model (discharge, water level, soil humidity, water storage etc ...). The hydrological platform presented here handles all the consecutive tasks necessary for operational hydrology from forcing and observations retrieval to the launch of the large scale hydrological model over a specified period and domain. The model used is the semi-distributed rainfall-runoff "Modelo de Grandes Bacias" or "Large Basins Model" developed by the Brazilian Institute of Hydraulic Research (IPH). The study focuses on the Niger basin, a trans-boundary river, which is the main source of fresh water for all the riparian countries and where geopolitical issues restrict the exchange of hydrological data.

Since the SWOT observations are not available yet and also to assess the skills of the

assimilation method, the study is carried out in the framework of an Observing System

Simulation Experiment (OSSE). Here, we assume that modeling errors are only due to

uncertainties in precipitations. The control ensemble is built by integrating the model forced by an ensemble of perturbed fields of precipitations leading to an ensemble of simulated hydrological states. A member of this ensemble is then randomly chosen and used to create virtual SWOT observations of discharge and water levels over the period 2012-2017.

Several configurations are tested in which we vary the number of control variables, the characteristics of the modeling and observation errors and the number of observations used for the assimilation.

The impact of the assimilation method on the Niger River modeling is estimated using various statistical scores and shows good potential for the future satellite mission SWOT to improve hydrological forecasts at global scale.

**Corresponding author:**

**Vanessa Pedinotti (Magellium, France)**, [vanessa.pedinotti@magellium.fr](mailto:vanessa.pedinotti@magellium.fr)

# Parabola and horizontal line detection in inland water radargrams

Léa Lasson (Ocean Next, LEGOS, France); Denis Blumstein (Centre National d'Etudes Spatiales, LEGOS, France)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_009

## **Abstract:**

Since few years, recent altimetric missions allow us to get valid measurements over inland water. However, most measures remain difficult to analyze and several physical effects were observed, especially the hooking effect with LRM mode in Jason3 mission (e.g. Quartly, Tournadre, ... etc). Actually, this artifact appears when the altimeter continues to measure a reflective surface that it just flew over while it is no more located above this one. So, the height estimated at this location is smaller than it should and we can observe parabola in the height measurements. Therefore, the presence of parabola in height measurements is really significant of water detection and the detection of these parabola is quite important to deduce a real height estimation.

To detect these parabola in height measurements, the algorithm used is an adaptation of the Hough transform [2]. This method allows to detect objects with simple shape, like lines, circles, ..., in binary image. It is more used in medical imaging and remote sensing and has the great advantage of supporting incomplete or overlapping objects. The principle of the Hough transform is to build a parabola in a new plan (the plane of parameters) for each point of the initial parabola. So, there are as many parabola in the new plan as there are points in the initial plan. In this new plan, a large majority of parabola will cross into a single point which represents the parabola in the initial plan and therefore we can deduce from it the estimated height that we are looking for. It is also possible to detect multiple parabola representing many objects, or even half parabola generally representing river banks. The same principle allows to identify horizontal line that can represent extensive water areas, lakes, flood plains, wide rivers with two half parabola separated by an horizontal segment ... etc.

This algorithm detect today  $60 \pm 5$  % of cases with at least one parabola,  $70 \pm 14$  % with at least one horizontal line and  $87 \pm 28$  % with at least one object (parabola or horizontal line) among 1056 overpasses. The error is determined with visual analysis on 384 overpasses. Furthermore, a method has been developed to calculate an error estimation on the height and on the position found by the algorithm and we got 12.4 cm for the height and 112 m for the position.

Today, the process needs to be further improved, optimized, tested and validated, however it already allows us to have a first encouraging results, especially for parabola. The addition of the horizontal line detection is a real asset in the analysis of altimetry measurements. This process of parabola detection can also serve to analyze and validate OLTC results. It can also be used to create a new retracker or to improve the current retracker, to analyze the temporal series, the power evolution received along track, the radargrams ... etc. Actually, many projects could be developed around this algorithm of parabola and horizontal line detection.

## **Corresponding author:**

Léa Lasson (Ocean Next, LEGOS, France), lea.lasson@legos.obs-mip.fr

# Enhancing the Sea Ice Thickness and Freeboard Record With Combined Sentinel-3A, Sentinel-3B and CryoSat Observations.

**Isobel Lawrence (University College London, United Kingdom);** Michel Tsamados (University College London, United Kingdom); Stroeve Julianne (University College London, United Kingdom); Alan Muir (University College London, United Kingdom); Thomas Armitage (JPL, USA); Pierre Féménias (ESA, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_010

## **Abstract:**

Sentinel-3B was launched by the European Space Agency in April 2018, joining Sentinel-3A (launched February 2016) in a mission devoted to long-term operational measurements of global surface topography. The two-satellite constellation (from the Copernicus Programme) provides optimum global coverage and short revisit times (less than two days) at the equator. The Sentinel-3 satellites are equipped with SRAL, a dual-frequency Ku / C band SAR altimeter, allowing surface elevation retrievals up to 81.5° latitude. By measuring the elevation difference between the ocean surface in leads and sea ice floes, sea ice freeboard can be retrieved, and in turn sea ice thickness and volume can be calculated. ESA's CryoSat-2 satellite, which has been successfully providing sea ice thickness estimates since 2010, is now nearly 5 years beyond its planned mission duration. Provided sea ice thickness results from Sentinel-3 are shown to be consistent with CryoSat-2, the mission ensures the continuation of the Arctic sea ice thickness record (up to 81.5° latitude) for the next 7-12 years. Furthermore, consistency between measurements permits the combination of observations from the three satellites, offering an unprecedented opportunity for high temporal/spatial resolution observations of Arctic sea ice from radar altimetry.

Here, we show the current performance of the Sentinel-3 L2 products over sea ice from the S3 Mission Performance Centre analysis and demonstrate how further improvements in sea ice freeboard measurement can be achieved by optimised CPOM sea ice processing similar to that employed for CryoSat-2. We show that the optimised results are consistent across the period of overlap between CryoSat-2 and the Sentinel-3 satellites. Sentinel-3B is now operational in the same orbit as Sentinel-3A but with a phase difference of 140°. We quantify the increase in spatial and temporal resolution afforded by the combination of CryoSat-2, Sentinel-3A, and -3B and showcase some 10-day time series of Arctic sea ice thickness in the Beaufort and Greenland seas.

## **Corresponding author:**

**Isobel Lawrence (University College London, United Kingdom),** [isobel.lawrence.15@ucl.ac.uk](mailto:isobel.lawrence.15@ucl.ac.uk)

# Towards homogeneous multi-mission altimeter processing in sea ice regions for retrieving SLA and sea ice parameters

**Jean-Christophe Poisson (CLS, France)**; Fanny Piras (CLS, France); Maël Smessaert (CLS, France); Pierre Thibaut (CLS, France); Amandine Guillot (CNES, France); François Boy (CNES, France); Nicolas Picot (CNES, France); Jérôme Bouffard (ESA, Italy); Pierre Féménias (ESA, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_011

## **Abstract:**

For many years, radar altimeter measurements have been exploited in sea ice regions to retrieve the freeboard height from which the sea ice thickness is derived. Sea Ice regions are very complex for radar altimeters because different surface types (water, sea ice, etc ..) are mixed in the altimeter footprint. Each altimetry mission has its own instrumental characteristics (different radar techniques, different radar frequencies, etc...) and specific processing algorithms have been developed to extract and monitor sea ice extent, freeboard height and sea level of the ice-covered ocean.

When using empirical retracking approaches (which is the technique mostly employed up to now), sea ice processing must be adapted to each mission, which makes the combination of two or more satellites very complex and uncertain. In the frame of different CNES (PEACHI, AltiGlacio) and ESA projects (Sea Level CCI, CryoSeaNice, CS+ Antarctica), CLS has developed and validated new sea ice lead identification methods and new retracking algorithms based on a physical modelling of the signal whatever the altimeter mode (LRM / SAR) and frequency (Ku/Ka). Thanks to these innovative algorithms, we are now able to derive improved multi-mission sea ice extent, concentration, freeboard, lead concentration and sea level anomaly maps of better quality. In this talk, we propose to present this homogeneous approach and to focus on the main results and performances over sea ice regions.

## **Corresponding author:**

**Jean-Christophe Poisson (CLS, France)**, [jpoisson@cls.fr](mailto:jpoisson@cls.fr)

# Water level retrieval from Delay Doppler altimetry

Luciana Fenoglio (University of Bonn, Germany); Salvatore Dinardo (HeSpace, Darmstadt, Germany); Bernd Uebbing (University of Bonn, Germany); Jürgen Kusche (University of Bonn, Germany); Jérôme Benveniste (ESA-ESRIN, Germany)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_012

## **Abstract:**

River discharge is a key variable to quantify the water cycle, its flux and stocks at different scales. Water level from classical and Delay Doppler altimeter measurements allow the computation of river discharge, once additional information and/or assumptions are made. Radar altimetry will become an imaging sensor in the SWOT mission, which is expected to significantly improve the spatial mapping and provide directly water level, river width and surface slope.

It has been shown that CA altimetry monitors about 15% of the global lake volume variation and large rivers with the accuracy being increased with the development of new sensors and retracers. Root mean square errors (RMSE) range between a few cm and 70 cm today for large rivers, depending on the CA altimeter, lake area and shape, surroundings and retracking method.

In this paper, we revise these limits for Sentinel-3A data in the Rhine and Po European rivers, where simultaneous in-situ data are available for validations. The performances of standard products available within Copernicus (from OCOG and SAMOSA2 retracers) are evaluated and compared to the GPOD ESA products (from the SAMOSA+ retracker and from the new SAMOSA++ retracker).

The results show a good agreement with in situ measurements for the Rhine and Po rivers, of width about 300 meters, with a root-mean-square errors (RMSEs) between 0.10 m and 0.30 m. Results are a clear improvement with respect to standard Jason-3 data and to values obtained from CryoSat-2. The GPOD results are also superior to the Copernicus Sentinel-3A results at all stations. We conclude that the Delay Doppler altimetry mode on Sentinel-3A improves the estimation of river heights on medium size rivers, especially when enhanced retracers are applied. The new virtual gauges are further used to derive river discharge at these locations.

## **Corresponding author:**

Luciana Fenoglio (University of Bonn, Germany), fenoglio@geod.uni-bonn.de

# Are global models correctly estimating water storage in major river basins? A comparison of remote sensed river channel storage and global model data

**Steve Coss (Ohio State University Main Campus, United States)**; Augusto Getirana (NASA Goddard, USA);  
Mike Durand (Ohio State University, Byrd Polar and Climate Research Center, USA)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_013

## **Abstract:**

Observing the water cycle using Spaceborne remote sensing data is a focus across the scientific community. When considering components of the water cycle, surface water arguably has the largest impact on society. Properly accounting for variation in surface water storage (SWS) is essential for understanding the interplay between humanity and terrestrial water systems. Unfortunately SWS is a relatively small portion (~8%) of Terrestrial Water Storage (TWS). While TWS is somewhat well accounted for with GRACE measurements, SWS is difficult to distinguish. In the past SWS has been estimated in ways that ignore contributions from rivers, wetlands, floodplains and even lakes and reservoirs. Fortunately advances in land surface models have allowed for much better constrained estimations of SWS. However, model scaling and process binning (channel and flood plain storage) can create artifacts that may not be representative of actual SWS processes. The spatial representation of storage in highly active sections of river channels (those where complex hydraulic processes take place e.g., ice jams, or backflow at confluences), are particularly problematic. While the modeled representations of these rivers may balance at the basin scale, using their data to evaluate potential for biogeochemical processes may be inaccurate. Using a combination of multi-mission radar altimeter and visual band remote sensed data, it is possible to measure channel water storage (CWS) for comparison with modeled data. We present a comparison of measured CWS and modeled SWS for 26 of the world's largest rivers. Preliminary results show notable spatial variation in CWS 'hot spots' in 16 of the study basins. Modeled main stem river cell SWS climatological amplitude is between 33% -98% higher than measured CSC values from the channel only.

## **Corresponding author:**

**Steve Coss (Ohio State University Main Campus, United States)**, [coss.31@osu.edu](mailto:coss.31@osu.edu)

# The ICESat-2 Mission: Global Geolocated Photons, and Surface-Specific Data Products

**Thomas Neumann (NASA Goddard Space Flight Center, United States);** Nathan Kurtz (NASA Goddard Space Flight Center, USA); Anthony Martino (NASA Goddard Space Flight Center, United States); Lori Magruder (University of Texas at Austin, Applied Research Lab, USA)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_014

## **Abstract:**

The Ice, Cloud, and land Elevation Satellite – 2 (ICESat-2) observatory was launched on 15 September 2018 to measure ice sheet and glacier elevation change, sea ice freeboard, and enable the determination of the heights of Earth's forests. ICESat-2's orbit inclination allows the Advanced Topographic Laser Altimeter System (ATLAS) instrument to collect data between 88 degrees north latitude and 88 degrees south latitude from nominally 500km elevation above Earth's surface. ATLAS uses green (532 nm) laser light and single-photon sensitive detection to measure elevation along each of its six beams ten thousand times per second. In this presentation, we describe the major components of the observatory and the ATLAS instrument. We summarize the first year (!) of on orbit data collection and present the status of the observatory and the ATLAS instrument. We present on the status of the lower-level data products including the Level-2A data product (ATL03), which provides the geodetic location (i.e. the latitude, longitude and elevation) of the ground bounce point of photons detected by ATLAS. The ATL03 data product is the primary product used for higher-level (Level 3A) surface-specific data products such as glacier and ice sheet elevation (ATL06), sea ice elevation (ATL07) and freeboard (ATL10), land elevation and vegetation canopy height (ATL08), ocean surface topography (ATL12), and inland water body elevation (ATL13). This presentation will also present the plans for future data collection, the geolocation uncertainty of the ATL03 global geolocated photon data product, the status of data product availability, and plans for data reprocessing.

## **Corresponding author:**

**Thomas Neumann (NASA Goddard Space Flight Center, United States),** [thomas.neumann@nasa.gov](mailto:thomas.neumann@nasa.gov)



# NRT, open-licensed and high-frequency hydrological variables time series in Tropical Basins from operational satellite altimetry

**Adrien Paris (CLS, France)**; Stéphane Calmant (LEGOS, IFCWS, IISc, Bangalore, India); Johary Andriambelosom (Institut et Observatoire de Géophysique d'Antananarivo (IOGA), Université d'Antananarivo, Madagascar); Ayan Fleischmann (IPH-UFRGS, Porto Alegre, Brazil); Cecile Dardel (GET, Université de Toulouse, CNRS, IRD, UPS, Toulouse, France); Marielle Gosset (GET, Université de Toulouse, CNRS, IRD, UPS, Toulouse, France); Daniel Medeiros Moreira (CPRM, Rio de Janeiro, Brazil); Vinicius Siqueira (IPH-UFRGS, Porto Alegre, Brazil); Thiago Santos (RHASA-UEA, Manaus, Brazil); Sakaros Bogning (Département de Sciences de la Terre, Université de Douala, BP 24 157 Douala, Camerou); Taina Conchy (RHASA-UEA, Manaus, Brazil); Rodrigo Cauduro Dias de Paiva (IPH-UFRGS, Porto Alegre, Brazil); Walter Collischonn (IPH-UFRGS, Porto Alegre, Brazil); Joecila Santos da Silva (RHASA-UEA, Manaus, Brazil); Maxime Vayre (CLS, Ramonville St Agne, France)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_015

## **Abstract:**

A unique dataset of -Manning consistent- stage/discharge rating curves (RCs) was built at virtual stations (VSs) from the 27-day repeat cycle Sentinel3-A and 10-day repeat cycle Jason-3 missions. For this purpose, we used discharges simulated with the MGB hydrologic-hydrodynamic model and the satellite altimetry time series in several tropical and sub-tropical hydrological watersheds, including the Amazon and Maroni basins in South America and the Niger, Congo, Ogooue and Tsiribihina basins in Africa. The resulting RCs were used to get a priori information on the RC's parameters at the newly released Sentinel3-B VSs.

Thus, we get a dense framework of RCs, ranging from less than ten (for the Tsiribihina basin) to hundreds (for the Congo and Amazon basins) of VSs per basin. The RCs validation was threefold: 1) a systematic validation of the rated discharge against simulated discharge in overlapping time period; 2) a validation against in-situ discharge was performed when available; and 3) field works provided some precious comparison between estimated depths and/or rating curve parameter and ground truth. Whenever possible and physically acceptable, time series in the close vicinity of each other were merged in order to increase the frequency of revisit.

Thanks to the operational status of the COPERNICUS Sentinel3-A&B and NASA/CNES Jason3 satellites, users are ensured to benefit from new observations of water height, hence from new estimates of depth and discharge, during the all mission lifetime, i.e. at least 15 years. Discharge information will shortly be released on the Hydroweb website (<http://hydroweb.theia-land.fr/>) under the form of the RC coefficients to be applied to the water surface elevation time series.

## **Corresponding author:**

**Adrien Paris (CLS, France)**, [aparis@groupcls.com](mailto:aparis@groupcls.com)

# CryoSat-2 for enhanced sea-ice thickness and ocean observations in Antarctica

## CryoSat+ Antarctica

**Michel Tsamados (CPOM, Earth Sciences, UCL, United Kingdom);** Baker Steve (MSSL, UK); Shepherd Andrew (CPOM, University of Leeds, UK); Fleury Sara (LEGOS, France); Thibaut Pierre (CLS, France); Andersen Ole (DTU, Denmark); Roca Monica (isardSAT, Catalonia); Jérôme Bouffard (ESA, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_016

### **Abstract:**

Why has Antarctic sea ice experienced a small increase in extent over the past decades in stark contrast to the rapid decline observed in the Arctic? What role are the Southern Ocean and sea ice playing in controlling the Deep Water formation and thermohaline circulation and the melting of the Antarctic ice shelves and sea level rise? Only satellite remote sensing can provide the pan-Antarctic view required to fully understand these changes to the Southern Hemisphere's sea ice and ocean fields in response to anthropogenic warming.

Over the last 8 years CryoSat-2 (CS2) has allowed a radically new view of the ice covered Arctic Ocean, providing us with the first pan-Arctic sea ice thickness maps, dynamic topography and geostrophic currents, and indirectly a wealth of geophysical products ranging from Eddy kinetic energy (EKE), Ekman upwelling / downwelling, to snow on sea ice, and improved tidal models, or better resolved bathymetry at the bottom ocean.

In Antarctica similar products have emerged but remain at a lower level of maturity. Specific challenges in the processing of the radar signal result from the complex surface characteristics of the ice covered Southern Ocean such as the sea ice flooding from snow loading or the highly fragmented and divergent marginal ice zone like nature of the sea ice cover. In addition, validation of sea ice and ocean products is hindered by the observational gap of in-situ and airborne data in the Southern Hemisphere.

The overarching objective of this ESA funded multi-centre funded CryoSat+ Antarctica project is to address these issues by developing new approaches and algorithms that could be implemented in ESA's CryoSat-2 ground segment processor to produce state of the art sea ice and ocean products that will be validated against a comprehensive dataset of airborne and in-situ measurements and result in scientific progress for our understanding of the Antarctic Climate system and ocean circulation.

Our product development and validation will have two streams that will bring together the expertise of our wide consortium. First, comparison of various detection and retracking algorithms and processing chains will be performed along-track as the satellite's footprint advances from open ocean, through sea ice, leads and polynyas while it switches between the LRM, SAR, and SARIN acquisition modes. Second, gridded products from the different groups will be compared at a pan-Antarctic scale and against in-situ, airborne and other satellite. This inter-comparison exercise will result in recommendation for an optimal processor and provide an estimated mean and standard deviation for the geophysical parameters of interest (i.e. sea ice thickness, dynamic topography) while uncertainty of these products will be provided when observational ground truth is available.

The expertise of the individuals within the project consortium is a major asset of this project. UCL (now also Leeds University) originally developed and proposed the CryoSat-2 (CS2) mission concept and the CS2 Level-2 ground segment processors and have an independent capability for processing CS2 mission data since its launch in April 2010. All team members from CLS, DTU, LEGOS, iSAT, UL, MSSL and ES are actively involved

in research projects producing, validating or using sea ice thickness and sea level products from a wide variety of datasets. Together they provide a great breadth of knowledge and expertise that will be exploited during this project. The team has an established track record of publishing work on sea ice and polar oceanography in high profile scientific journals.

In this presentation we will give an overview of the latest results from our all our consortium partners on the CryoSat+ Antarctica ESA project.

**Corresponding author:**

**Michel Tsamados (CPOM, Earth Sciences, UCL, United Kingdom),** [m.tsamados@ucl.ac.uk](mailto:m.tsamados@ucl.ac.uk)

# Arctic Altimetric Sea Level Cross-Validation of IceSat-2, SARAL/AltiKa, Sentinel-3 and CryoSat-2

Carsten Ludwigsen (DTU, Denmark)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_017

## **Abstract:**

Determining sea level variation and trends in the Arctic is still in uncertain large areas. Contamination from sea-ice makes it impossible to have a full spatial and temporal data coverage. With launch of IceSat-2 (IS2) in October 2018, IS2 is the only second satellite after CryoSat-2 (CS2) to cover the entire Arctic area (up to 88N). Together with Sentinel-3A/B and SARAL, four different satellite altimetry systems are covering the Arctic.

The four data sources are complementary in the sense that IS2 is a photon-based product where as C2, Sentinel-3 and SARAL are radar altimeters employing different frequencies (Ka vs Ku band) and different technologies. SARAL is a conventional altimeter with a pulse radar frequency (PRF) of 4000 hz whereas Sentinel-3 and C2 have SAR altimeters (C2 with SARin in selected coastal regions incl Svalbard) with an efficient PRF close to 600 Hz.

In this presentation we can validate the SSH recovery in the northernmost Atlantic Ocean close to Svalbard, which is also a location of one of the few accessible Arctic Ocean tide gauge with an associated GPS receiver. It is a region where we have data from the first months of IS2, Sentinel-3 (SAR altimetry), C2 (SAR-In altimetry) and Saral/AltiKa (conventional LRM altimetry). We will also look at cross arctic data availability and looking into the sea level budget equation,  $SSH = Steric + Mass$ . A gridded steric product (DTUSteric) based on Arctic in-situ data is used together with latest released GRACE-FO Ocean Bottom Pressure (OBP) estimates.

## **Corresponding author:**

**Carsten Ludwigsen (DTU, Denmark)**, caanlu@space.dtu.dk

# G-REALM: Investigating the Jason-3 and Sentinel-3A Data Sets for the Next Phase of Operational Lake and Reservoir Monitoring

**Martina Ricko (KBR/NASA-GSFC, Greenbelt, MD, United States)**; Charon Birkett (ESSIC, University of Maryland, College Park, MD, USA); Xu Yang (KBR/NASA-GSFC, Greenbelt, MD, USA); Brian Beckley (KBR/NASA-GSFC, Greenbelt, MD, USA); Curt Reynolds (USDA/FAS, Washington, DC, USA); Elias Deeb (ERDC/USACE, Hanover, NH, USA)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_018

## **Abstract:**

G-REALM is a NASA/USDA funded operational program offering water-level products for lakes and reservoirs that are currently derived from the NASA/CNES TOPEX/Jason series of radar altimeters. The main stakeholder is the USDA/Foreign Agricultural Service, though many other end-users utilize the products for a variety of interdisciplinary science and operational programs. The products are additionally delivered to NASA PO.DAAC archive for the MEaSUREs Earth Science Data Records (ESDR) Program. There is an increasing demand for a more global monitoring service that in particular captures the variations in the smallest (1 to 100 km<sup>2</sup>) reservoirs and water holdings in arid and semi-arid regions. Here, water resources are critical to both agriculture and regional security. There is also a demand for surface water level products across wetland zones in respect of inland fisheries and assessments of catch potential.

Recent efforts to increase the number of monitored lakes, and to extend the TOPEX/Jason time series to achieve a 25yr observation set for Climate/Earth Record considerations, has shown that great care needs to be taken with respect to the merger of results from multiple instrument platforms, and with respect to the varying location of the satellite overpasses. Effort has also been focused on the creation of products from the Sentinel-3A mission, and on merging the results with the SARAL/ENVISAT/ERS archive. Noting here that all three missions, Jason-3, Sentinel-3A and Sentinel-3B will be utilized for the delivery of operational products for the USDA Decisions Support System.

The use of multiple radar altimeters for operational water level monitoring is also being applied in a parallel program called "Water Watch". Here, test case river reaches and wetland regions are additionally included for projects looking to natural hazards (flood monitoring) and wetland conservation.

## **Corresponding author:**

**Martina Ricko (KBR/NASA-GSFC, Greenbelt, MD, United States)**, mricko@sgt-inc.com

# A Robust Error Characterization Method for SAR Altimetry over the Inland Water Domain

**Martina Wenzl (ESA/ESRIN, Italy);** Marco Restano (SERCO c/o ESA/ESRIN, ITALY); Jérôme Benveniste (ESA/ESRIN, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_019

## **Abstract:**

The advent of SAR altimetry allowed the production of data with a high spatial resolution (300 m along-track). Investigations in the inland water domain clearly benefited from SAR data and future processing strategies (e.g. the fully-focused SAR, FF-SAR) are expected to improve further the quantity of data points over water bodies of a reduced size.

The proposed work aims at investigating the quality of Sentinel-3 water level retrievals over two targets of different characteristics: the Ohio River and the Great Salt Lake. Data are processed through the ESA G-POD SARvatore online and on-demand processing service for the exploitation of CryoSat-2 and Sentinel-3 data ([https://gpod.eo.esa.int/services/SENTINEL3\\_SAR/](https://gpod.eo.esa.int/services/SENTINEL3_SAR/)) and obtained by using the SAMOSA2, SAMOSA+ & SAMOSA++ retracers. The selected posting rate of measurements is 80Hz to optimize the number of data points over the Ohio River (80 m spatial resolution along-track). Empirical retracers outputs, available in the official 20-Hz Sentinel-3 LAN products, are also considered and water masks from (Pekel et al., 2016) are used to select data points acquired over water bodies.

The main goal of this study is to analyse the key parameters characterizing both the L1b SAR waveform and the retracking (e.g. the Pulse Peakiness, the Misfit...) to define a robust error characterization method that is expected to filter out an increased number of outliers. A validation exercise using in situ data will be presented to demonstrate that the proposed method leads to the definition of a reduced, highly reliable dataset, associated with a realistic error characterization model.

The study is expected to unlock possible synergies with SWOT and support the comparison of SAR estimates to FF-SAR estimates obtained at a comparable along-track resolution.

## **Corresponding author:**

**Martina Wenzl (ESA/ESRIN, Italy),** [Martina.Wenzl@esa.int](mailto:Martina.Wenzl@esa.int)

# SPICE: Sentinel-3 Performance Improvement for Ice Sheets

**McMillan Malcolm (Lancaster University, United Kingdom);** Roger Escola (isardSAT, UK); Jeremie Aublanc (CLS, France); Thibaut Pierre (CLS, France); Marco Restano (ESA, Italy); Americo Ambrozio (ESA, Italy); Jerome Benveniste (ESA, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_020

## **Abstract:**

For the past 25 years, polar-orbiting satellite radar altimeters have provided a valuable record of ice sheet elevation change and mass balance. One of the principle challenges associated with radar altimetry comes from the relatively large ground footprint of conventional pulse-limited radars, which reduces their capacity to make measurements in areas of complex topographic terrain. In recent years, progress has been made towards improving ground resolution, through the implementation of Synthetic Aperture Radar (SAR), or Delay-Doppler, techniques. In 2010, the launch of CryoSat-2 heralded the start of a new era of SAR Interferometric (SARIn) altimetry. However, because the satellite operated in SARIn and LRM mode over the ice sheets, many of the non-interferometric SAR altimeter processing techniques have been optimized for water and sea ice surfaces only. The launch of Sentinel-3, which provides full non-interferometric SAR coverage of the ice sheets, therefore presents the opportunity to further develop these SAR processing methodologies over ice sheets, for the purpose of scientific exploitation of this operational mission.

Here we present results from SPICE (Sentinel-3 Performance Improvement for Ice Sheets), a 2 year study that has focused on (1) developing Sentinel-3 SAR altimetry processing methodologies over the Polar ice sheets, and (2) investigating radar wave penetration through comparisons of Ku- and Ka-band satellite measurements. The project, which is funded by ESA's SEOM (Scientific Exploitation of Operational Missions) programme, has worked in advance of the operational phase of Sentinel-3, to emulate Sentinel-3 SAR and pseudo-LRM data from dedicated CryoSat-2 SAR acquisitions made at the Lake Vostok, Dome C and Spirit sites in East Antarctica, and from reprocessed SARIn data in Greenland. In Phase 1 of the project we have evaluated existing processing methodologies, and in Phase 2 we have investigated new evolutions to the L1b Delay-Doppler Processing and L2 retracking chains. In this presentation we focus on (1) the novel L2 processing developments used to improve retracking over complex topographic surfaces, such as those found across the margins of the Antarctic Ice Sheet, and (2) the impact of volume scattering on SAR retrievals, through a comparison of SAR waveforms to equivalent Ku- and Ka-band LRM acquisitions.

## **Corresponding author:**

**McMillan Malcolm (Lancaster University, United Kingdom),** [m.mcmillan@lancaster.ac.uk](mailto:m.mcmillan@lancaster.ac.uk)

# Sentinel-3 Hydrologic Altimetry Processor prototype (SHAPE): Project achievements

**Nicolas Bercher (ALONG-TRACK, France);** Pierre Fabry (ALONG-TRACK, France); Albert García-Mondéjar (isardSAT Ltd, UK); Joana Fernandes (University of Porto / Science Faculty, Portugal); David Gustafsson (SMHI, Sweden); Marco Restano (Serco/ESRIN, Italy); Américo Ambrózio (Deimos/ESRIN, Italy); Jérôme Benveniste (ESA/ESRIN, Italy)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_021

## **Abstract:**

The SHAPE project is part of SEOM, Scientific Exploitation of Operational Missions, an ESA program element which aims at expanding the international research community, strengthening the leadership of the European EO research community and addressing new scientific researches.

This Research and Development intends to make the best use of SAR (delay-Doppler) altimetry data for applications in hydrology. The study focuses on three main variables of interest: river water level (RWL), river discharge (RWD) and lake water level (LWL), RWD and LWL being part of the Terrestrial Essential Climate Variables (TECV) defined by GCOS.

The project embraces data processing from L1A altimetry products up to L2 (geophysical products), L3 (water level time series) and L4 (River discharge). It started with CryoSat-2 data (before the launch of Sentinel-3A) and is integrating Sentinel-3A as another input for the SHAPE processor.

The project has developed its own modular and configurable altimetric processor comprising a delay-Doppler processor (from L1A to L1b), a L2 processor including state-of-the-art geophysical corrections and new SARM retracers. On top of this, the SHAPE project also implements its own L3 processor (from L2 to RWL and LWL) and L4 processors (from RWL to RWD) and a validation and verification framework. With the confidence brought by the validation and verification steps, the project implements hydrological dynamic and semi-distributed models of river catchments able to assimilate RWL measurements in order to estimate RWD.

The high level of configuration of the processor allows to work in parallel on two different baselines. The first one is dedicated to mimic as much as possible the real Sentinel-3 baseline and the second a baseline optimised for hydrology, at all processing levels.

The project focuses on 3 rivers (Amazon, Danube and Brahmaputra) and 2 lakes (Vänern and Titicaca). Sentinel-3A L1A data is considered to be used on the Brahmaputra river while CryoSat-2 L1A data is used on the other water bodies.

In this communication, we report both on the achievements made by the project as well as providing results, we also report about its status and planning.

## **Corresponding author:**

**Nicolas Bercher (ALONG-TRACK, France),** [nbercher@along-track.com](mailto:nbercher@along-track.com)





# Quality Status of the CryoSat Data Products

**Erica Webb (Telespazio VEGA UK Ltd, United Kingdom);** Amanda Hall (Telespazio VEGA UK Ltd, UK); Ben Wright (Telespazio VEGA UK Ltd, UK); Marco Meloni (SERCO c/o ESA/ESRIN, Italy); Jerome Bouffard (ESA/ESRIN, Italy); Tommaso Parrinello (ESA/ESRIN, Italy); Steven Baker (UCL/MSSL, UK); David Brockley (UCL/MSSL, UK)

**Session:** Science IV: Altimetry for Cryosphere and Hydrology

**Presentation type:** Poster

**Poster number:** SC4\_022

## **Abstract:**

Launched in 2010, the European Space Agency's (ESA) polar-orbiting CryoSat satellite was specifically designed to measure changes in the thickness of polar sea ice and the elevation of the ice sheets and mountain glaciers. Beyond the primary mission objectives, CryoSat is also a valuable source of data for the oceanographic community and CryoSat's sophisticated SAR Interferometric Radar Altimeter can measure high-resolution geophysical parameters from the open ocean to the coast.

CryoSat data is processed operationally using two independent processing chains: Ice and Ocean. In order to ensure that the CryoSat products meet the highest data quality and performance standards, the CryoSat Instrument Processing Facilities (IPFs) are periodically updated. Processing algorithms are improved based on feedback and recommendations from Quality Control (QC) activities, Calibration and Validation campaigns, the CryoSat Expert Support Laboratory (ESL), and the Scientific Community.

Since May 2019, the CryoSat ice products are generated with Baseline-D, which represented a major processor upgrade and implemented several improvements, including the optimisation of freeboard computation in SARIn mode, improvements to sea ice and land ice retracking and the migration from Earth Explorer Format to NetCDF.

The CryoSat Ocean products are also generated in NetCDF, following a processor upgrade in November 2017 (Baseline-C). Improvements implemented in this new Baseline include the generation of ocean products for all data acquisition modes, therefore providing complete data coverage for ocean users. This upgrade also implemented innovative algorithms, refined existing ones and added new parameters and corrections to the products.

The CryoSat ice and ocean products are routinely monitored as part of QC activities by the ESA/ESRIN Sensor Performance, Products and Algorithms (SPPA) office with the support of the Instrument Data quality Evaluation and Analysis Service (IDEAS+) led by Telespazio VEGA UK. These new processor updates are expected to bring significant improvements to the quality of CryoSat ice and ocean products, in turn having a positive impact on the scientific exploitation of CryoSat measurements over all surface types.

This poster provides an overview of the CryoSat data quality status, covering all QC activities performed by the Telespazio VEGA UK led IDEAS+ consortium, as well as the evolutions and improvements implemented in the latest upgrades to the ice and ocean processors.

## **Corresponding author:**

**Erica Webb (Telespazio VEGA UK Ltd, United Kingdom),** [erica.webb@telespazio.com](mailto:erica.webb@telespazio.com)

