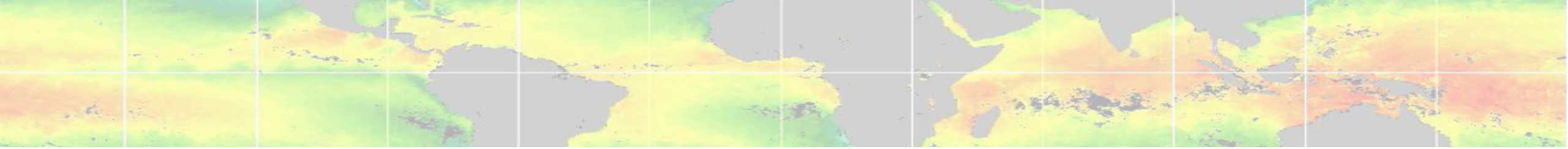

Using Ship-board Radiometers to Generate Climate Data Records of Satellite-Derived Sea-Surface Temperature

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Generating Climate Data Records of SST

- Sea-Surface Temperature is an Essential Climate Variable.
- A Climate Data Record requires long duration measurements with well defined accuracies.
- The requirements for SST CDRs are an accuracy of 0.1 K and a decadal stability of 0.04 K.*
- Satellite-derived SST provide global and consistent fields suitable for a CDR.
- To ensure long time series, data from multiple sources are required.
- Accuracy is assessed by comparison with independent surface measurements.
- Accuracy assessment has to involve an unbroken chain of calibration to SI references.

*Ohring, G., Wielicki, B., Spencer, R., Emery, B., & Datla, R. (2005). Satellite Instrument Calibration for Measuring Global Climate Change: Report of a Workshop. *Bulletin of the American Meteorological Society 86*, 1303-1313.

Validation by Comparison with Surface Measurements

Buoys

- Numerous, but not uniformly distributed in space or time.
- Long time series, starting in early 1980s.
- Subsurface measurement.
- Calibration issues.
- Not a comparison of like-with-like.

Radiometers

- Fewer, and not uniformly distributed in space or time.
- Began in mid-1990's.
- Skin SST measurement.
- Very good calibration, repeatable and traceable to SI-standards.
- Is a comparison of like-with-like.

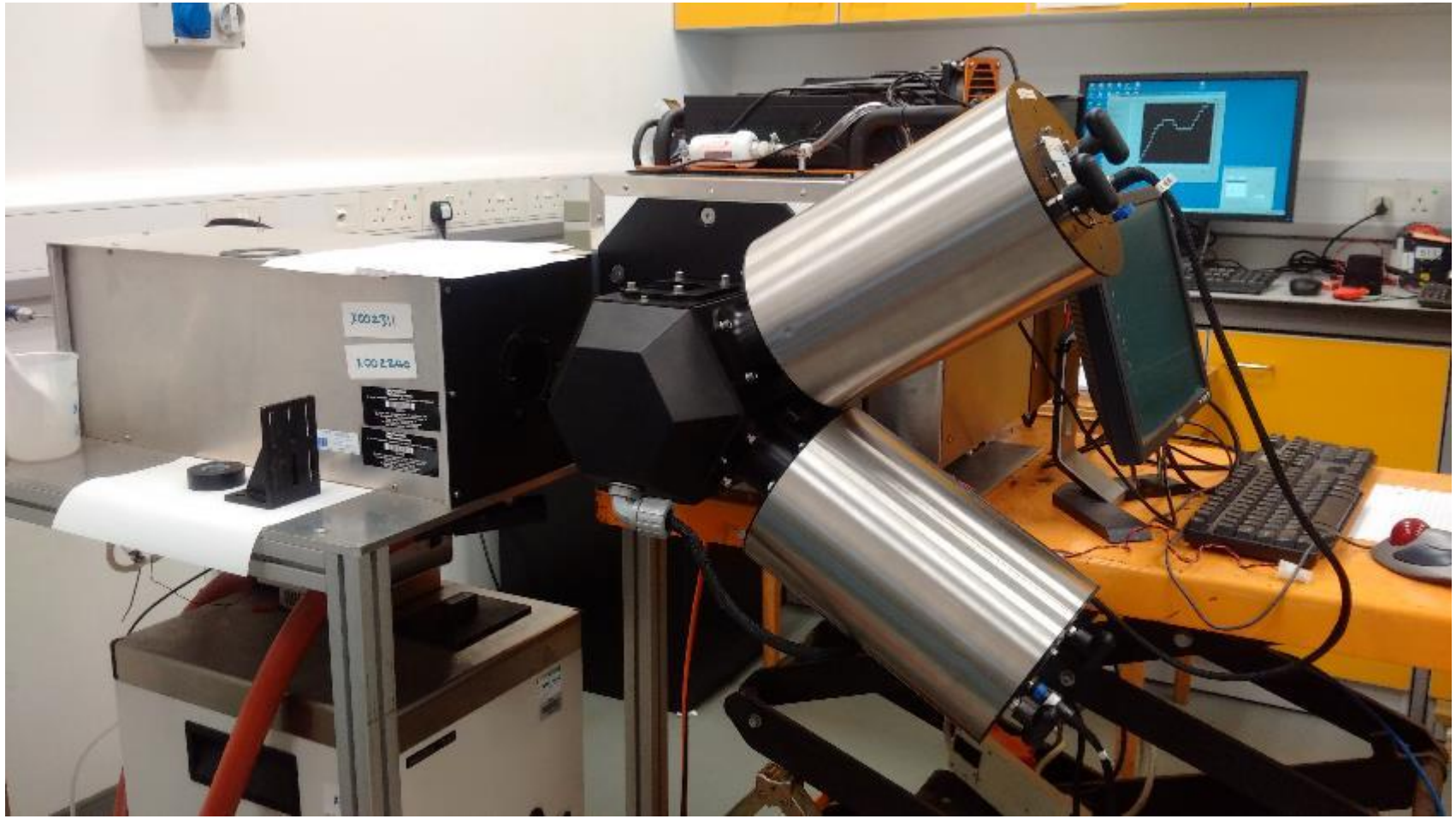
Best approach to use both, but here focus on radiometers.

Marine-Atmospheric Emitted Radiance Interferometer

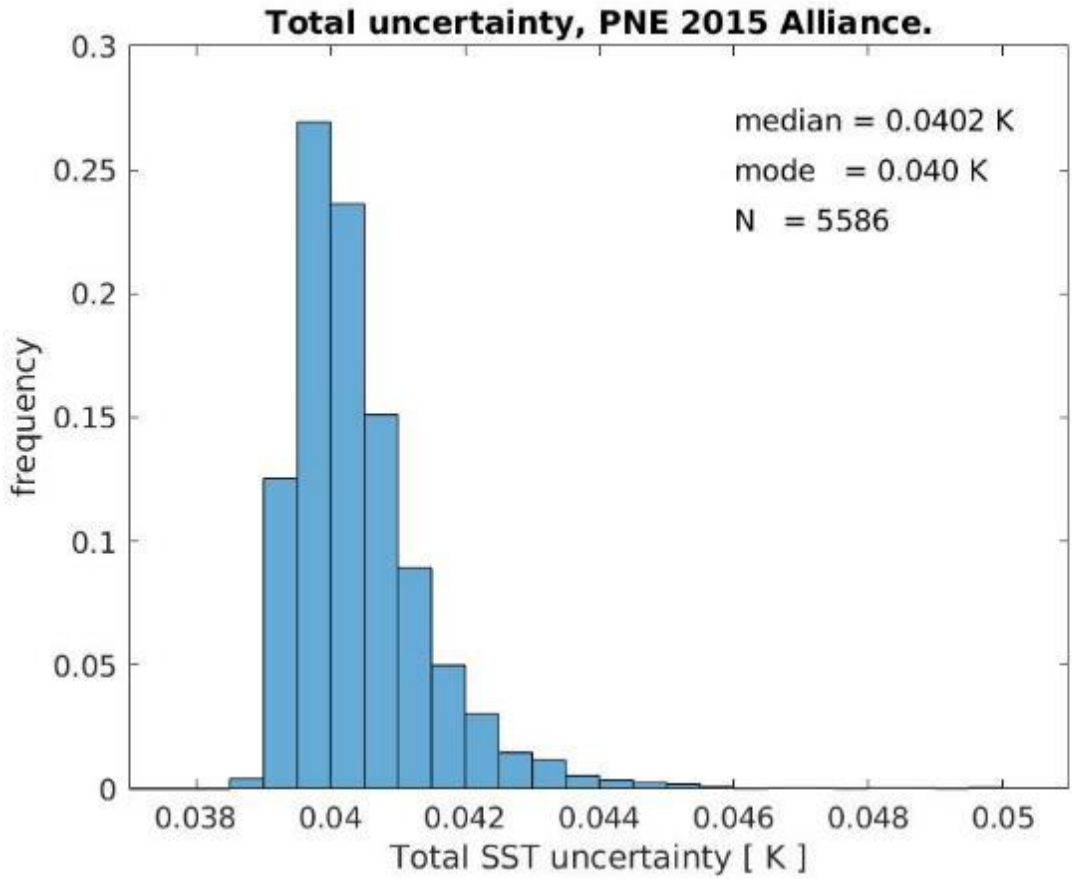
- M-AERI is a very well-calibrated and stable sea-going Fourier Transform Infrared Interferometer.
- At sea calibration by two internal blackbody cavities with thermometers with NIST-traceable calibration.
- Calibration sequence before and after each cycle of measurements.
- Calibration before and after deployments using NIST-designed water-bath blackbody calibration target at RSMAS. Uses SI-traceable thermometers with mK accuracy.
- Periodic radiometric characterization of RSMAS water-bath blackbody calibration target by NIST TXR and NPL AMBER.

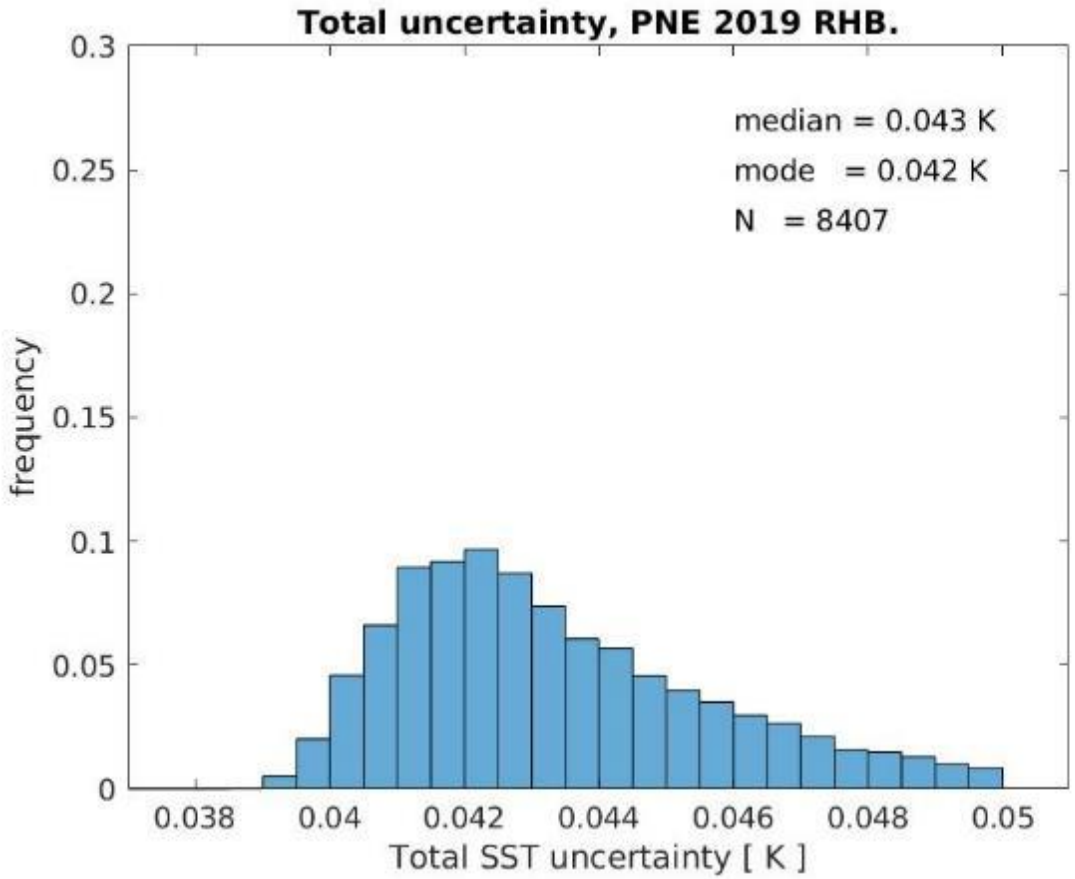
Fiducial Measurements for Surface Temperatures Workshop – NPL, June 2016.

Fiducial Measurements for Surface Temperatures Workshop – NPL, June 2016.



M-AERI SST_{skin} Accuracy



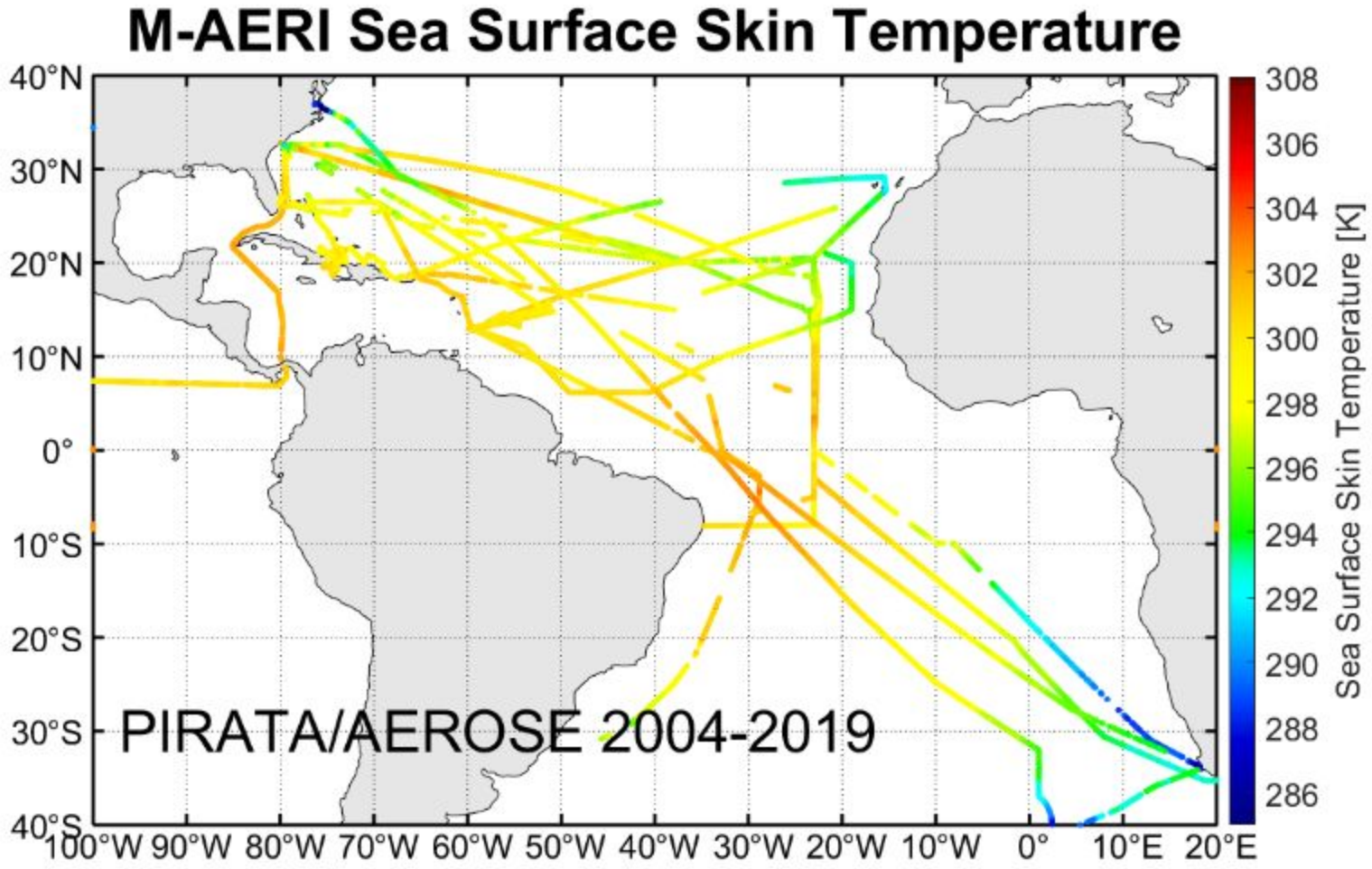


M-AERI deployments

- M-AERI deployments began in 1996.
- M-AERI Mk2 and Mk3 now operate autonomously, with monitoring over satellite internet link.
- Three Mk2 M-AERI's are usually deployed on Royal Caribbean International ships, but due to Covid-19, RCI ships are not sailing.
- One Mk3 deployed on research ships. Currently on the NOAA Ship *Ronald H Brown*.

M-AERI Mk 3 on NOAA Ship *Ronald H Brown*

M-AERI deployment on PNE – Tropical Atlantic area



Excluding RCI cruise ship data in Caribbean Sea and N. E. Atlantic Ocean.

MODIS SST_{skin} vs M-AERI SST_{skin}

PIRATA Cruise	Terra MODIS, SST Night			Aqua MODIS, SST		
	Median	Robust St. Dev.	N	Median	Robust St. Dev.	N
2004	-0.041	0.348	93	-0.155	0.401	101
2006	-0.545	0.789	16	1.041	1.155	10
2008	-0.208	0.189	11	0.023	0.521	6
2009	-1.180	0.387	33	-0.642	0.495	50
2011	-0.027	0.405	24	-0.230	0.407	47
2013	-0.130	0.389	179	-0.067	0.307	217
2015	-0.262	0.308	182	-0.140	0.340	169
Global	-0.091	0.446	19399	-0.066	0.412	18781

Temperatures in K

S-NPP SST_{skin} vs M-AERI SST_{skin}

Quality Level	Mean	Median	Standard Deviation	Robust Standard Deviation	Count
SST_{skin} day					
0	0.077	0.066	0.260	0.193	7380
1	-0.035	-0.020	0.427	0.316	5878
SST_{skin} night					
0	0.029	0.043	0.411	0.305	10074
1	-0.205	-0.192	0.643	0.477	4906
SST_{triple} night					
0	0.053	0.090	0.468	0.347	4359
1	-0.162	-0.117	0.633	0.470	3792

Temperatures in K

Global statistics for VIIRS SST_{skin} retrievals compared to SST_{skin} derived from M-AERIs.

Sentinel-3a SLSTR Comparison Statistics

Cruises	START	END	N	Mean	Med	STD	RMS	RSD
2017 Equinox	20170701	20171231	929	-0.274	-0.059	0.742	0.790	0.473
2017 Allure	20171002	20171126	205	-0.179	-0.023	0.780	0.799	0.313
2018 Equinox	20180111	20180415	532	-0.200	-0.106	0.691	0.719	0.326
2018 Leg1 Adventure	20180212	20180527	451	-0.116	-0.029	0.529	0.541	0.291
2018 Leg2 Adventure	20180601	20181231	1344	0.038	0.033	0.385	0.386	0.242
2018 RHB	20180307	20181023	921	-0.001	0.044	0.415	0.415	0.275
2019 RHB	20190224	20190329	394	-0.143	-0.050	0.471	0.492	0.326
Total	20170701	20190329	5216	-0.098	-0.008	0.565	0.574	0.296

Temperatures in K

M-AERI data in doi.org/10.17604/bswq-0119

CRUISES	AREA	START	END	DAYS OF DATA
2013 Knorr	Atlantic Ocean	2013-02-13	2013-02-28	16
2013 RHB	North Atlantic Ocean	2013-11-11	2013-12-08	27
2014 Equinox	Caribbean Sea	2014-05-09	2014-06-20	42
2014 Allure	Caribbean Sea	2014-08-24	2014-12-31	130
2014 Equinox	Caribbean Sea	2014-11-16	2014-12-31	46
2015 Allure	Caribbean Sea, North Atlantic Ocean, and Mediterranean Sea	2015-01-01	2015-11-29	360
2015 Equinox	Caribbean Sea	2015-01-01	2015-12-26	360
2015 Minerva Uno	Mediterranean Sea	2015-03-27	2015-04-13	17
2015 Alliance	North Atlantic Ocean	2015-11-17	2015-12-14	28
2016 Equinox	Caribbean Sea, North Atlantic Ocean, and Mediterranean Sea	2016-01-02	2016-12-31	365
2016 RHB	Pacific	2016-11-07	2017-03-19	132
2017 Equinox	Caribbean Sea	2017-01-01	2017-12-31	365
2017 Allure	Caribbean Sea	2017-10-02	2017-11-26	56
2017 Minerva Uno	Mediterranean Sea	2017-05-25	2017-06-11	17
2018 Equinox	Caribbean Sea	2018-01-11	2018-09-23	255
2018 Adventure	Caribbean Sea and US East Coast	2018-02-12	2018-12-31	322
2018 Allure	Caribbean Sea	2018-02-18	2018-10-14	238
2018 RHB	Global	2018-03-07	2018-10-23	231
2019 Adventure	Caribbean Sea and US East Coast	2019-01-01	2019-10-30	302
2019 RHB PNE	North Atlantic Ocean	2019-02-24	2019-03-29	34
2019 RHB 2019 RHB UNOLS	US East Coast	2019-05-07	2019-05-31	24
2019 RHB JASON	US East Coast	2019-04-08	2019-04-30	22
2020 RHB Leg 1	Caribbean Sea	2020-01-06	2020-02-13	38
2020 RHB Leg 2	Caribbean Sea and Atlantic Ocean	2020-02-21	2020-04-17	57
Total	--	2013-02-13	2020-04-17	3484

Allure: RCI Ship Allure of the Seas.
Equinox: RCI Ship Celebrity Equinox.
Adventure: RCI Ship Adventure of the Seas.
RHB: NOAA Ship Ronald H. Brown.
Knorr: Woods Hole Oceanographic Institution R/V Knorr
JASON: NOAA ROV Jason team onboard Ship Ronald H. Brown.
Minerva Uno: Italy R/V Minerva Uno.
Alliance: North Atlantic Treaty Organization (NATO) R/V Alliance.
PNE: PIRATA (Prediction and Research Moored Array in the Tropical Atlantic) -North East extension moorings
UNOLS: University-National Oceanographic Laboratory System

Summary

- The M-AERIs are robust and maintain their calibration during at-sea deployment over many months.
- The M-AERIs run autonomously, with ~daily checks on their wellbeing over ships' internet.
- M-AERI data, including those from the PIRATA cruises, form the basis of a CDR of SST.
- PIRATA cruise data are especially valuable given occurrence of Saharan Air Layers and dust aerosols. See presentation and poster by Bingkun Luo.
- Deployment on the *Ronald H Brown* has resumed; deployments on RCI ships will resume eventually.
- Data available from doi.org/10.17604/bswq-0119.
- M-AERI data are fundamental to many scientific investigations.

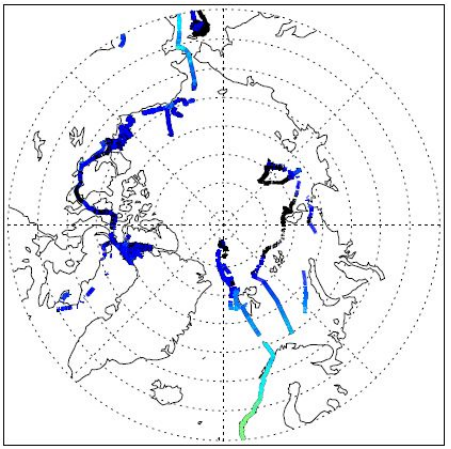
Acknowledgements

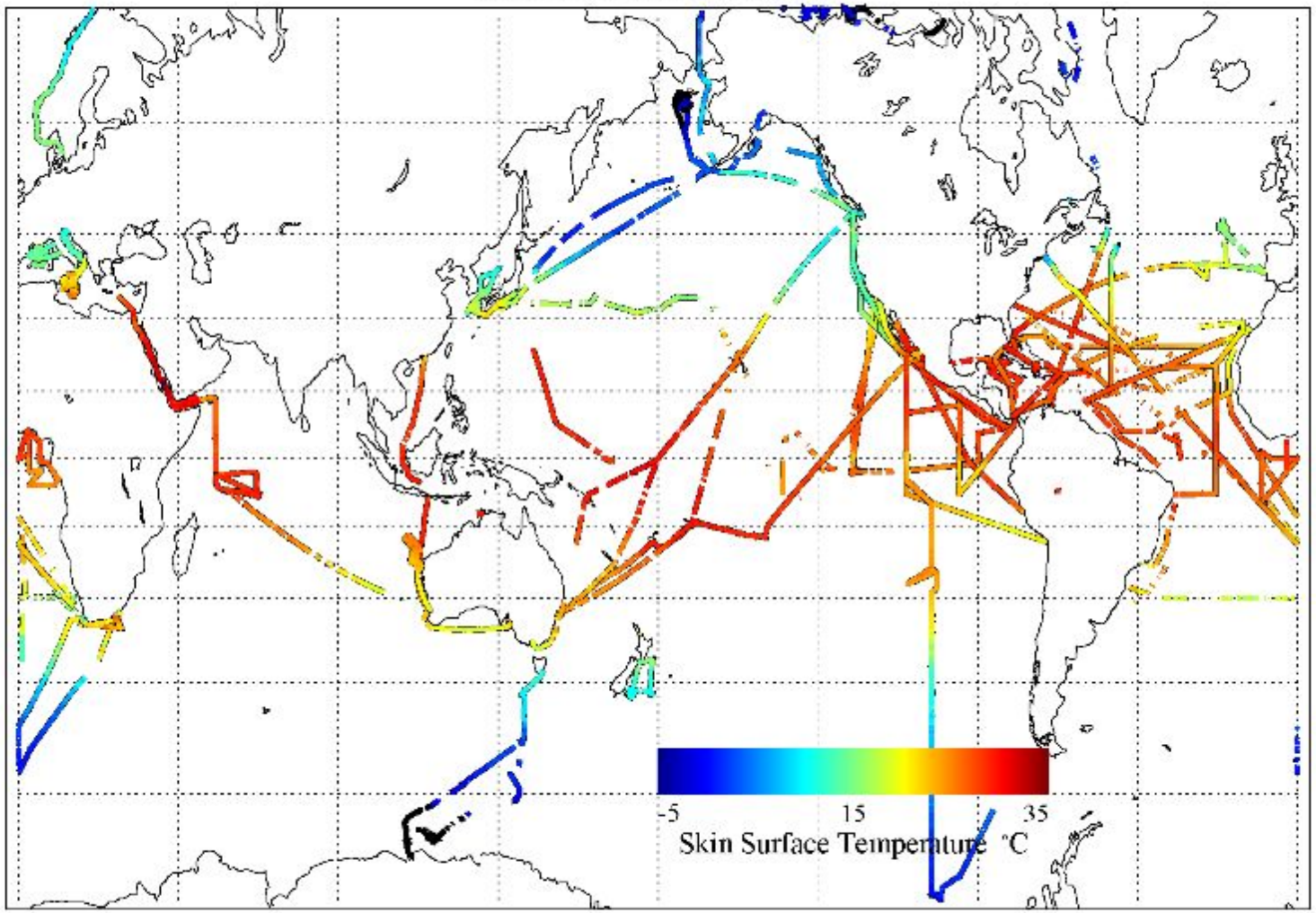
- Captains, officers and crew of NOAA Ship Ronald H. Brown, and other ships.
- Support from RCI.
- Funding from NASA Physical Oceanography, MODIS project, Participating Investigator Program.

- Thank you for your attention.

Reserve slides

M-AERI Cruises





Explorer of the Seas

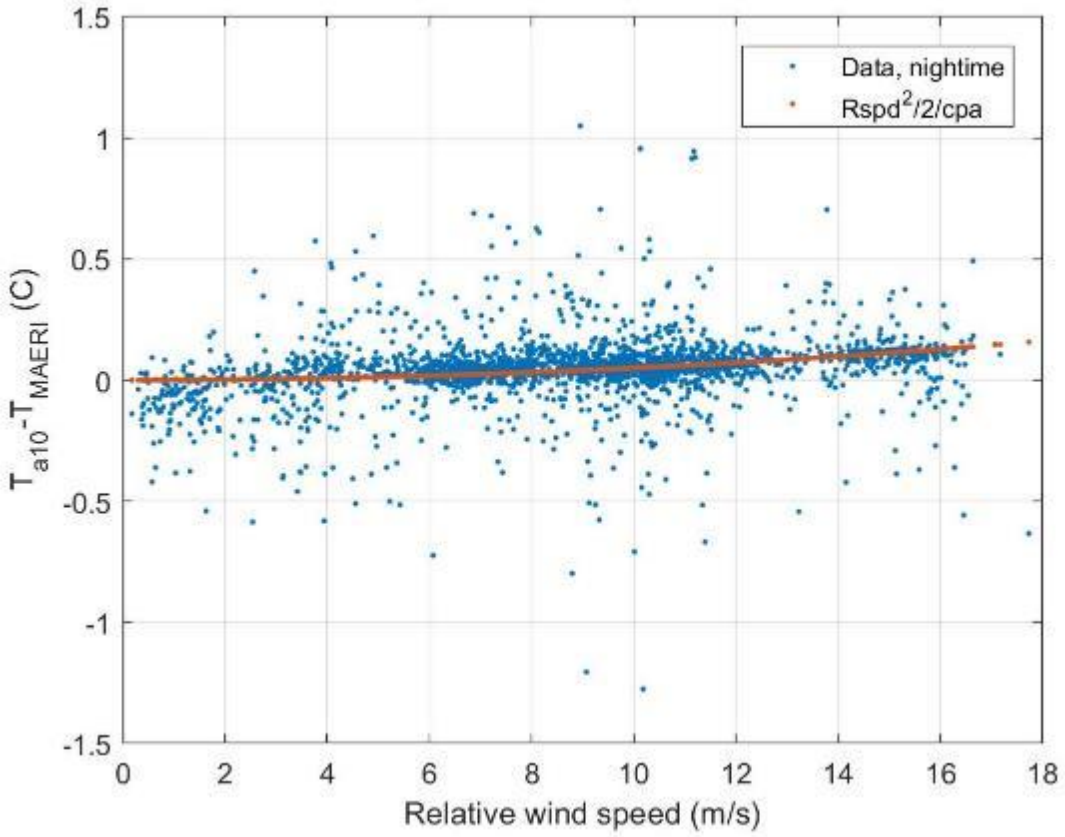
Explorer of the Seas: near continuous operation December 2000 – December 2007.

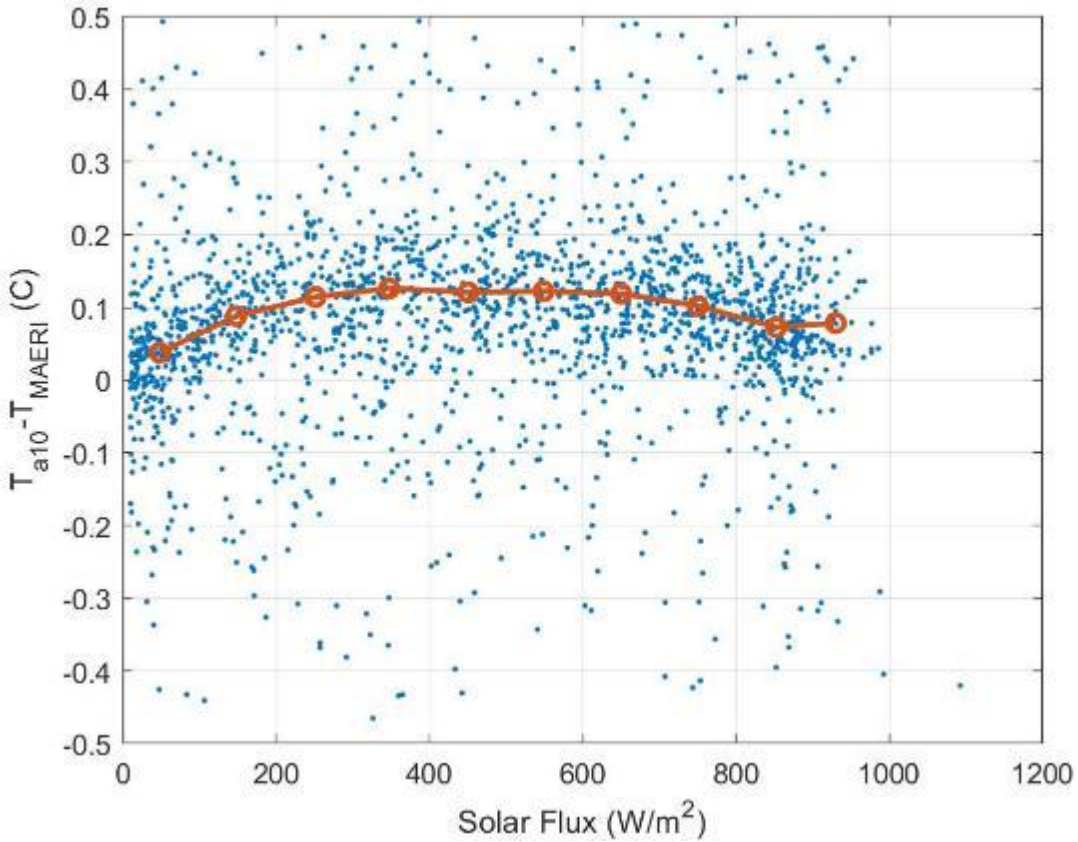
M-AERI accuracies - T_{air}

- An estimate of the near-surface air temperature can be made from the measured spectra of the atmospheric CO_2 emission where the photon e-folding path length is ~7m.
- Comparisons between M-AERI radiometric and research grade conventional measurements on recent ATOMIC (Atlantic Tradewind Ocean-Atmosphere Mesoscale Interaction Campaign) cruise on the RHB are very interesting.

Minnett, P.J., Maillet, K.A., Hanafin, J.A., & Osborne, B.J. (2005). Infrared interferometric measurements of the near surface air temperature over the oceans. *Journal of Atmospheric and Oceanic Technology 22*, 1016-1029.

ATOMIC T_{air} Comparison





Analysis and figures from Chris Fairall, NOAA ESRL