Emerging Capabilities toward Decadal Prediction - NASA

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Motivation/Interest for Decadal Prediction/Projection at NASA

NASA has no direct mandate to provide forecasts on any time scale to the nation; however, NASA has interests in maintaining state of the art forecasting systems.

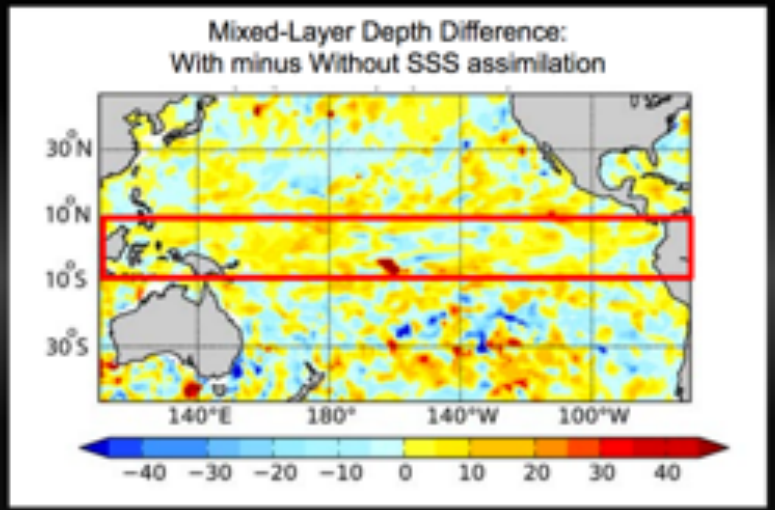
NASA's modeling efforts are "observation driven", ie., the direction of the modeling/assimilation work is guided by available and anticipated observations and its goal is to extract from the observations as much value as possible.

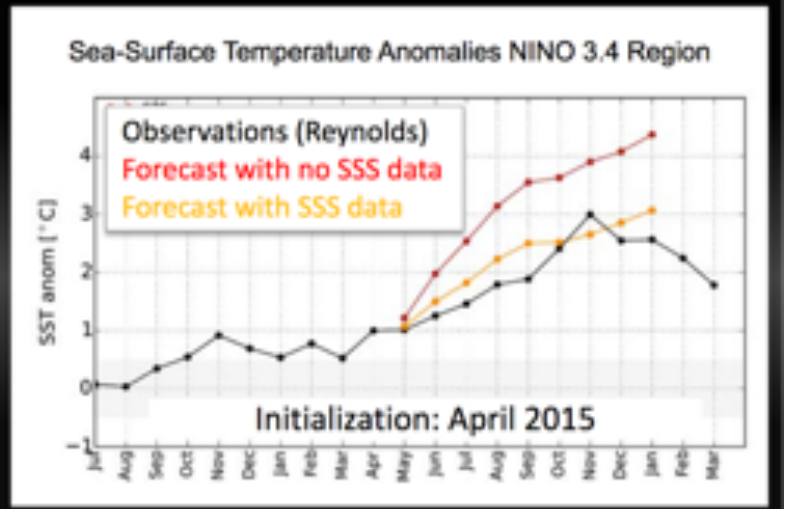
In particular, this means that NASA is interested in determining the impact of current and planned NASA (and other satellite) observations on prediction skill.

Impact of observations on weather and seasonal forecasts has been clearly demonstrated. At seasonal scales, for instance, the impact of altimetry and surface salinity on ENSO forecast skill has been shown.

Example: impact of assimilating surface salinity on ENSO forecast skill

Beneficial Impact on ENSO Predictions of Assimilating Satellite Sea Surface Salinity Observations in GEOS S2S





LEFT: Differences in oceanic mixed-layer depth in the GEOS analyses with minus without assimilation of the Aquarius and SMAP SSS observations. **RIGHT:** NINO3.4 ensemble forecast plume average plots initialized from the April 2015 experiment that assimilates all available satellite SSS (gold line) versus no SSS assimilation (red line). The validating SST anomalies are in black.

From: Eric Hackert

Motivation/Interest for Decadal Prediction/Projection at NASA

The impacts of present and future observations on decadal prediction skill has not yet been demonstrated. NASA's modeling and assimilation capabilities will be extended to assess these impacts.

Observations with potential impact on decadal prediction:

- **Mass balance information, ie., GRACE and GRACE-FO**
- **Altimetry (long record has been used to show decadal variability)**

Potential future observations needed/to be assessed for improving decadal prediction

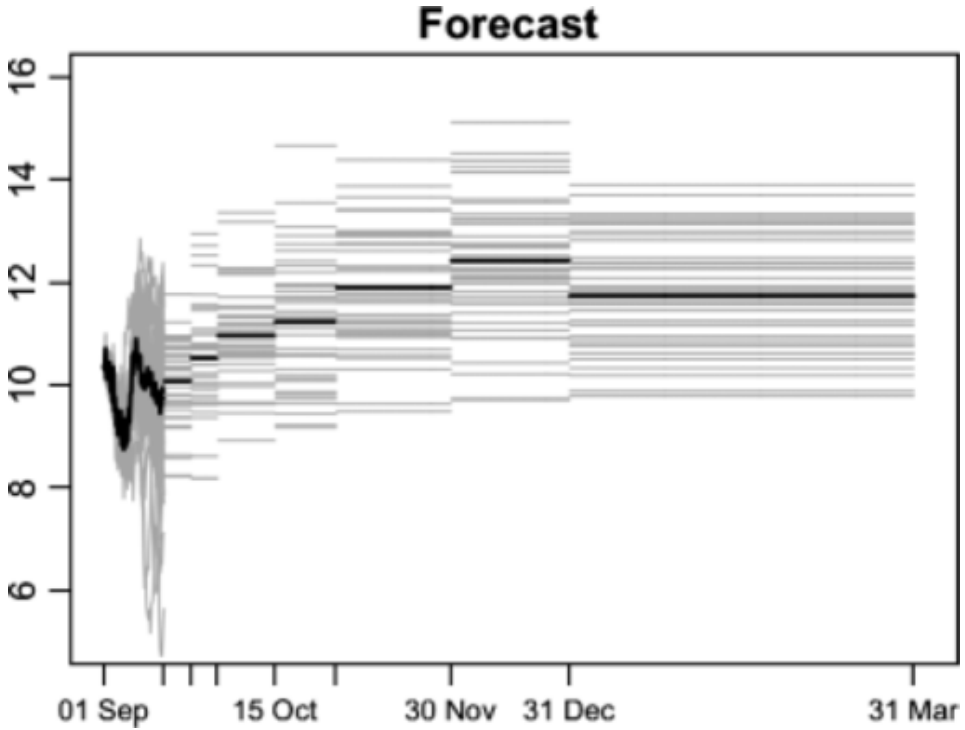
- **Sea ice thickness**
- **Permafrost**
- **Soil Moisture**
- **Methane**
- **Deep ARGO**

Sources of Decadal Predictability – Motivation for Strategy

- Response to a big event that impacts forcing: eg., volcanic eruption. The signal in the stratosphere remains for years and may impact ENSO (Pinatubo)
- Longer time scale memory in the ocean: Ventilation time scales at depths below ~500 m in some ocean basins are longer than 10 years.
- Long term variability: Phase of PDO, for example
- Longer time scale memory in the land/carbon cycle
- Climate time scale trends (eg., sea level)

Model/Data Assimilation/Initialization strategy must account for/take advantage of the sources of predictability

Sources of Decadal Predictability – Motivation for Strategy



Troccoli, 2010

The longer the lead time, the longer the period of time average needed. This increases the signal to noise ratio enough to obtain reliable forecasts.

Not clear what is required at longer lead times

Experience at NASA Relevant to Decadal Prediction

GMAO - Numerical Weather Prediction and Sub/Seasonal Prediction:

- Near-real time production systems for NWP and Seasonal Prediction have been running since ~1998
- Sub/Seasonal prediction products have contributed to multi-model comparisons

GMAO - Decadal Prediction

- Submitted the suite of decadal forecasts to CMIP5 (with S2S Version 1 - Version 2 in near real-time production since 2017, Version 3 to be released this summer)
- Near term: Version 3 system retrospective forecasts will be extended to 10-30 years to assess skill of decadal projections

GISS - Climate projection:

- Participated in all the CMIP projects and results were part of IPCC reports

JPL – Ocean State Estimation:

- ECCO (latest is v4) ocean climate estimate(s) for 1992-2015

Current Activities: NASA GMAO uses coupled Earth-System models and analyses, in conjunction with satellite and *in situ* observations, to study and predict phenomena that evolve on seasonal to decadal timescales. A central motivation for NASA and GMAO is the innovative use of NASA satellite data to improve forecast skill

- **Atmosphere/Ocean Coupled Model Development**
- **Ocean Analysis Development**
- **Development of Initialization Strategy for ensembles of Sub/Seasonal Forecasts**
- **Coupled Assimilation Strategy Development**

- **Production of Coupled Data Assimilation (Re)Analysis**
- **Production of Sub/Seasonal Forecasts**
- **Dissemination of Sub/Seasonal Forecasts**

- **Validation/Assessment of Forecast Fidelity and Assimilated Ocean State**

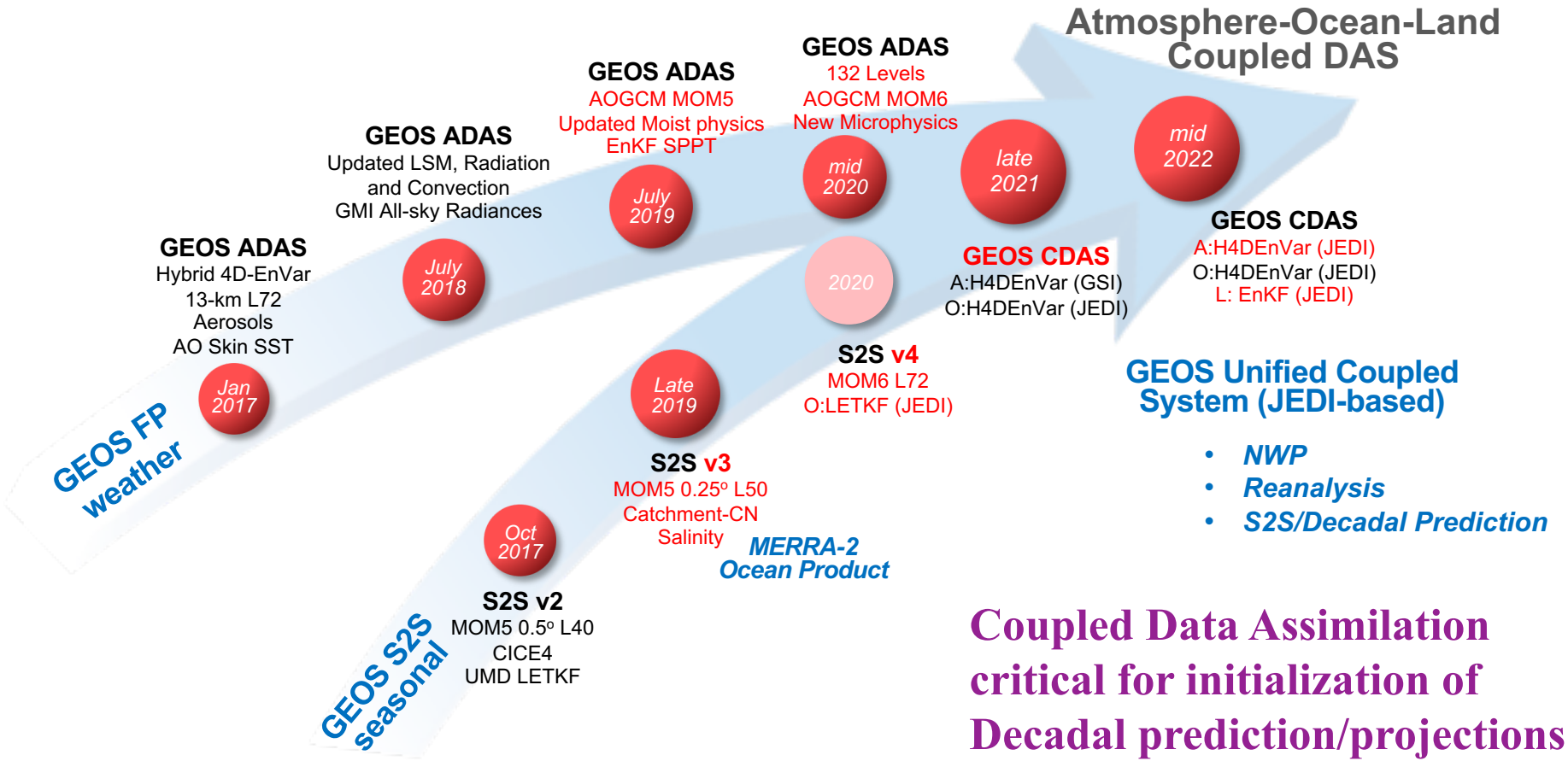
- **Predictability Studies**

Current Community Seasonal Prediction System Characteristics

Model	Atm Horiz	Atm-Vert	Oc-Horiz	Oc-Vert	# Ensembles
ECMWF	~36 km	91	~25 km	75	50
Navy*	~37 km	60	~25 km (9 Eq)	41	60
UK Met Office	~50 km	85	~25 km	75	40
GMAO	~50 km	72	~25 km	50	30/10
GFDL-FLOR	~50 km	32	~100 km (30 Eq)	50	24
MeteoFrance	~75 km	91	~100 km	42	50
CFSv2	~100 km	64	~50 km (25 Eq)	40	24
NCAR	~100 km	26	~100 km (25 Eq)	60	10
JMA	~110 km	60	~100 km (50 Eq)		
GFDL CM2.1	~200 km	24	~100 km (30 Eq)	50	10
CMC1	~200 km	31	~90 km	40	10
CMC2	~200 km	35	~90 km	40	10

* Run for single season only, soon to be in production

GMAO recent/planned coupled modeling and data assimilation



Coupled Data Assimilation critical for initialization of Decadal prediction/projections

GEOS-ECCO - New Modeling Tool for Decadal Prediction

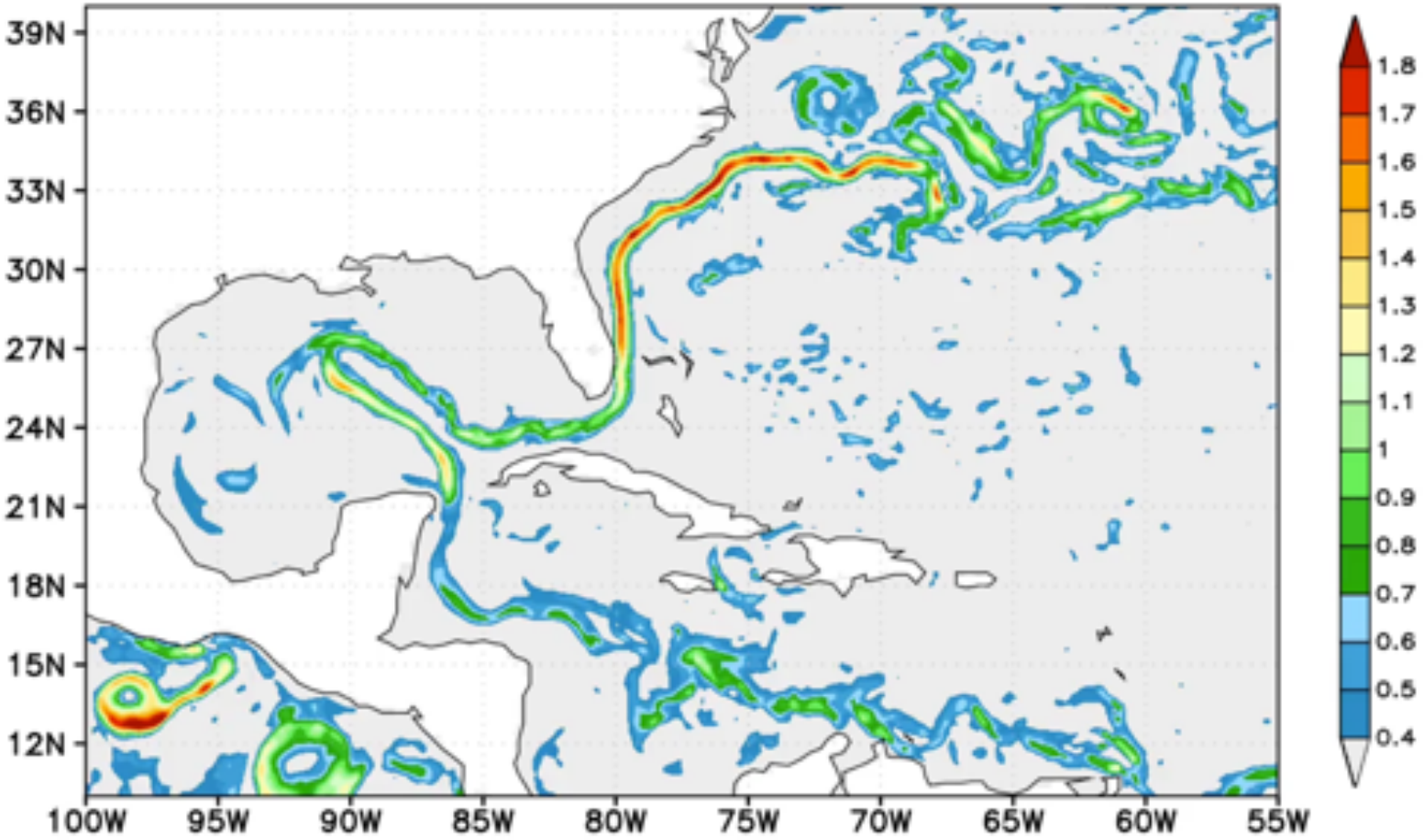
GSFC-JPL-MIT-U. Texas MAP funded project: "Recent sea ice and ice sheet changes and their relation to the coupled ocean-atmosphere system" includes as its core development goals:

- **Couple the models underlying the MERRA-2 atmospheric reanalysis (GEOS) and the ECCO-v4 ocean state estimate (MITgcm)**
- **Develop a prototype ocean-ice-atmosphere coupled data assimilation system by exploiting and leveraging GEOS 4D Hybrid En-Var atmosphere and MITgcm 4D-Var ocean data assimilation capabilities**

Advantages for decadal prediction:

- **4D-Var ocean data assimilation with long data window. The entire 20-year model trajectory is adjusted simultaneously. Potential to capture the longer time scale for better initialization of decadal forecasts**
- **Configurations with high vertical resolution of MITgcm. Potential for better resolution at ocean depths below available observations**

GEOS-MITgcm 1-year simulation, ~12 km atmosphere, ~10 km ocean



GMAO Plans for Decadal Prediction

Based on emerging capabilities GMAO will explore:

Coupled data assimilation (weakly) with:

- **Version 3 S2S system**
- **GEOS-ECCO using a sliding long data window**

to initialize a DCPP-like suite of decadal predictions

Note: The timeline for these plans will depend in part on competed funding

Potential for Declining Capabilities to be Avoided

Recall the clear demonstration of the impact of assimilating satellite surface salinity for seasonal prediction skill. There is a similar case to be made for soil moisture assimilation. The record is from SMOS, Aquarius, SMAP.

BUT - Is there a Follow on to surface salinity/soil moisture from satellites? NASA has no concrete plan, perhaps the French have some plans….