Impacts of NASA's Earth Observations on Subseasonal and Seasonal Forecasts

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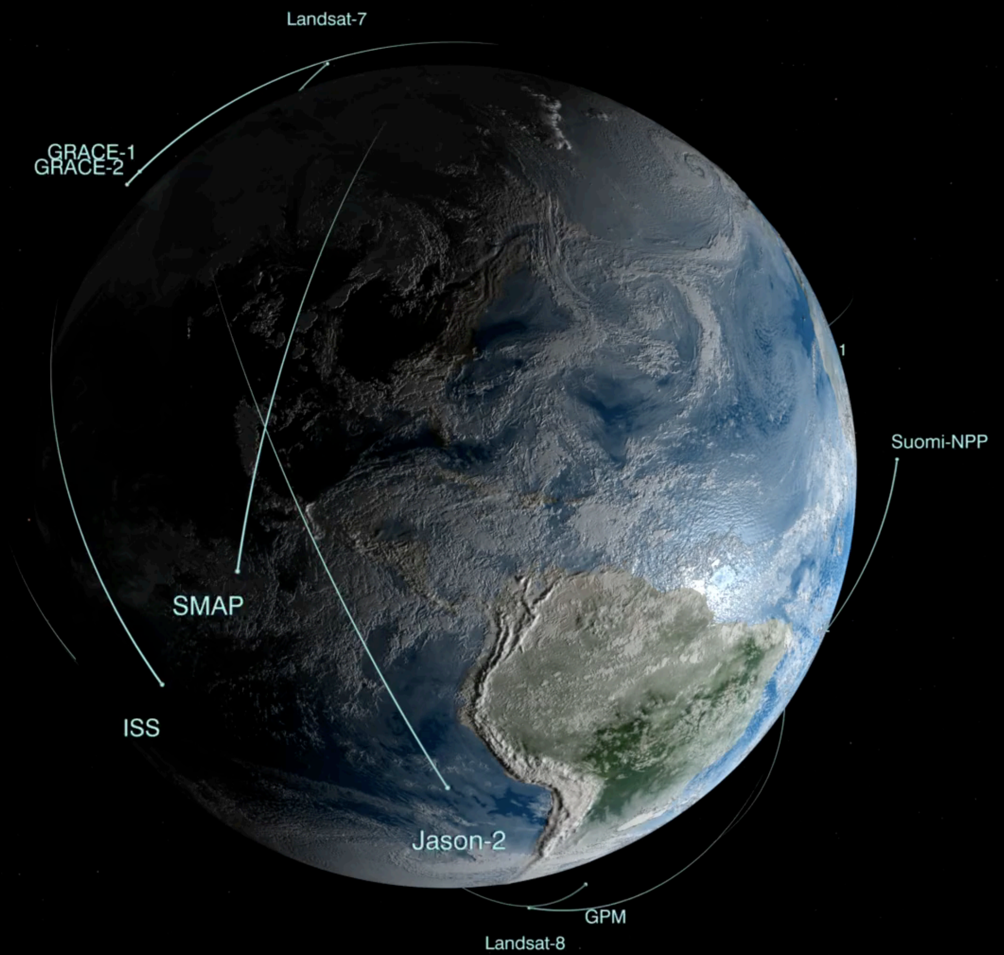
It's not wrong to wish on space hardware – I wish, I wish, I wish you'd care
(apologies to Billy Bragg)

Overall Objectives

- Explain NASA's engagement in the sub-seasonal to seasonal forecasting project – expanding on space-based data assets
- Describe NASA GMAO's GEOS modeling and assimilation system, especially the current GEOS S2S incarnation
- Discuss the model-observation linkages through some examples of research studies
- Mention some limitations of present practices in forecasting to timescales beyond "weather"
- Point to future directions in coupled reanalysis and prediction on timescales of days to seasons

What is the potential value of NASA's unique space-based observations for Earth System prediction on timescales spanning days to months?

NASA's Fleet of Satellites

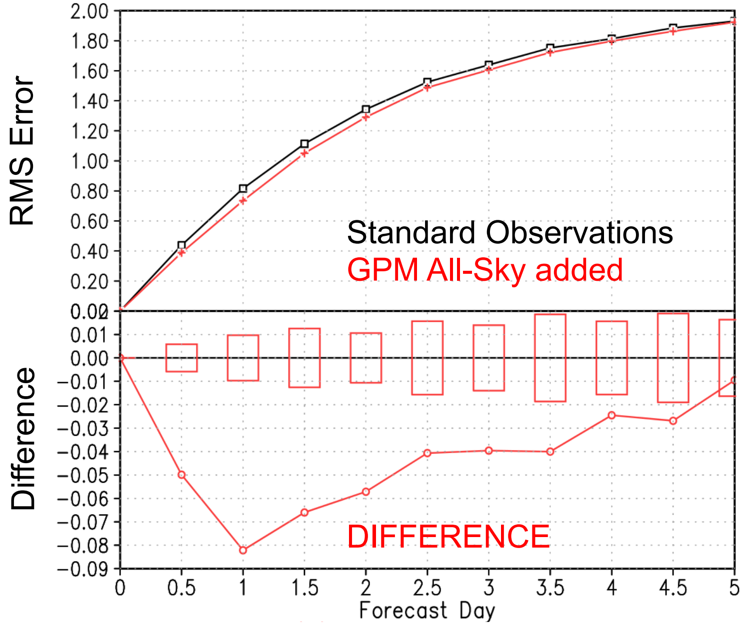


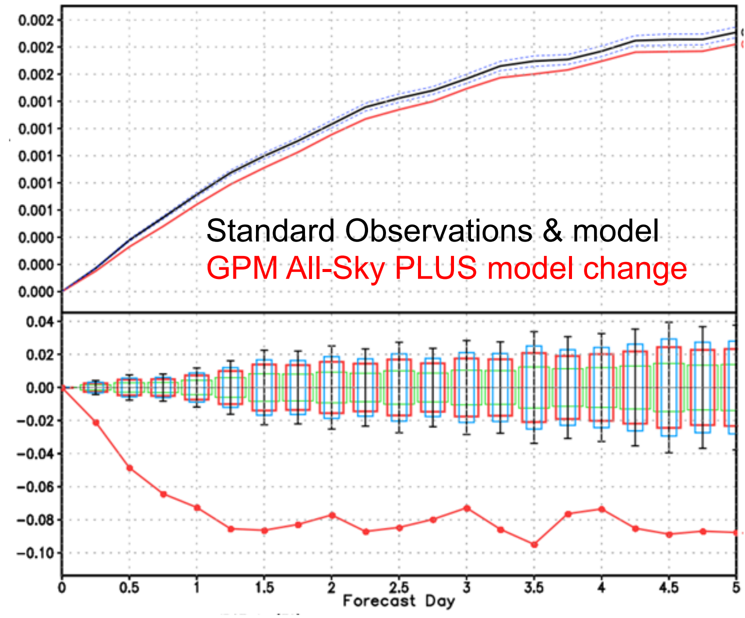
About 20 NASA platforms presently observe the Earth, providing unique information that is not available (globally) from other sources

Impact of All-Sky Radiances on Forecast

Radiances from the NASA/JAXA Global Precipitation Mission (GPM)

RMS error of 850-hPa tropical humidity as a function of forecast time (to 5 days)





Adding GPM all-sky radiances leads to reduced error, especially in the Tropics. Best impact is at one day forecast; no significant change by five days

Additional enhancements in the model cloud physics parametrizations extend the beneficial impacts throughout the five-day forecast period

The GEOS Earth System Model

The Goddard Earth Observing System (GEOS) model:

- Built around a modular collection of Earth System components
- Scale-aware representations of atmospheric physics, developed predominantly in the GMAO
- Catchment-CN land model, includes river routing and dynamic vegetation components
- Options for the MOM5 or MITgcm ocean models
- CICE ice model
- Includes aerosol modules (GOCART is widely used)
- Options for stratospheric ozone chemistry, GMI, or GEOS-Chem
- Aerosol/gas emissions modules, based partly on observations

GMAO's products based on the GEOS model include MERRA-2 (50-km reanalysis), GEOS-FP (12-km weather analysis/forecasts), GEOS-CF (25-km Composition Forecasting), and GEOS S2S (50-km S2S)

GEOS S2S Configuration (Version 2.1)

Model

- AGCM: Post MERRA-2 (current GMAO NWP) generation C180 (50km), 72 hybrid sigma/pressure levels; GOCART interactive aerosol model, cloud indirect effect (2-moment cloud microphysics); MERRA-2 generation cryosphere
- OGCM: MOM5, 0.5 degree, 40 levels
- Sea Ice: CICE-4.0

Weakly (Loosely) Coupled Ocean Data Assimilation System

- atmosphere “replayed” to “forward processing for instrument teams” (like MERRA-2)
- NCEP-like code/system, set here to behave as Ensemble OI
- forecasts: initialized from ODAS, perturbations produced from analysis diffs
- hindcasts: re-initialized from 5-day ODAS run, perturbations from analysis diffs

Observations

- nudging of SST and sea ice fraction from MERRA-2 boundary conditions
- assimilation of satellite along-track ADT (Jason, Saral, ERS, GEOSAT, HY-2A, CryoSat-2)
- assimilation of *in situ* Tz and Sz including Argo, XBT, CTD, tropical moorings

Interplay Between “Representation” and “Complexity”

Complexity of Earth System model:

Physical AOLI (implicit)

+ cloud microphysics

+ aerosol (binned or modal)

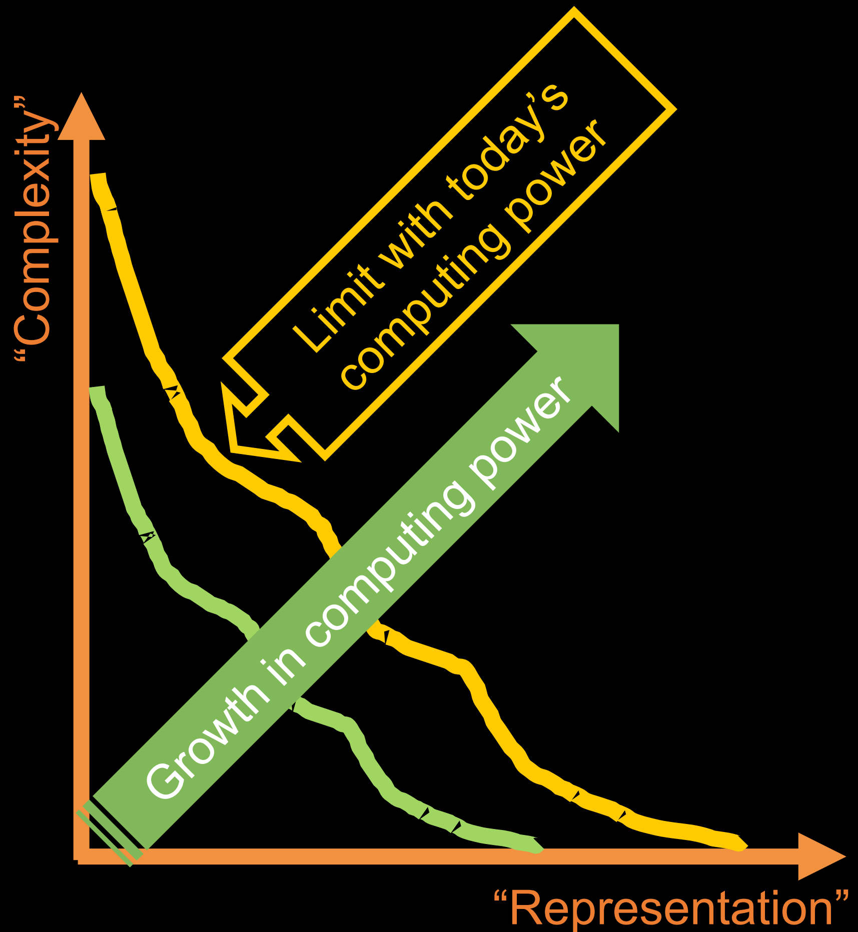
+ ice-snow-meltwater

+ gaseous chemistry

+ dynamic vegetation

+ ocean biogeochemistry

+ …



Computational “representation” of features in physical Earth System model:

Baseline horizontal/vertical resolution + ensemble size/resolution + precision + (stochastic physics) + (choice about stratosphere) + …

NASA's Unique Role in Earth System Prediction

Observations being examined:

Soil moisture (SMAP, GRACE)

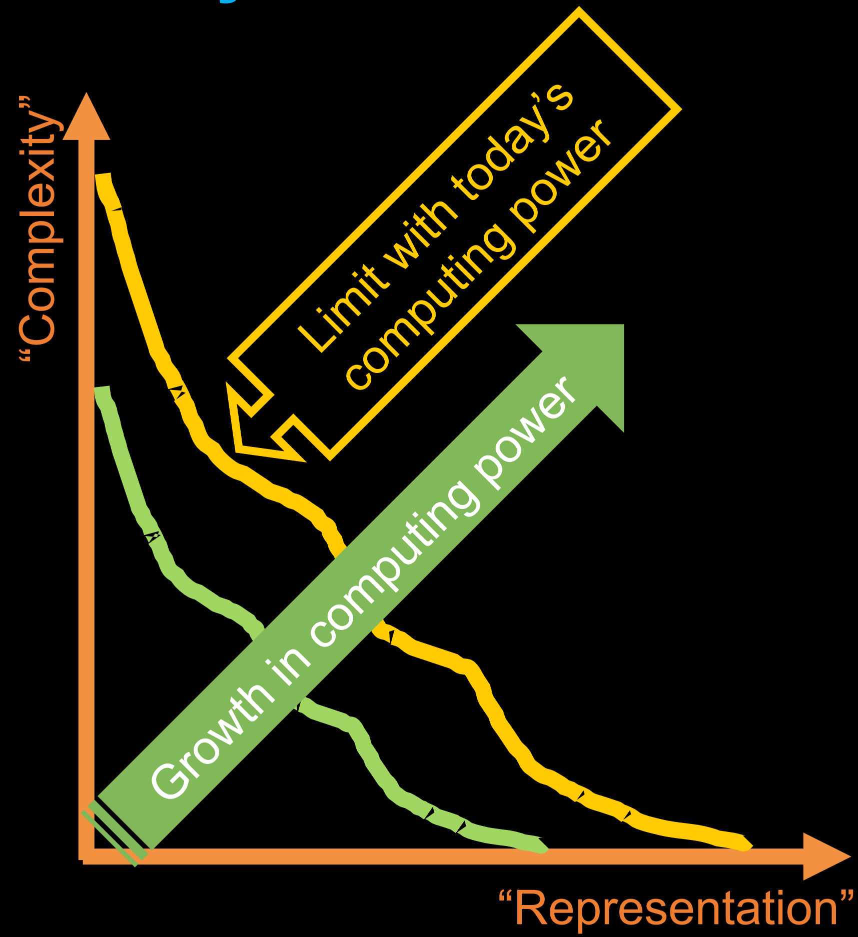
Salinity (Aquarius, SMAP)

Sea ice (pre-IceSat)

(Altimetry is widely used)

Aerosols (MODIS, AVHRR,VIIRS)

(Ozone and composition)



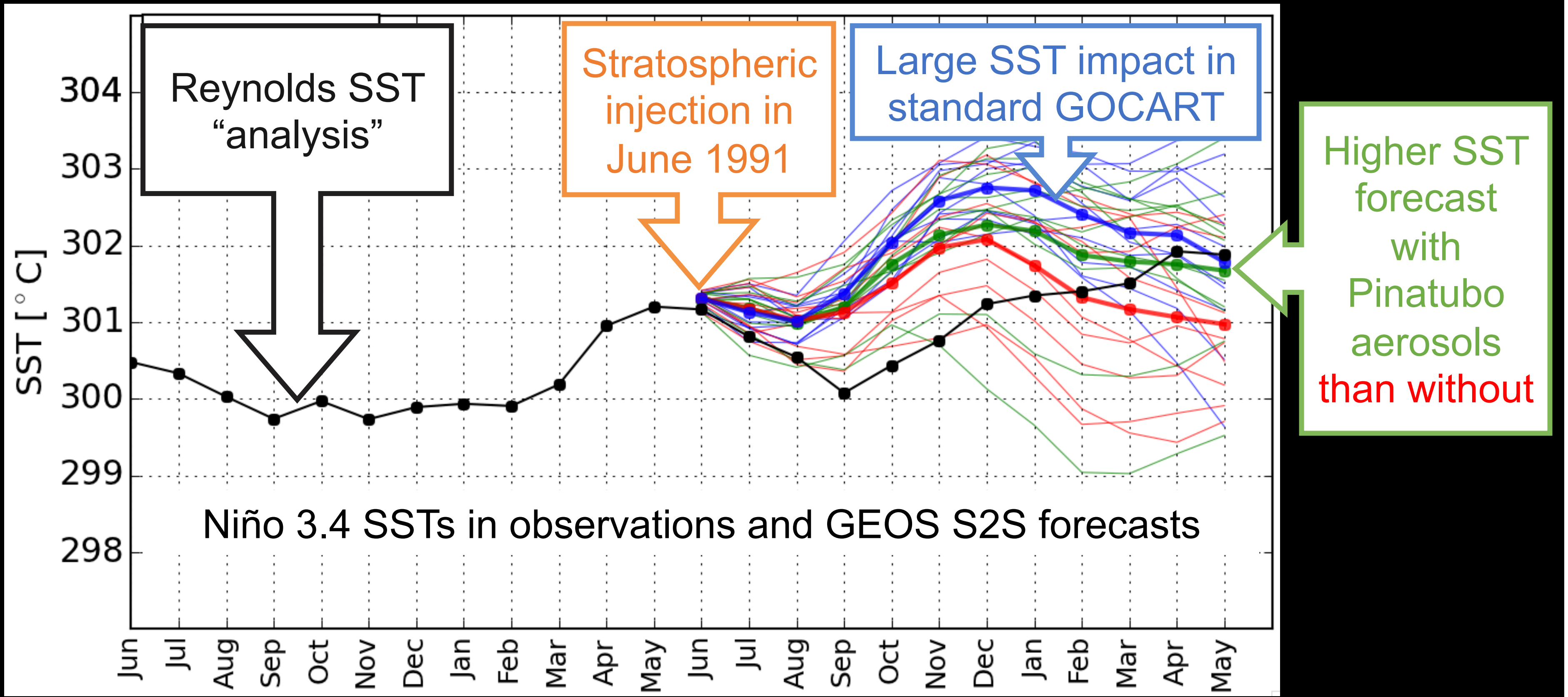
GMAO develops Earth System analysis and modeling capabilities that demonstrate the value of NASA's observations to the integrity of forecasts

Stratospheric Aerosol – Pinatubo Eruption

Experimental details:

- June 1991 initial states from MERRA-2 includes assimilated aerosols
- Pinatubo eruption injects SO_2 into stratosphere – NASA data (SAGE) are basis of this injection, which is prescribed in GEOS S2S
- Three seasonal forecast ensembles (nine-month, 11-member ensembles) performed with GEOS S2S system:
    - With Pinatubo emissions into standard GOCART model
    - With Pinatubo emissions into updated GOCART includes a second (finer) sulfate aerosol, appropriate for the stratosphere
    - No Pinatubo aerosols injected (other GOCART aerosols included)
- Discernable warming impact on tropical SSTs, in accord with prior studies using free-running models (e.g., Predybaylo et al., 2017), along with global cooling impact (blocking out solar radiation)

Stratospheric Aerosol – Pinatubo Eruption



Tropical El Niño event in forecasts was strengthened by Pinatubo aerosols

Preliminary results from ongoing study.

Niki Mukherjee, Valentina Aquila, Jelena Marshak, et al.

Additional Comments on Aerosols in GEOS S2S

Current "production" version includes:

- GOCART aerosol module
- Flow-dependent emissions of dust and sea salt
- Specified anthropogenic emissions of sulfate and carbon
- Satellite-derived emissions of biomass-burning (carbon) emissions, with a persistence forecast:
    - Prognostic emissions modules being examined
    - Simple fire-weather model is a candidate for GEOS S2S Version 3
- Volcanic aerosol emissions will be handled better (initial conditions)
- Range of NASA and other observations will be expanded

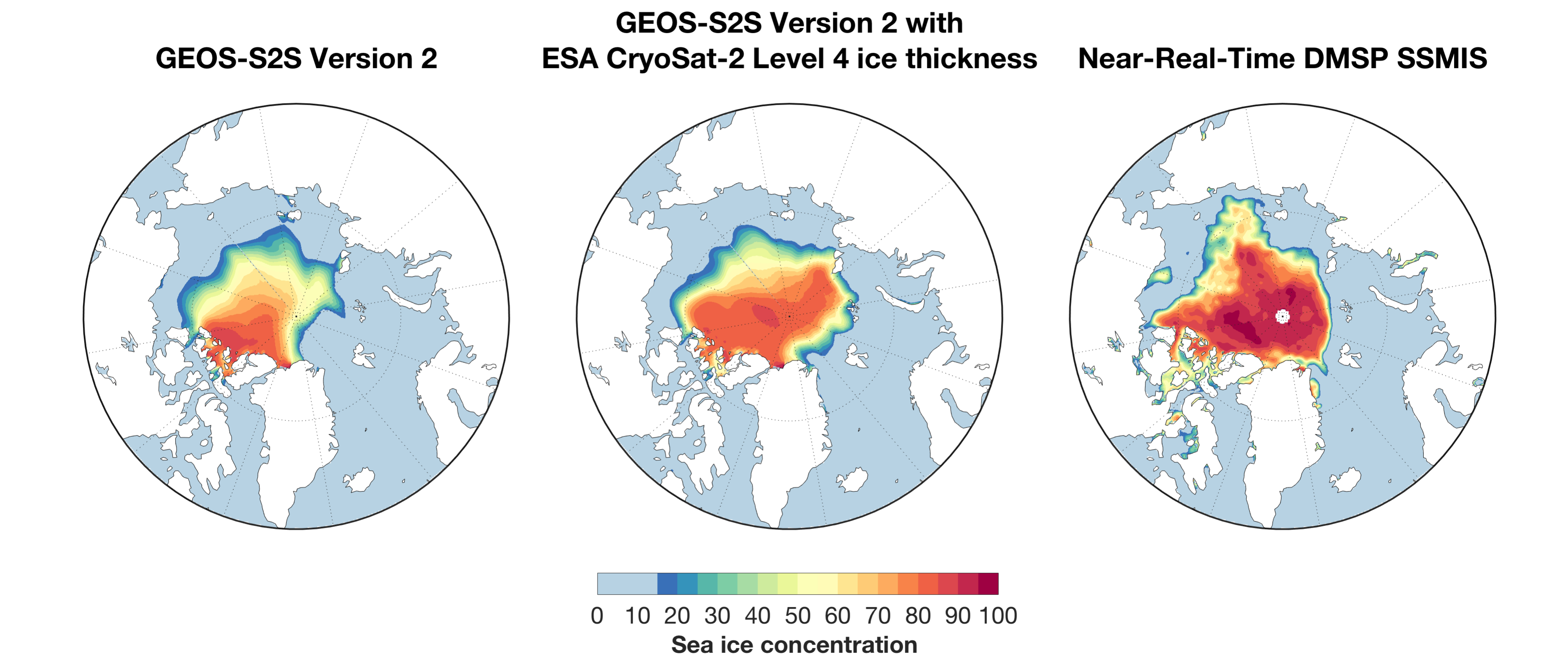
Impacts of CryoSat-2 Sea Ice

Experimental details:

- Baseline GEOS S2S includes CICE model and an analysis of sea-ice concentrations
- NASA has substantial investments in cryospheric observations (IceSat, IceBridge aircraft series, and IceSat-2) plus others
- Seasonal experiments underway using CryoSat-2 observations:
  - Ensemble Initialized on May 31, 2018
  - Examined mean fields for August 2018
  - Forecasts have improved in this case study
- Discernable impact of the initialization on predicted Arctic sea-ice fields and lower atmospheric temperatures at several months lead time

National Aeronautics and Space Administration

Impacts of CryoSat-2 Sea Ice

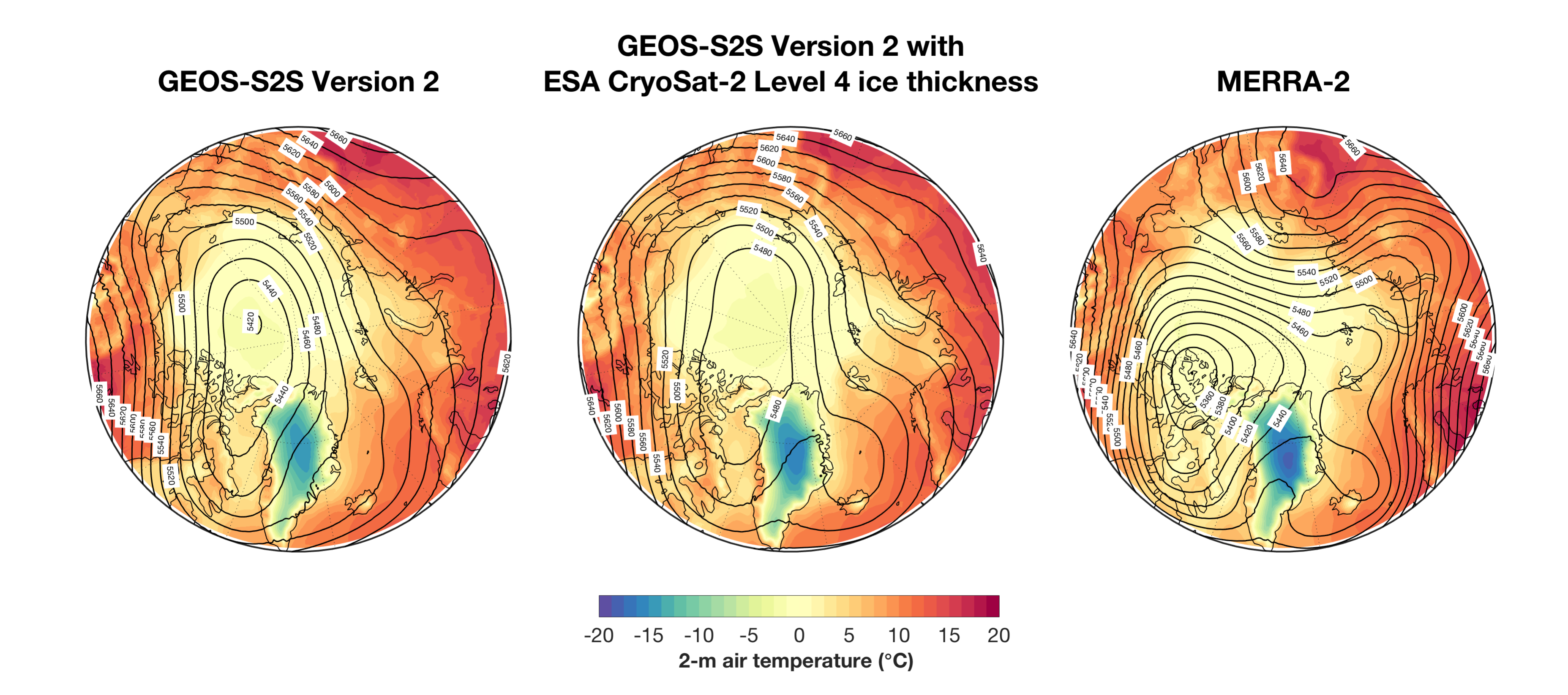


Forecast Arctic sea ice concentration in August was improved by assimilating sea-ice thickness from the ESA instrument Cryosat-2

Preliminary results from ongoing study.

Lauren Andrews, Richard Cullather, Bin Zhao et al.

Impacts of CryoSat-2 Sea Ice



Feedbacks are evident on the atmospheric structure when assimilating Cryosat-2 sea-ice thickness – but tangled in the atmospheric flow

Preliminary results from ongoing study.

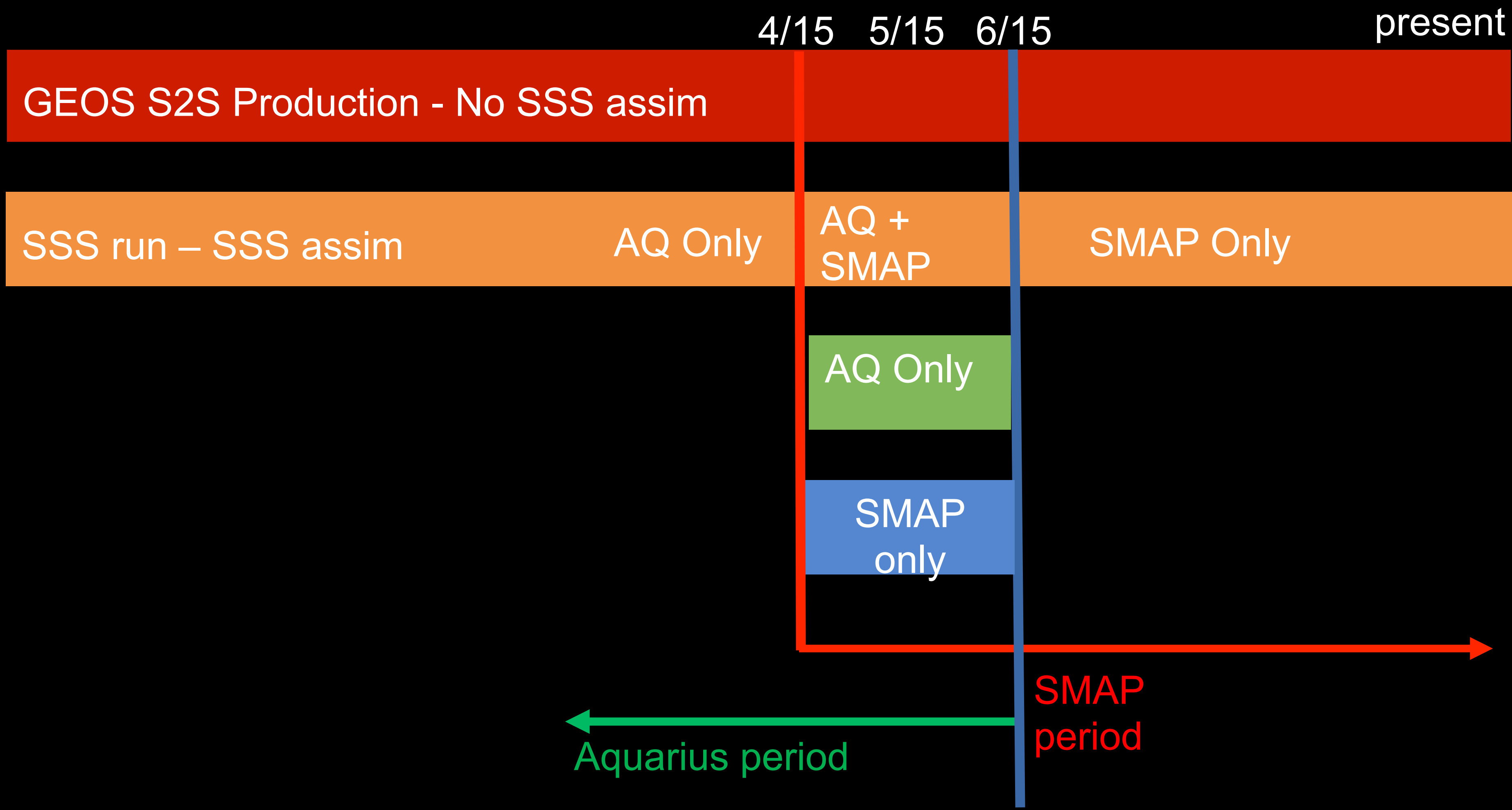
Lauren Andrews, Richard Cullather, Bin Zhao et al.

Sea-Surface Salinity from Aquarius and SMAP

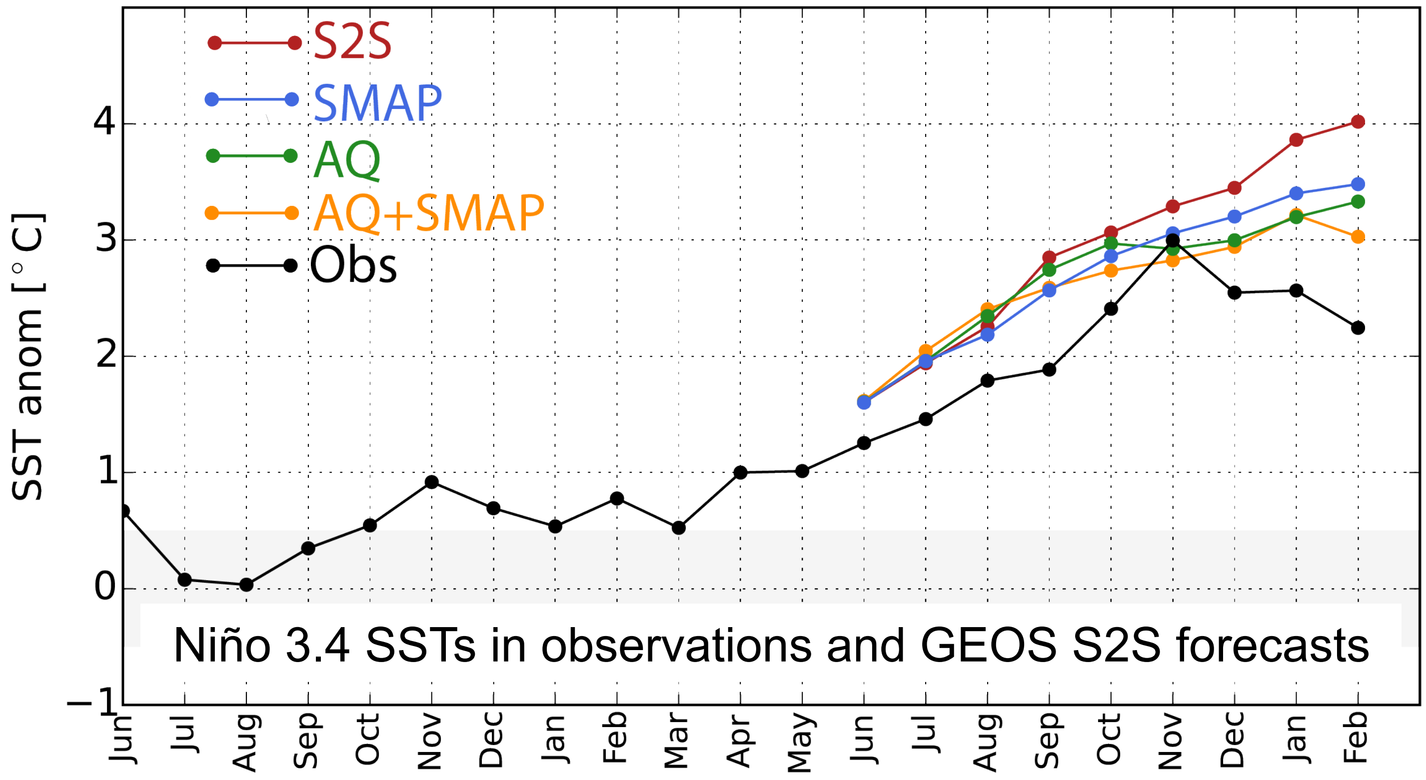
Experimental details:

- Reference state: GEOS S2S production run
- Aquarius (2013 – May 2015) and SMAP (March 2015 – present) Sea Surface Salinity (SSS) assimilation has been added
- Three “data addition” analyses and seasonal forecast ensembles (nine-month, 11-member ensembles) have been performed :
  - With Aquarius (AQ) and SMAP SSS observations assimilated
  - With AQ SSS only (March – May 2015)
  - With SMAP SSS only (March - May 2015)
- Discernable improvement in predictions of Niño 3.4 SSTs when SSS data are included

Sea-Surface Salinity Data from Aquarius and SMAP



Sea-Surface Salinity Assimilation: Impacts



Tropical El Niño event in 2015 forecasts was improved by using SSS

Preliminary results from ongoing study.

Eric Hackert, Robin Kovach, et al.

Summary of Results

Demonstrating the value of new observations to S2S predictive skill is not always straightforward:

- "Data ingest" and "model complexity" each important
- Experimental framework not well suited to research observations
- More complex "impact metrics" are needed

Promising results from the GEOS system pertaining to:

- Volcanic aerosols (Mount Pinatubo)
- Sea Ice
- Salinity

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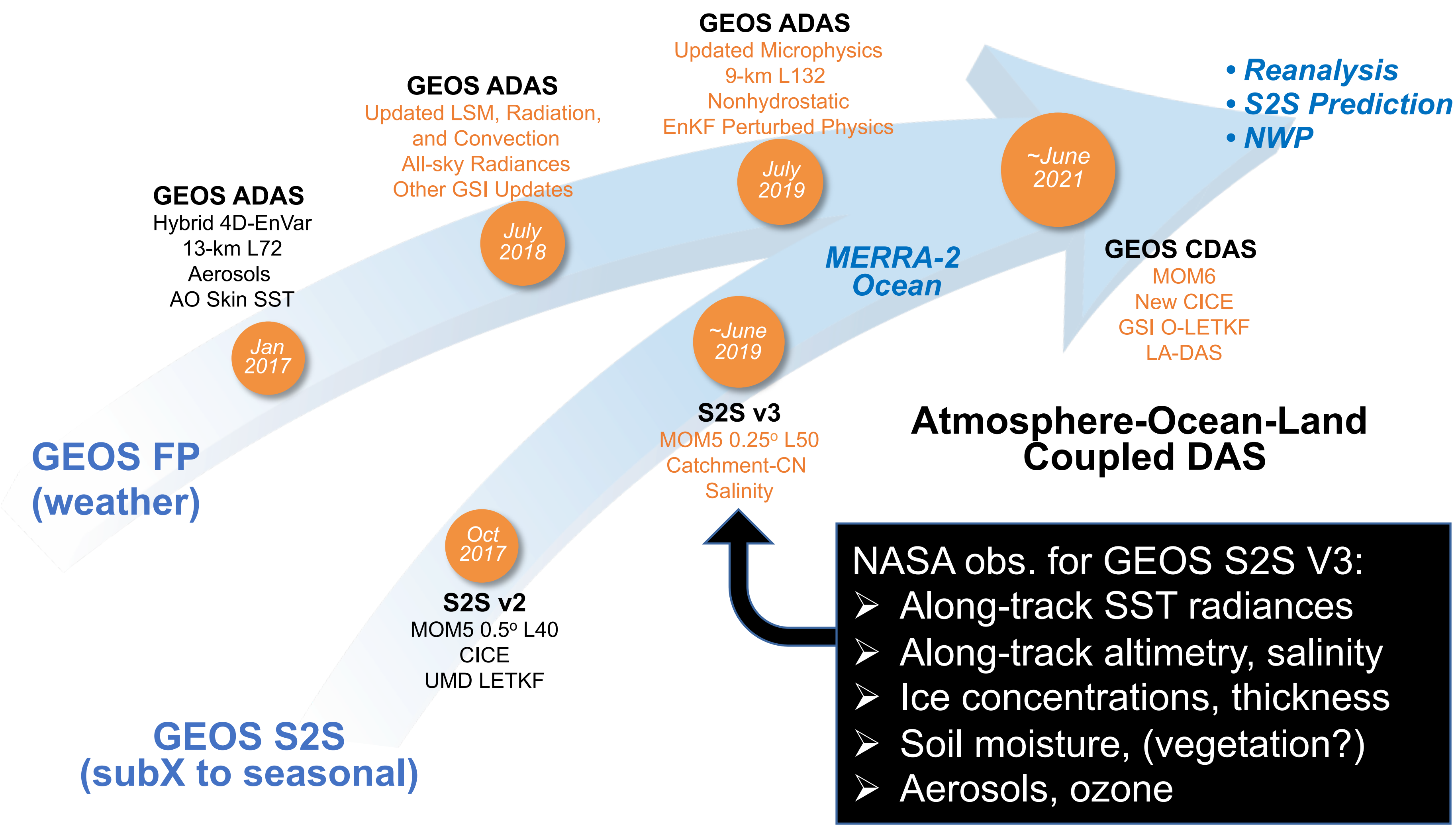
Looking Ahead



Discussion Points

- Demonstrable benefits of including research quality datasets in the initialization of the system (case studies)
- Adopting new observations typically requires substantial changes to the model (complexity) and assimilation
- Continued focus on “anomalies” may obscure physical improvements in the systems
- The cost of multi-decadal hindcasts impedes our ability to update S2S systems on timescales that capture evolution in model and assimilation capabilities

Challenge remains to improve the underlying models in ways that allow the S2S community to focus on processes, not anomalies