MERRA-2 Ocean: The NASA Global Modeling and Assimilation Office's Weakly Coupled Atmosphere-Ocean Reanalysis Using GEOS-S2S Version 3

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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 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/Dissemination of Sub/Seasonal Forecasts**

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

- **Predictability Studies**

GEOS-S2S-2 was released in November, 2017 (Molod et al., 2019)
GEOS-S2S-3 due for release December 2020 (System to be “frozen” early 2020)

GEOS-S2S-3 System Characteristics

Model

- AGCM: Current GMAO NWP (including aerosol model) + two-moment cloud microphysics
- OGCM: **MOM5, ~0.25 deg, 50 levels**; **Ice Sheet runoff to proper location**
- **New "atmosphere-ocean interface layer" - diurnal warming and cool layer**
- Sea Ice: CICE-4.0

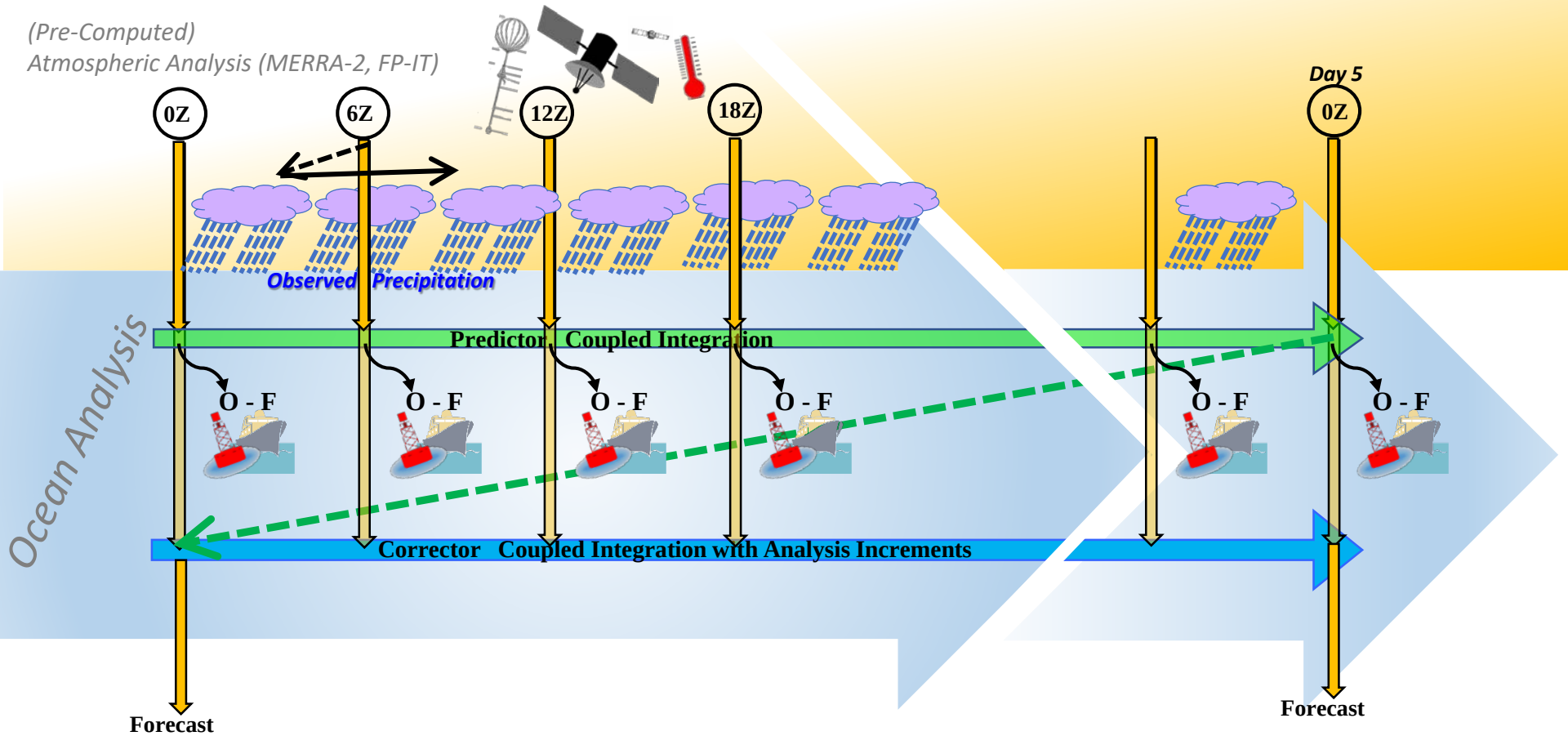
Coupled Ocean Data Assimilation System

- atmosphere is "replayed" to **MERRA-2 and** "FPIT" (like MERRA-2); precipitation correction over land, **modified "replay" methodology**
- NCEP-like LETKF code/system, set here using **(updated)** static background error statistics;
- Forecasts: **initialized from MERRA-2 ocean reanalysis, new perturbation/ensemble strategy;**
- Hindcasts: **initialized from MERRA-2 ocean reanalysis, new perturbation/ensemble strategy;**

Observations

- nudging of SST and sea ice fraction from MERRA-2 boundary conditions, **new technique for sea ice;**
- assimilation of *in situ* Tz and Sz including Argo, XBT, CTD, tropical moorings;
- assimilation of satellite along-track ADT (Jason, Saral, ERS, GEOSAT, HY-2A, CryoSat-2);
- sea ice concentration from the National Snow and Ice Data Center (NSIDC).
- **assimilation of SMAP, Aquarius sea surface salinity**

GEOS-S2S Coupled Ocean/Atmosphere Data Assimilation



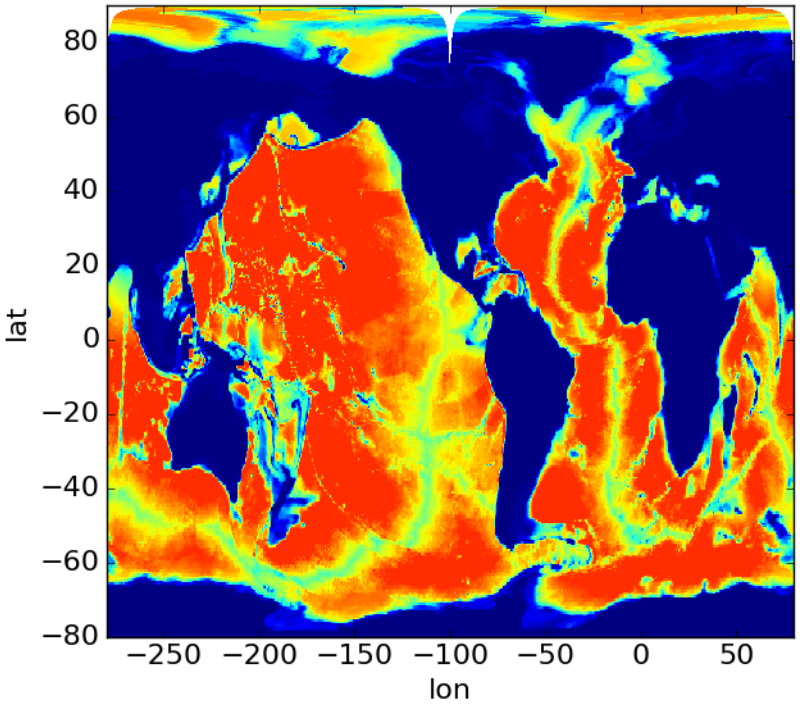
"MERRA-2 Ocean" will run from 1982-present, continue in near-real time

GEOS-S2S-2 → GEOS-S2S-3
Model and AODAS Upgrades with Major Impact:

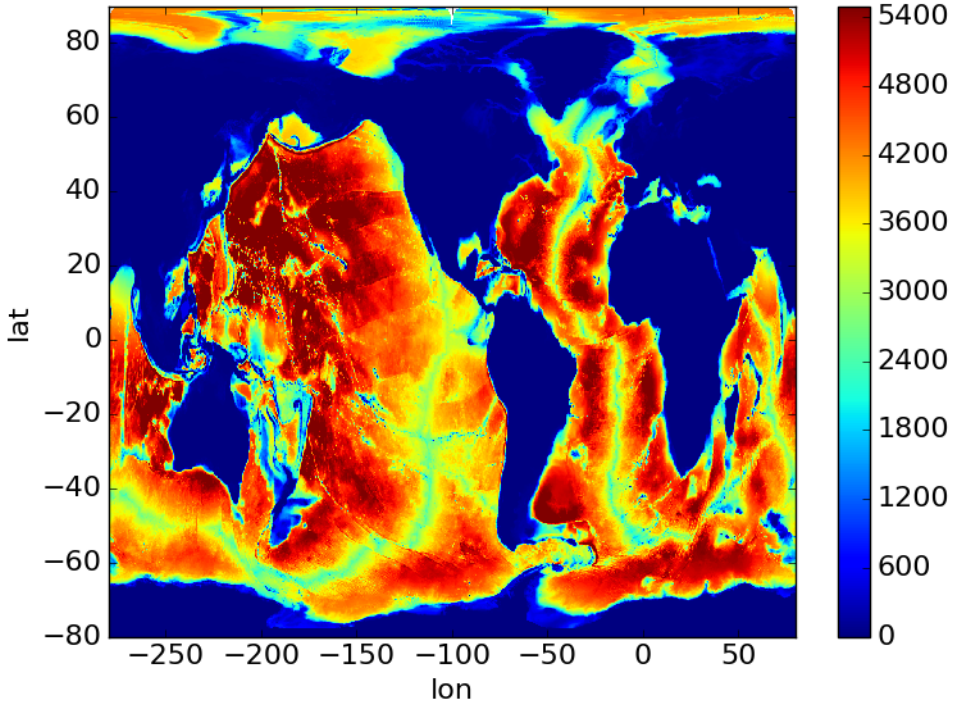
- **Ocean Resolution – Model, Forecasts and AODAS**
- **Assimilation of Sea Surface Salinity – AODAS and Forecasts**
- **“Dual Ocean” for Weakly Coupled Assimilation – AODAS**
- **New Ensemble Strategy – Forecasts**

Ocean Resolution – Bathymetry

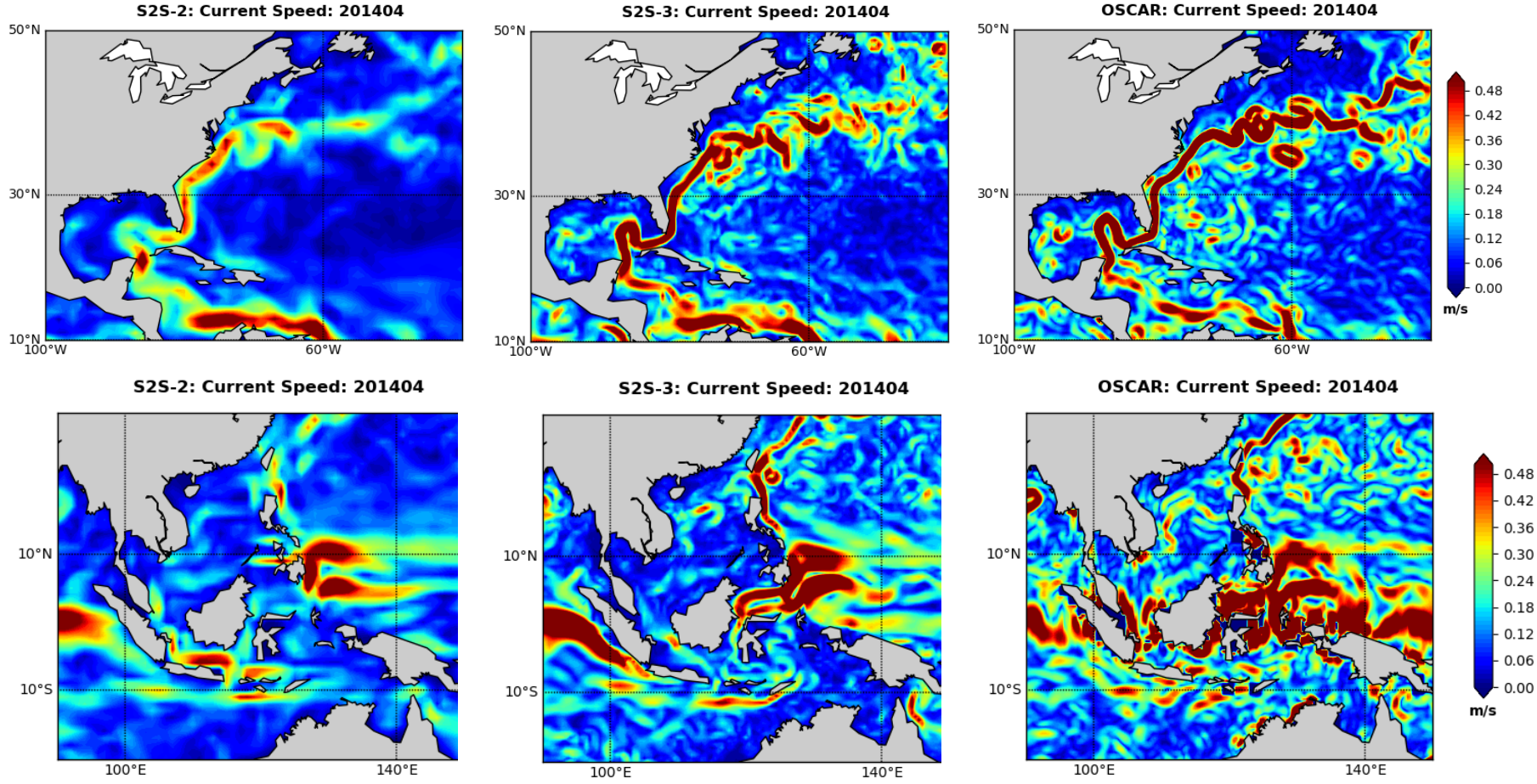
GEOS-S2S-2: 0.5º, 40L



GEOS-S2S-3: 0.25º, 50L

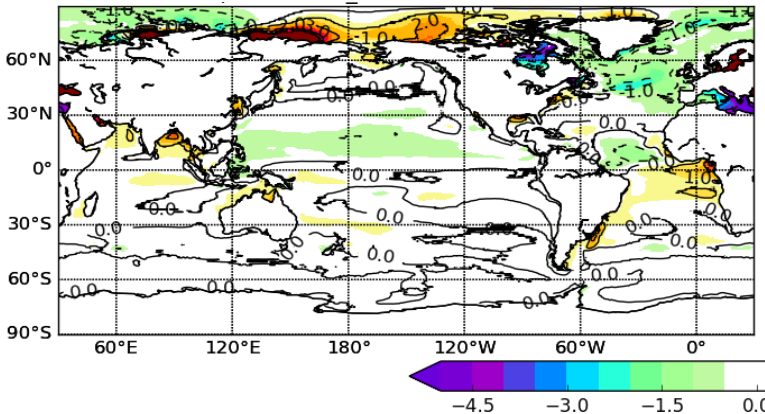


Ocean Resolution – Surface Currents

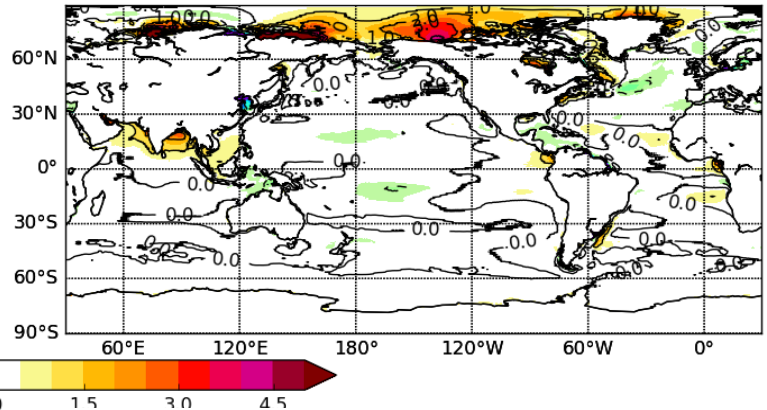


Ocean Resolution – Impact on Transport

GEOS-S2S-2

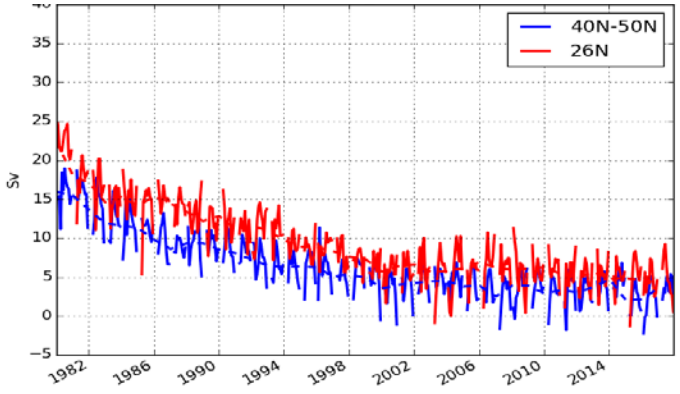


GEOS-S2S-3

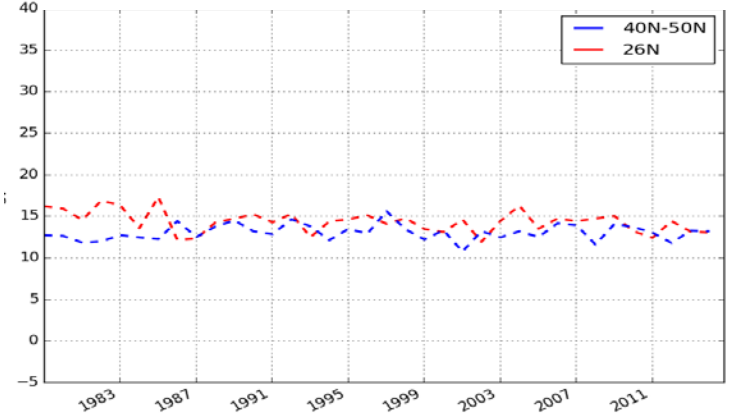


GEOS-S2S-3 has smaller bias in salinity relative to the World Ocean Atlas Version 13

GEOS-S2S-2



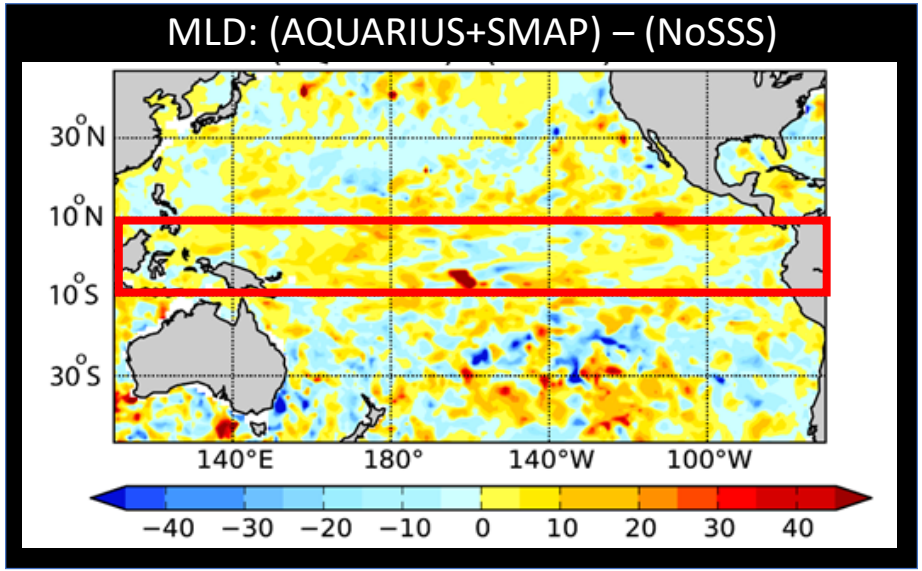
GEOS-S2S-3



GEOS-S2S-3 has Stronger Atlantic Meridional Overturning Circulation AMOC) in Sv

Assimilation of Satellite Sea Surface Salinity

Assimilation sea surface salinity (SSS) from Aquarius (V5) and SMAP (V4.0) improves the near-surface density and mixed layer depth (MLD) and modulates the Kelvin waves associated with ENSO.

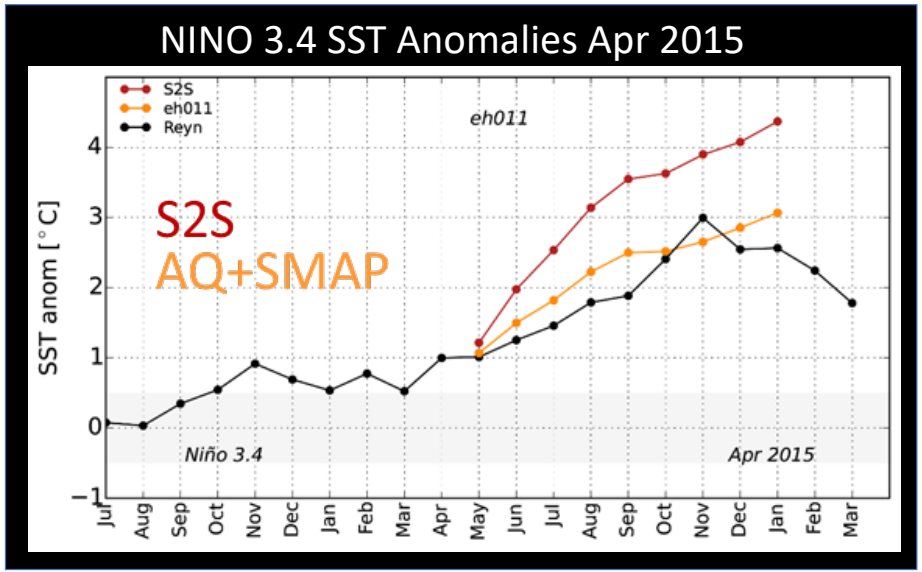


May 2015 differences between the experiment that assimilates both Aquarius and SMAP SSS minus the experiment that withholds SSS assimilation. Improved (saltier) SSS increases near-surface density within the equatorial waveguide leading to deeper MLD and damped ENSO response due to reduced efficiency of wind forcing on a relatively deeper MLD.

From: Hackert et al., 2019

Assimilation of Satellite Sea Surface Salinity

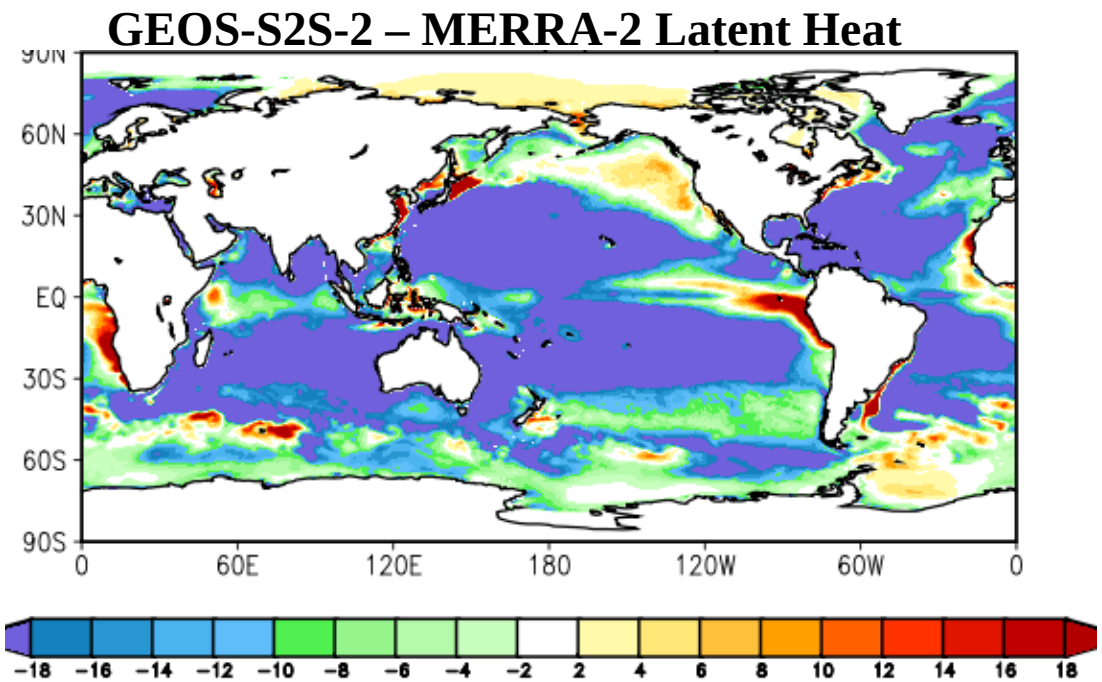
The deeper MLD acts to dampen the ENSO Kelvin signal resulting in improved forecasts for the 2015 El Niño



NINO3.4 ensemble forecast plume average plots initialized from 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: Hackert et al., 2019

“Dual Ocean”



Latent heat flux was reduced to values that are 30% lower than the latent heat produced by MERRA-2

(Analogous behavior found using MITgcm ocean by Strobach et al., 2018)

Motivation for Change:

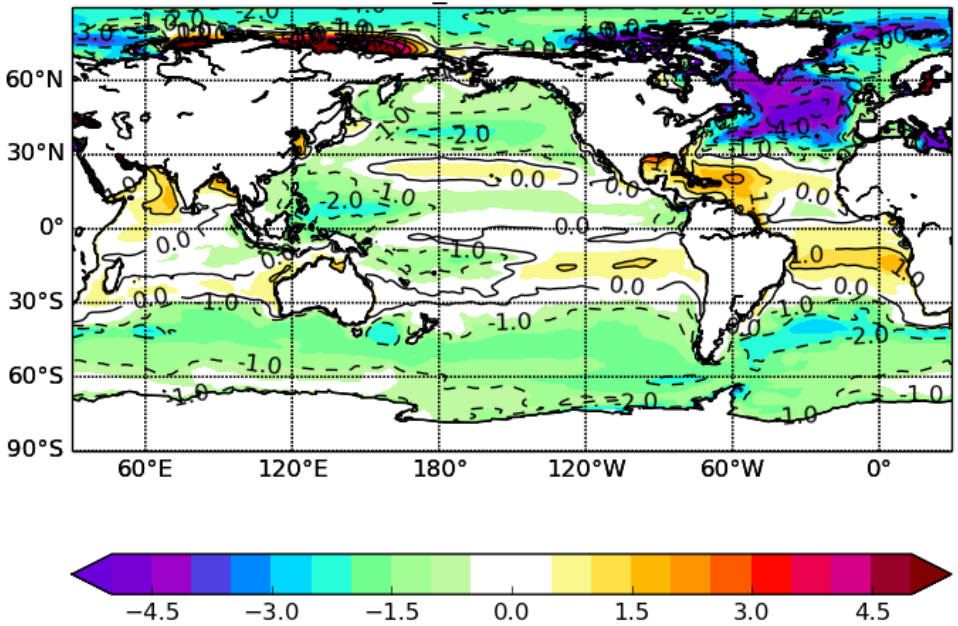
During Atmospheric DA the lower atmosphere “saw” a different SST than is predicted in coupled model

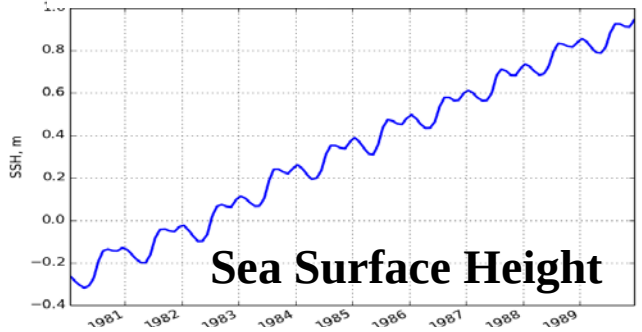
Even with ocean analysis, near-surface temperature gradient changed stability

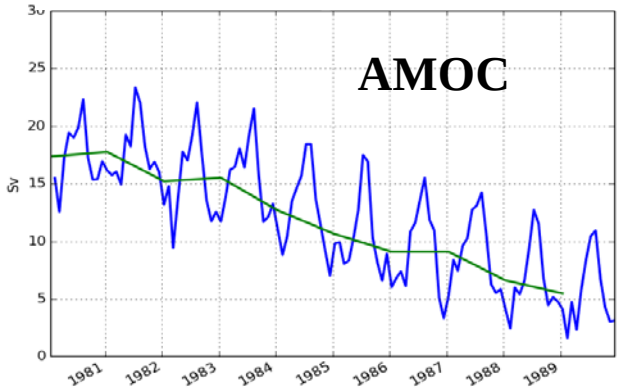
In our case, this resulted in reduced evaporation

“Dual Ocean”

GEOS-S2S-2 – WOA Surface Salinity







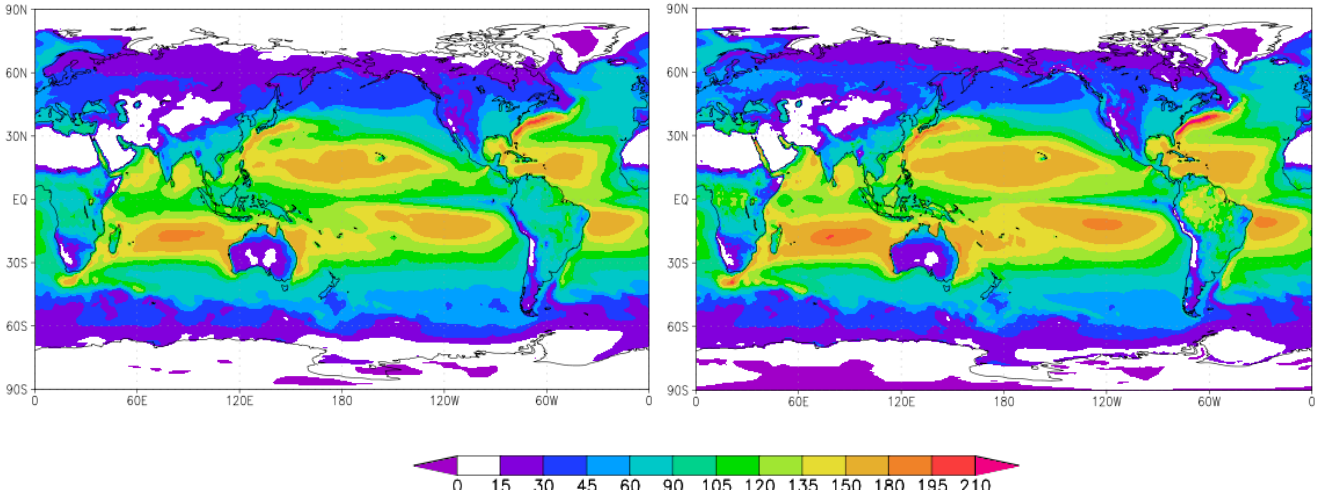
Reduced Latent Heat had the potential to result in:
Freshened Ocean, Sea Level Rise, Weakened AMOC

“Dual Ocean”

GEOS-S2S-3 Solution:

Compute near surface stability and latent heat flux (bulk formulae) using the SST that the data assimilation (MERRA-2) “saw”

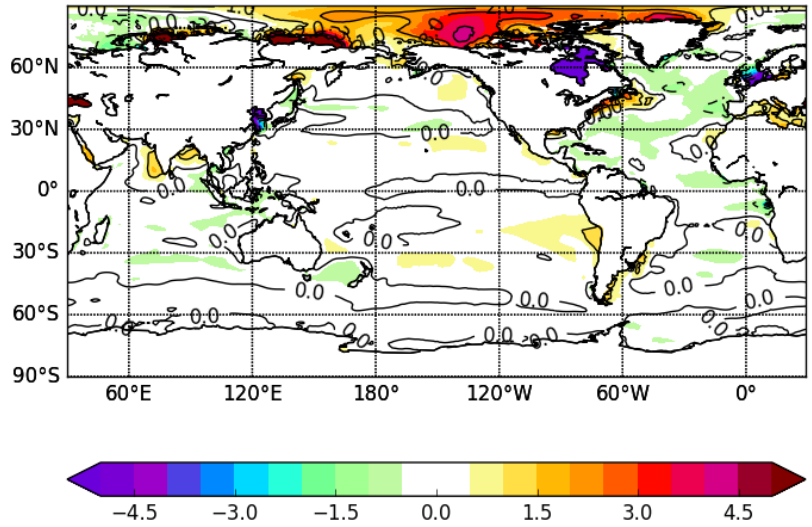
“Dual Ocean” Latent Flux **MERRA-2 Latent Flux**

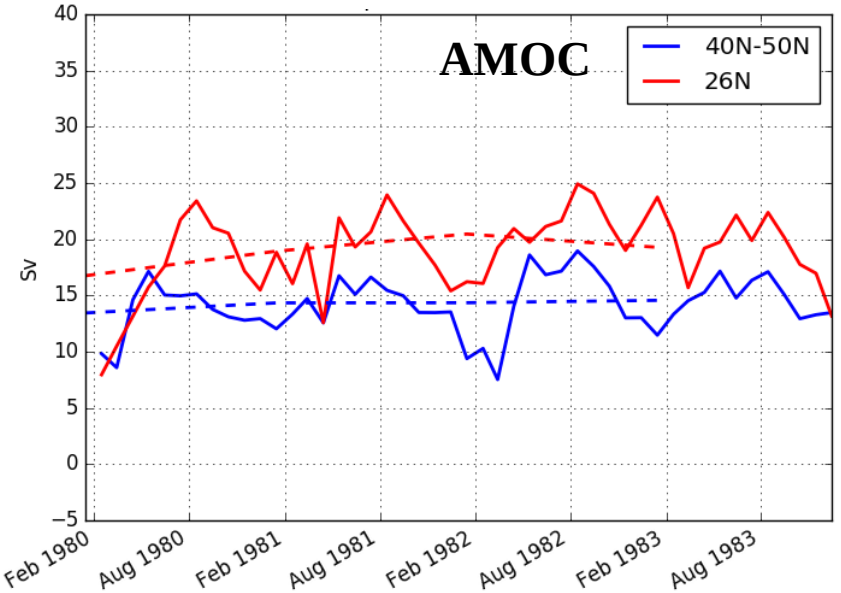


With “dual ocean”, latent heat flux was increased to within 5% of MERRA-2

“Dual Ocean”

GEOS-S2S-3 – WOA Surface Salinity





“Dual Ocean” results in: Improved surface salinity, Steady AMOC

Summary

- **"MERRA-2 Ocean", NASA/GMAO's weakly (one-way) coupled atmosphere-land-ocean reanalysis will cover the period 1982-present and is due for public release late 2020**
- **Upgrade of ocean resolution in the GEOS-S2S-3 system used in "MERRA-2 Ocean" resulted in improved surface currents, ocean mass transport and surface salinity**
- **The ocean data assimilation now includes SMOS/Aquarius/SMAP sea surface salinity, and results in improved tropical density and mixed layer depth, and so improved propagation of equatorial Kelvin/Rossby waves and ENSO forecasts**
- **A "pitfall" of weakly coupled assimilation systems was identified and "dual ocean" strategy was implemented.**