An Introduction to the NASA GMAO Coupled Atmosphere-Ocean System - GEOS-S2S Version 3

GMAO Seasonal Prediction Development/Validation Group

Andrea Molod, *Eric Hackert*
Santha Akella, Lauren Andrews, Nathan Arnold, Donifan Barahona, Anna Borovikov, Richard Cullather, Yehui Chang, Robin Kovach, Randal Koster, Zhao Li, Young-Kwon Lim, Jelena Marshak, Kazumi Nakada, Siegfried Schubert, Yury Vikhliaev, Bin Zhao, Guillaume Vernieres, James Carton

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**

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**; **Improved Ice Sheet runoff**
- **New "atmosphere-ocean interface layer" - diurnal warm/cool layer (S. Akella - OM24B-3120)**
- 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 = "Dual Ocean"**
- ODAS - LETKF (Penny et al, 2013), using **(updated)** static background error statistics
- Forecasts/Hindcasts: **initialized from MERRA-2 ocean reanalysis, new perturbation/ensemble strategy (A. Borovikov - OM24B-3128)**

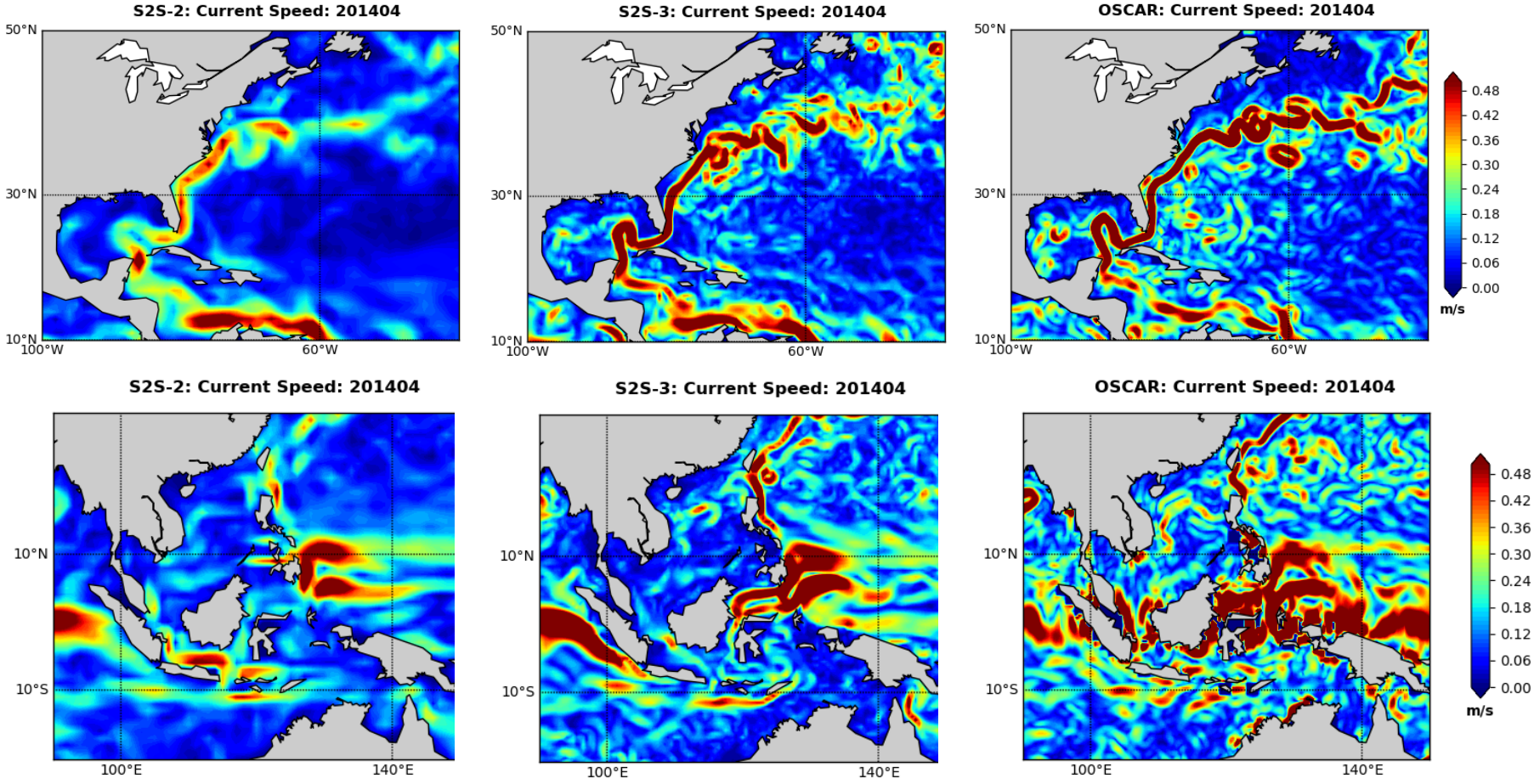
Observations

- nudging of SST and sea ice fraction from MERRA-2 boundary conditions**;**
- assimilation of *in situ* T_z and S_z including Argo, XBT, CTD, tropical moorings;
- assimilation of satellite along-track ADT (Jason-3, Saral-Altika, CryoSat-2, Sentinel-3, etc.);
- sea ice concentration from the National Snow and Ice Data Center (NSIDC).
- **assimilation of SMOS, SMAP, Aquarius sea surface salinity (E. Hackert Poster - PL24A-2643)**

GEOS-S2S-2 ➡ GEOS-S2S-3
Model Upgrades with Major Impact:

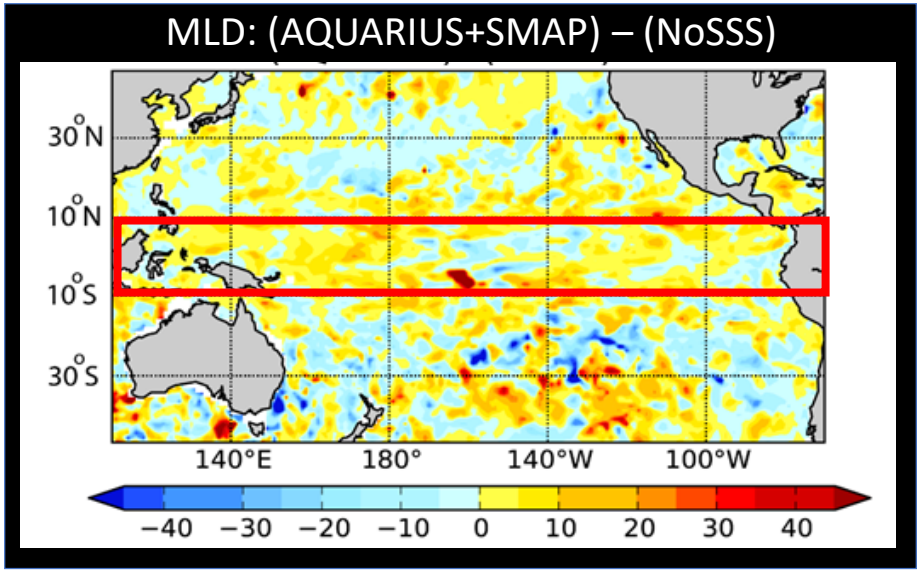
- **Ocean Resolution – Model, Forecasts**
- **Assimilation of Sea Surface Salinity – Ocean density and Forecasts**
- **“Dual Ocean” for Weakly Coupled Assimilation – Improved coupled fluxes**

Ocean Resolution – Surface Currents



Assimilation of Satellite Sea Surface Salinity

Assimilation sea surface salinity (SSS) from Aquarius (V5) and SMAP (V4.2) improves the near-surface density and mixed layer depth (MLD) and modulates the Kelvin waves associated with ENSO.

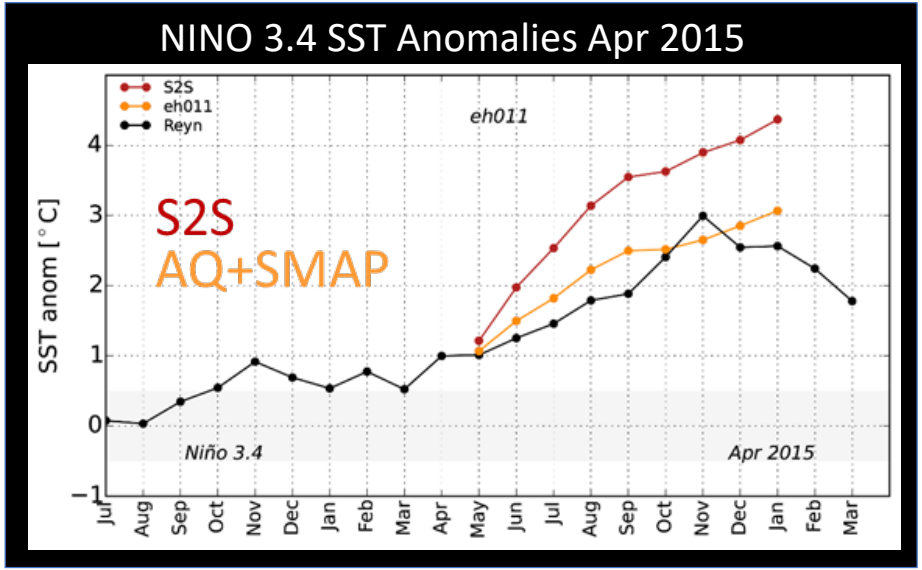


May 2015 differences between the experiment that assimilates both Aquarius and SMAP SSS minus the experiment that withholds SSS assimilation. Improved (saltier) SSS increases near-surface density within the equatorial waveguide leading to deeper MLD and damped ENSO response due to reduced efficiency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

From: Hackert et al., 2020

Assimilation of Satellite Sea Surface Salinity

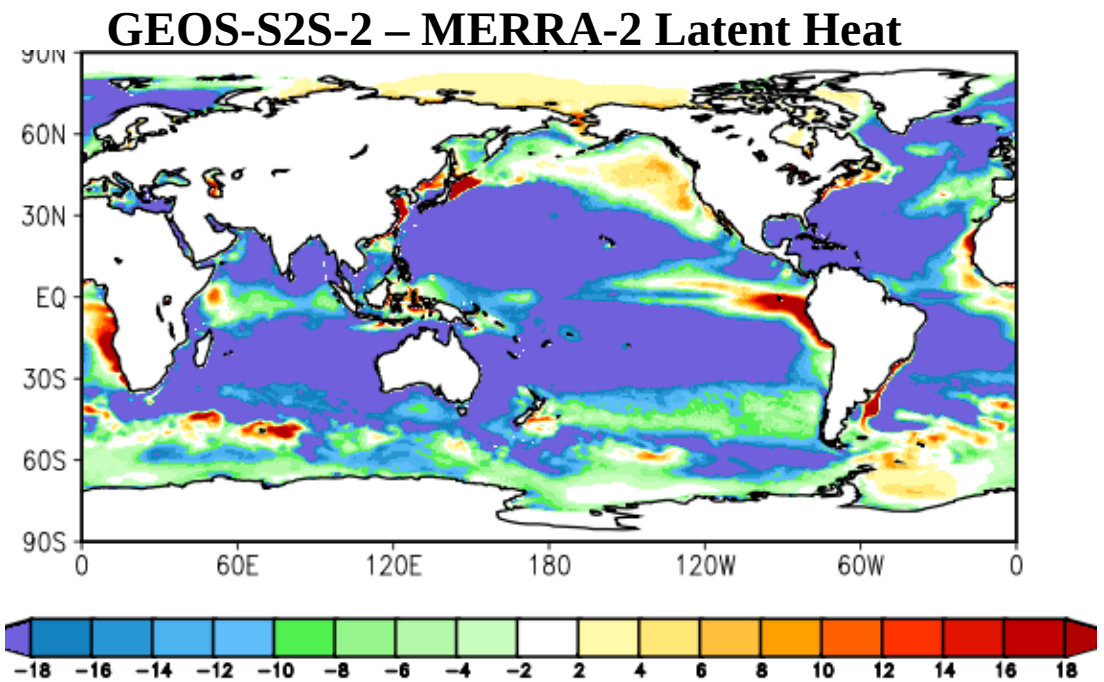
The deeper MLD acts to dampen the ENSO Kelvin signal resulting in improved forecasts for the 2015 El Niño



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., 2020

“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:

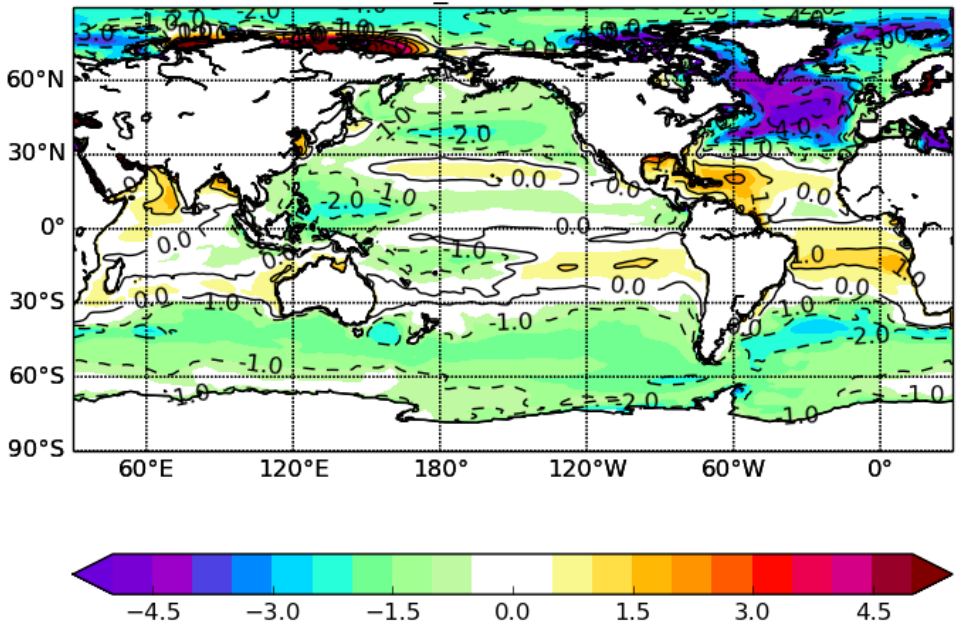
During Atmospheric DA the lower atmosphere “saw” a different SST than is predicted in coupled model

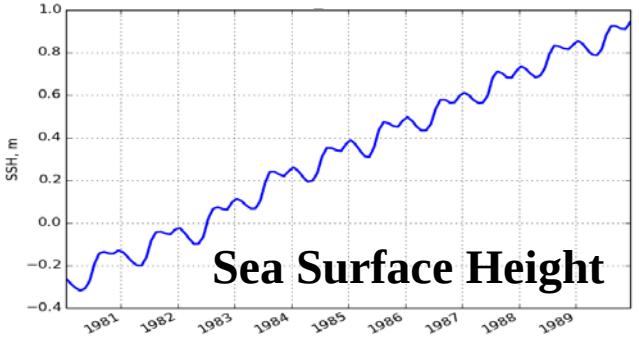
Even with ocean analysis, near-surface temperature gradient changed stability

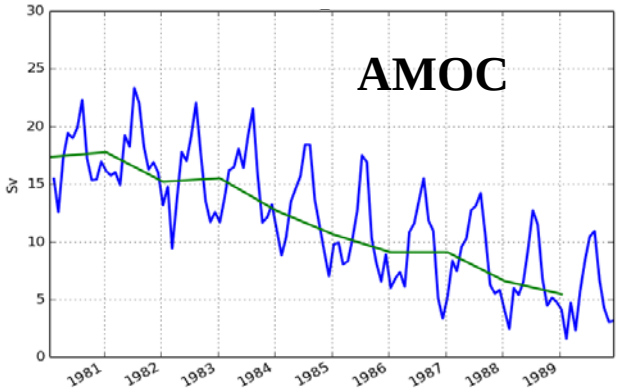
In our case, this resulted in reduced evaporation

“Dual Ocean”

GEOS-S2S-2 – WOA Surface Salinity





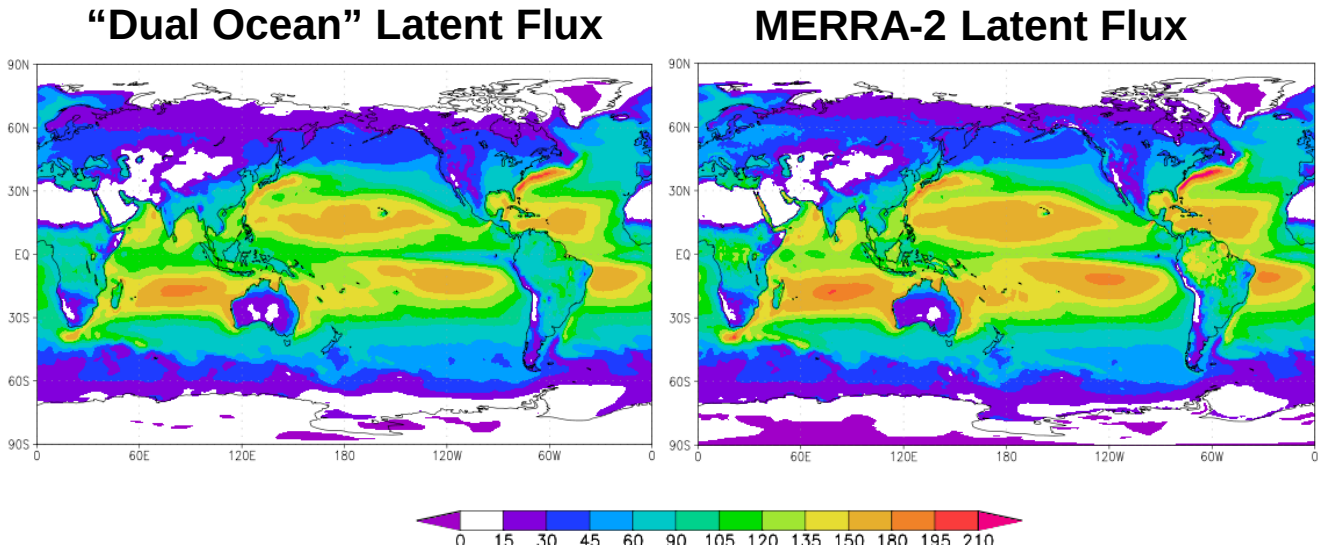


Reduced Latent Heat had the potential to result in:
Freshened Ocean, Sea Level Rise, Weakened AMOC

“Dual Ocean”

GEOS-S2S-3 Solution:

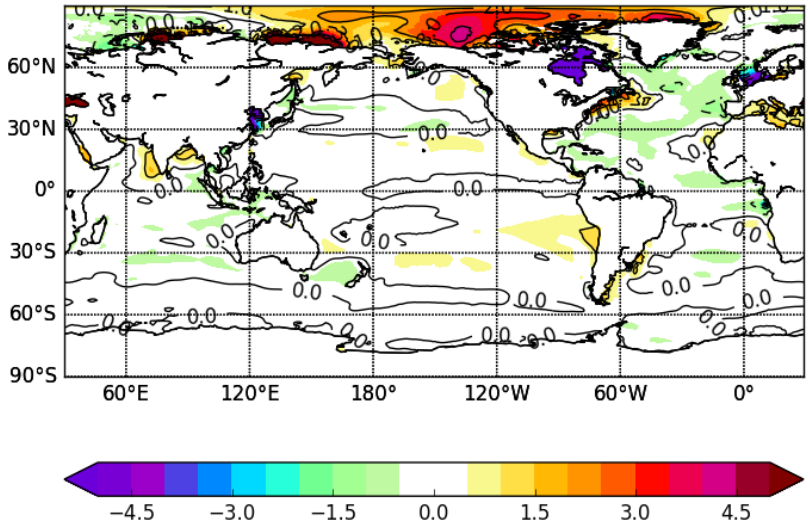
Compute near surface stability and latent heat flux (bulk formulae) using the SST that the data assimilation (MERRA-2) “saw”

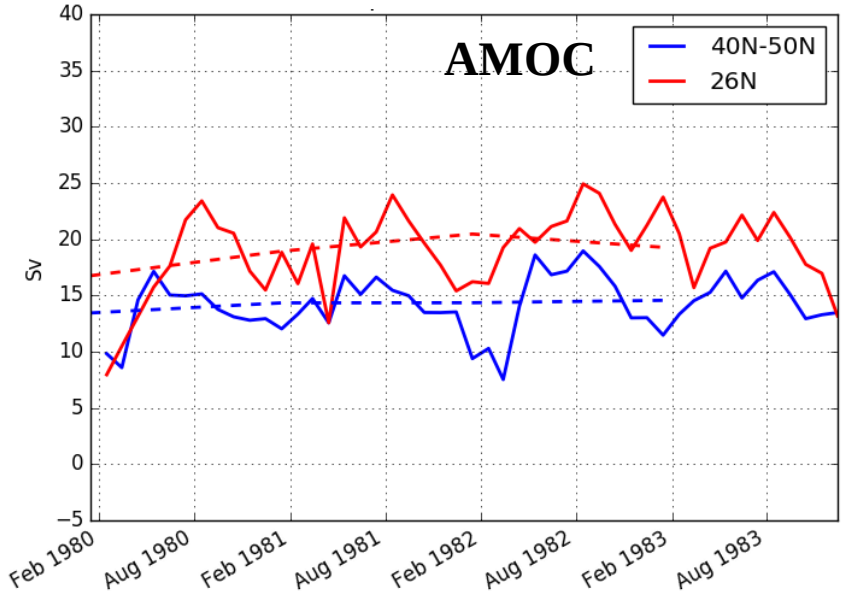


With “dual ocean”, latent heat flux was increased to within 5% of MERRA-2

“Dual Ocean”

GEOS-S2S-3 – WOA Surface Salinity

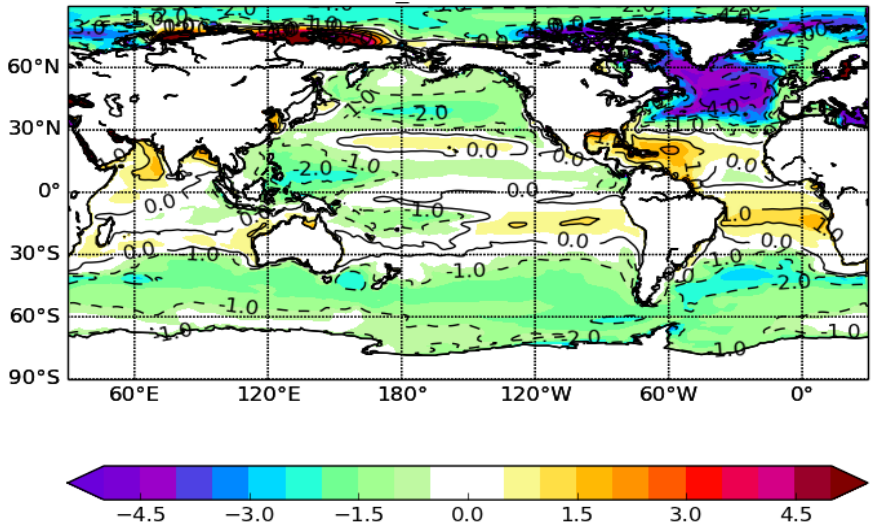




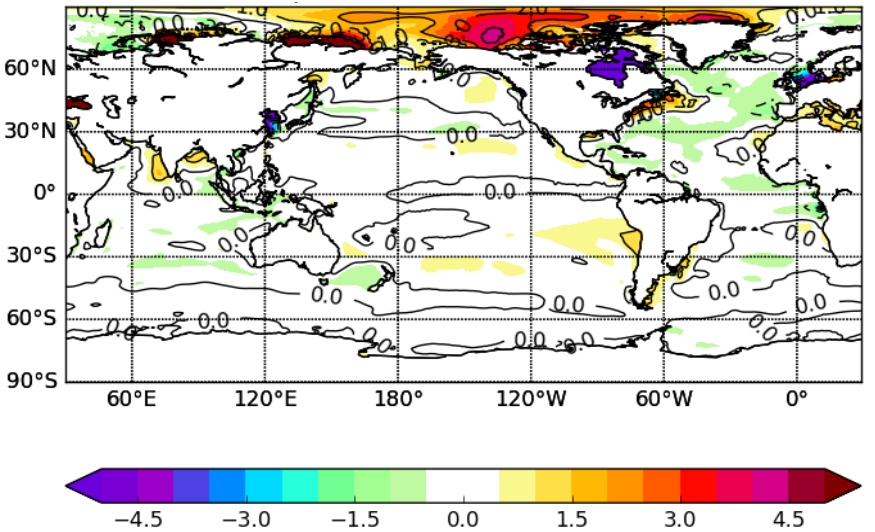
“Dual Ocean” results in: Improved surface salinity, Steady AMOC

“Dual Ocean”

GEOS-S2S-2 – WOA Surface Salinity



GEOS-S2S-3 – WOA Surface Salinity



“Dual Ocean” results in: Improved fluxes ➡ improved ocean model performance

Summary

- **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 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 (simply stated: atmosphere now sees observed SST to calculate fluxes)**

- **Preliminary results show that the model, ODAS, and seasonal forecasts are performing well**

Future/Ongoing Work

- GEOS-S2S-3 model, ODAS, and forecasts are currently being refined (including choices for ODAS background strategy)
- "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
- Retrospective "MERRA-2 Ocean" reanalysis will be used to spawn hindcasts/forecasts from 1982 until present (e.g. 1982-2010 to be used for detrending NMME forecasts)
- GEOS-S2S-3 will become our production seasonal prediction system and will replace the current system (estimated late 2020).

THANKS

Other GEOS-S2S-3 Topics

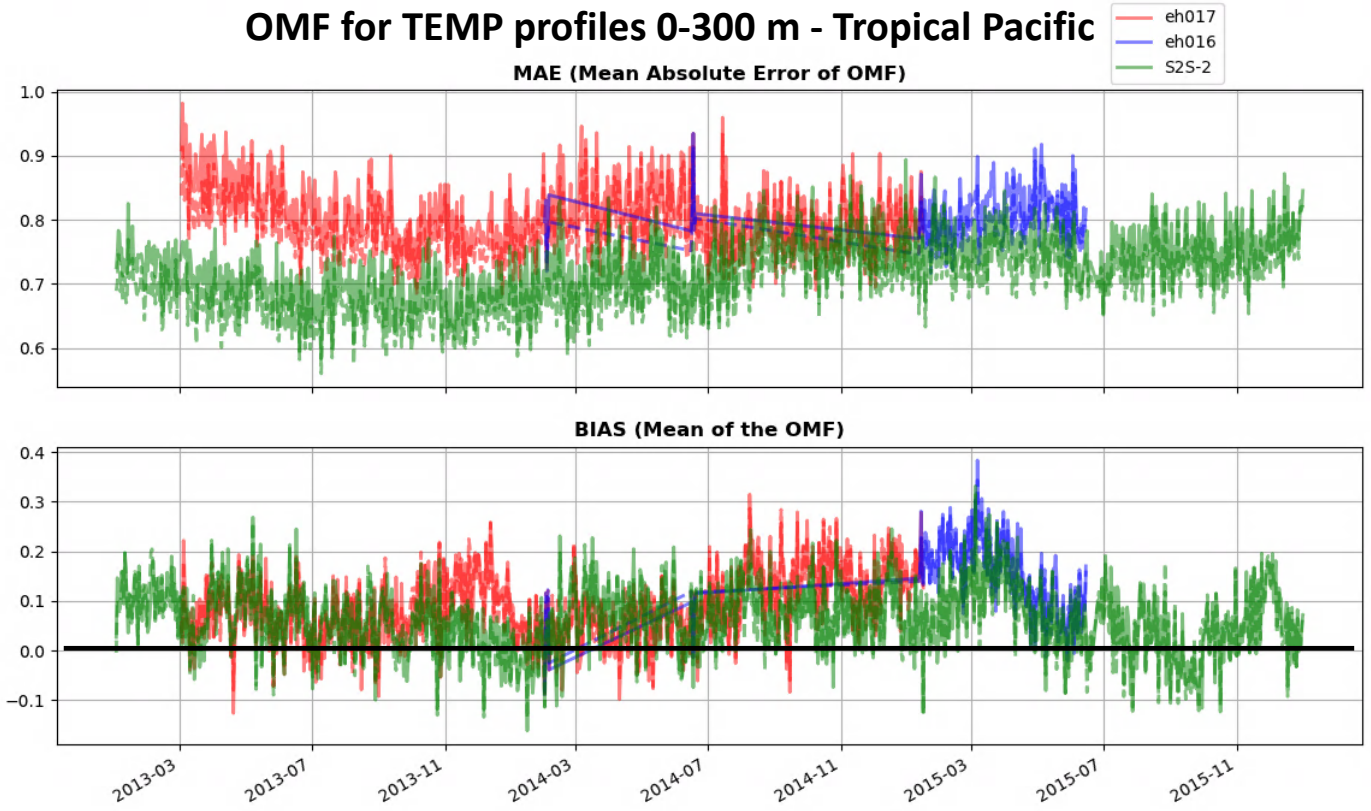
- Impact of SSS Assimilation (Hackert, PL24A-2643)
- New Atmosphere/Ocean Interface Layer (Akella, OM24B-3120)
- New Ensemble Strategy (Borovikov - OM24B-3128)

NASA

Validation GEOS-S2S-2 versus GEOS-S2S-3

- **<u>Very</u> preliminary validation of GEOS-S2S-2 versus GEOS-S2S-3**
- **Observation minus forecast (OMF) statistics for the tropical Pacific (30ºN-30ºS) and 0-300m**
  - **Temperature, Salinity , Absolute Dynamic Topography (ADT)**
  - **Mean OMF (top), Bias OMF (bottom), solid = forecast, dashed = analysis**
- **Forecasts from June – November, 1982**

Validation GEOS-S2S-2 versus GEOS-S2S-3



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S2S-3
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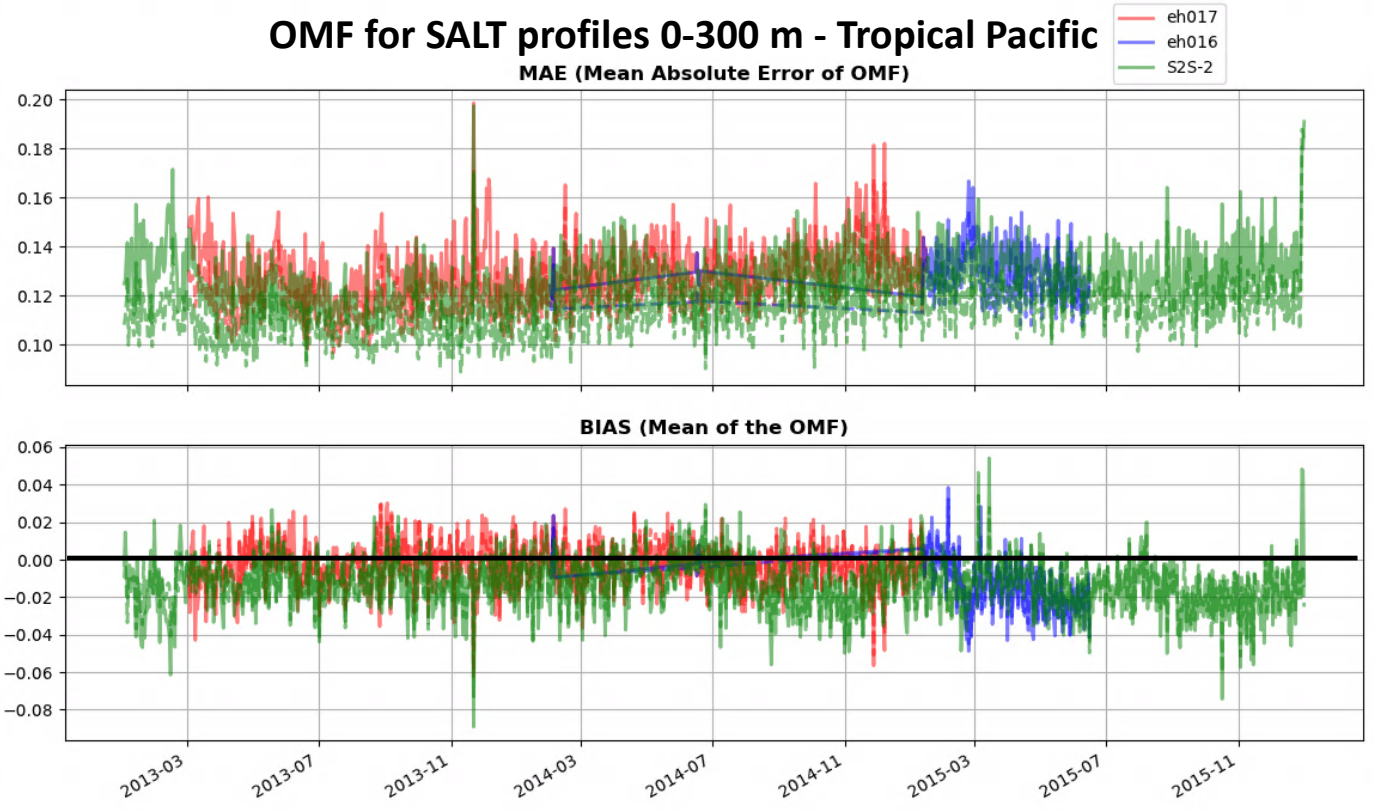
Validation GEOS-S2S-2 versus GEOS-S2S-3



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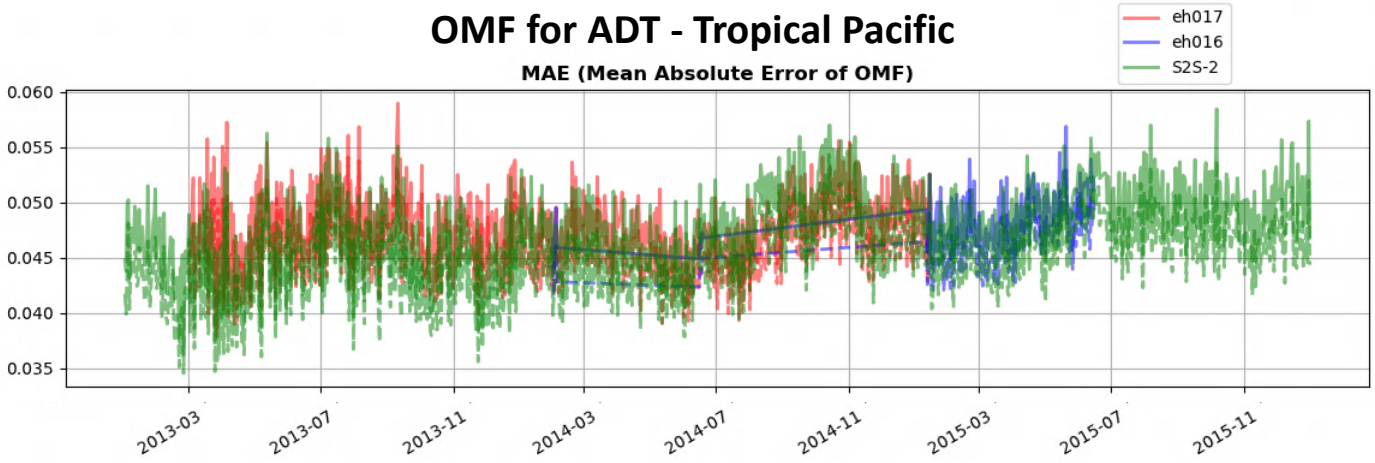
Validation GEOS-S2S-2 versus GEOS-S2S-3



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Validation GEOS-S2S-2 versus GEOS-S2S-3

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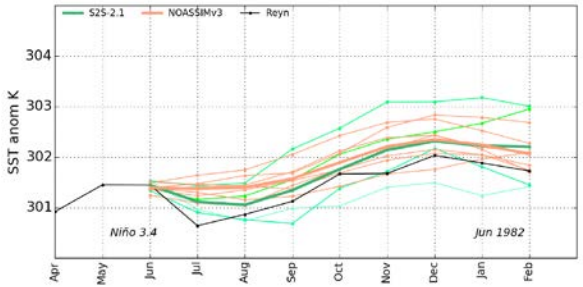
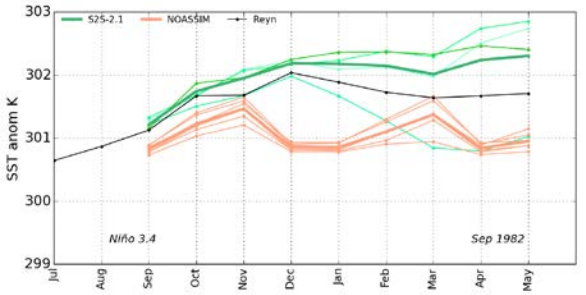
S2S-2

S2S-3

Production S2S-2 vs S2S-3 initialized from NOASSIM 1982 IC

JUN 82





SEP 82

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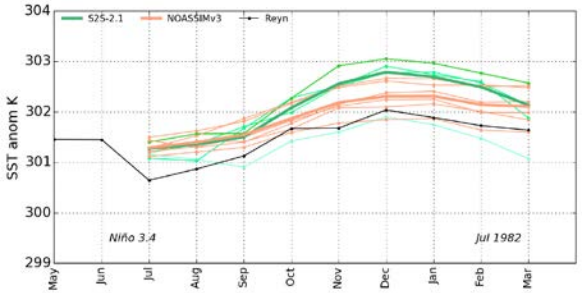
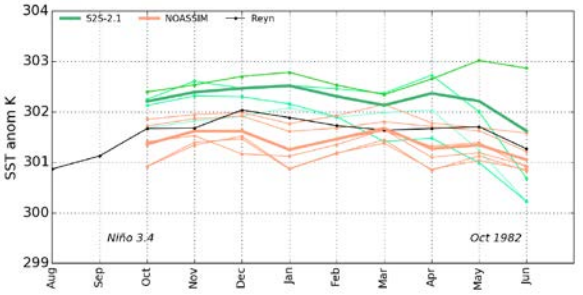
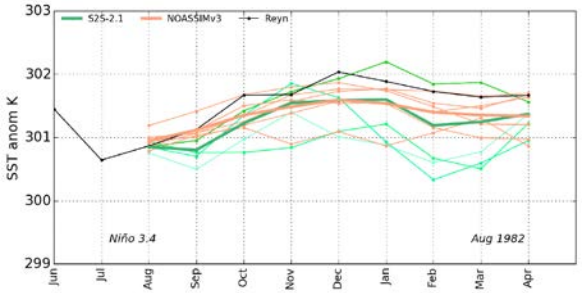
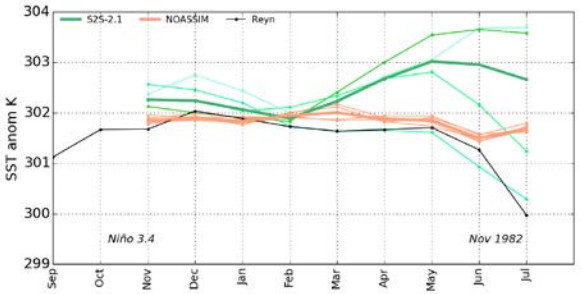




OCT 82

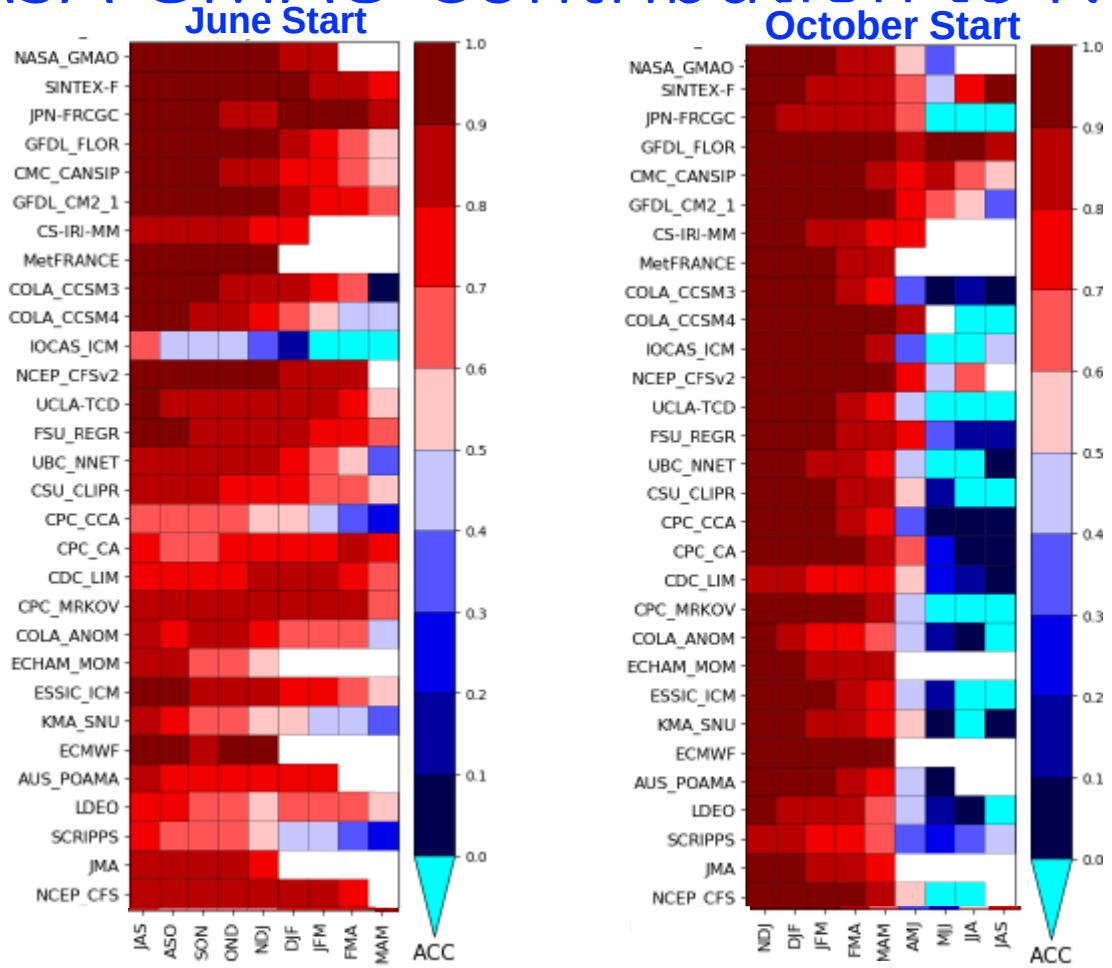
AUG 82





NOV 82

NASA GMAO Contribution to NMME



NINO3.4 Anomaly Correlation Coefficient for 2012-July 2019

From 2019 NASA Summer Student Lennard Poliakov