GEOS-S2S Version 3: The New GMAO Seasonal Prediction and Coupled Reanalysis System

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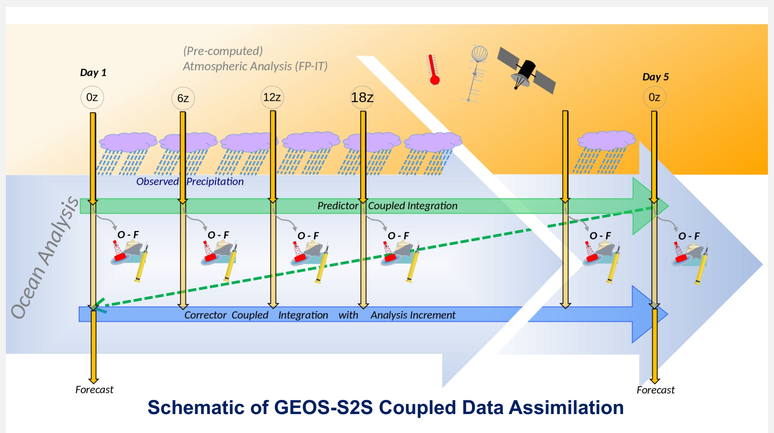
GMAO Global Modeling & Assimilation Office

Motivation

NASA/GSFC's Global Modeling and Assimilation Office (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.
GMAO's GEOS S2S system Version 3 will be released in late 2019, and will be used for MERRA-2 Ocean, a weakly coupled reanalysis spanning 1982 to present.

GMAO Coupled Ocean/Atmosphere DAS



Schematic of GEOS-S2S Coupled Data Assimilation

The GEOS-S2S AODAS includes an ocean predictor sequence (the green line near the middle of the figure) and a corrector sequence (the blue line along the bottom of the figure). As the predictor segment proceeds, every 6-hours the "ocean observers" are used to compute the departure of the model trajectory. These innovations are then used to perform an LETKF analysis. The analysis increments are applied over the first 18 hours of the corrector sequence.

The weak coupling mechanism is through the model. During all stages of the data assimilation, the coupled AOGCM performs the simulations, during which the atmospheric state is "replayed" to a pre-existing atmospheric analysis.

S2S Version 3: Models and Assimilation

Model
- AGCM: Post MERRA-2 generation, cubed sphere grid at ~0.5º, 72 hybrid sigma/pressure levels; GOCART interactive aerosol model, cloud indirect effect (2-moment cloud microphysics); MERRA-2 generation cryosphere; Glacier runoff to proper location in ocean
- OGCM: MOM5, ~0.25º, 50 levels
- Sea Ice: CICE-4.0

Coupled Ocean Data Assimilation System
- atmosphere is "replayed" to "FPIT" (like MERRA-2); precipitation correction over land; "Dual Ocean" during assimilation
- NCEP-like LETKF code/system
- Forecasts: initialized from MERRA2-Ocean ODAS
- Ensemble perturbations from analysis differences

Observations
- nudging of SST and sea ice fraction from MERRA-2 data;
- assimilation of in situ Tz and Sz including Argo, XBT, CTD, moorings;
- assimilation of satellite along-track Absolute Dynamic Topography
- sea ice concentration from the National Snow and Ice Data Center
- Assimilation of sea surface salinity from Aquarius/SMAP

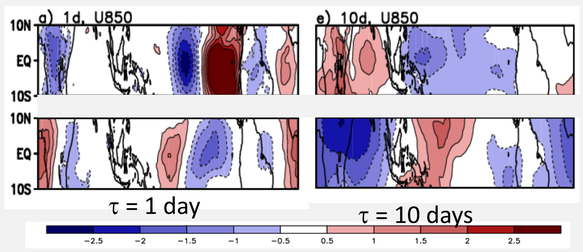
Upgrades with Major Impact:
- **New Ensemble Strategy**
- **Assimilation of Sea Surface Salinity**
- **"Dual Ocean" for Coupled Assimilation**

New GEOS-S2S-3 Ensemble Strategy

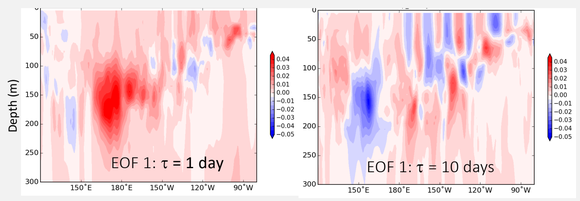
Motivation for Change in Ensemble Strategy: GEOS-S2S Tropical Pacific SST was found to be under-dispersive early in the forecast and over-dispersive later (Molod et al., 2019). This prompted the change in the ensemble perturbation strategy. Extratropical skill was lower than other state-of-the-art systems because of the small ensemble size. This prompted the change in ensemble size and the new approach to the number of ensembles.

Ensemble Perturbations

Typical structure of atmospheric perturbations in the tropics for zonal wind at 850mb and 200mb during December, January and February (DJF). The patterns are the leading EOFS computed from 1 day and 10 day differences . Results are based on based on MERRA-2.

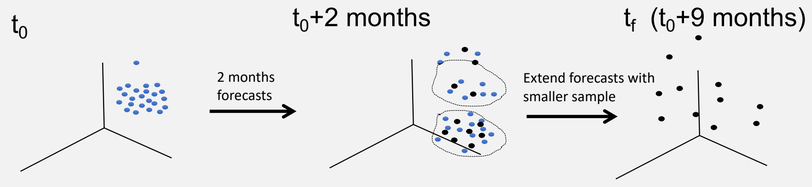


Typical structure of ocean temperature perturbations at t equal 1 day, and 10 day separations. The structures are the leading EOFs of the Pacific equatorial x-z cross section of temperature averaged between 2°S-2°N, and extending down to a depth of 300meters. Results are based on 100 randomly chosen pairs of ODAS restarts taken from SON of 2017.



From: Schubert et al., 2019

Ensemble Size

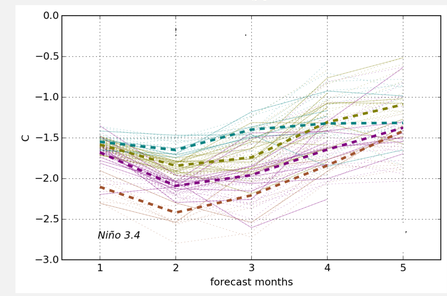


Initial ensemble size should be as large as possible for carrying out two month forecasts
After the first 2 months most atmospheric teleconnections and land impacts have little skill tied to initial conditions.

Stratify based on emerging directions of error growth, and allocate optimally (Neyman) or proportionally within each stratum
This is done based on the Nino3.4 index since it is largely ENSO that matters after the first 2 months. 3 strata were found to be adequate.

Final long-lead forecasts with the small subset of the initial larger ensemble

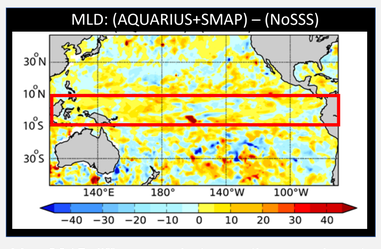
GEOS-S2S-3 Prototype Stratification



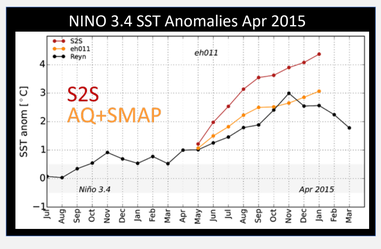
Example of results from stratification. Each color represents a different cluster based on the month 2 forecast, and the dark lines are the ensemble member selected to continue.

Impact of Satellite Sea Surface Salinity Observations on GMAO ENSO Predictions

Assimilation satellite sea surface salinity (SSS) from Aquarius (V5) and SMAP (V4.0) improves the near-surface density and the mixed layer depth (MLD) and modulates the Kelvin waves associated with ENSO. The deeper MLD (left) acts to dampen the ENSO Kelvin signal resulting in improved forecasts for the 2015 El Niño (right).



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.



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.

References

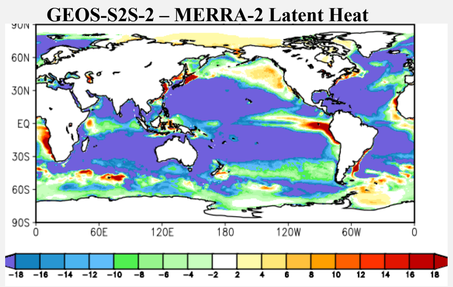
Molod, A., et al. (2019). GEOS-S2S Version 2: The GMAO High Resolution Coupled Model and Assimilation System for Seasonal Prediction. To be submitted to JGR Atmospheres

Schubert, S., A. Borovikov, Y-K. Lim, and A. Molod (2019). Ensemble Generation Strategies Employed in the GMAO GEOS-S2S Forecast System. NASA Tech. Memo. 104606, Volume 53, Tech. Rep. Series on Global Modeling and Data Assimilation 2019.

"Dual Ocean"

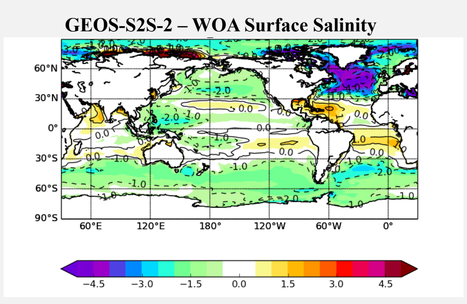
Motivation for Change: During Atmospheric DA the lower atmosphere "saw" a different SST than is predicted in coupled model

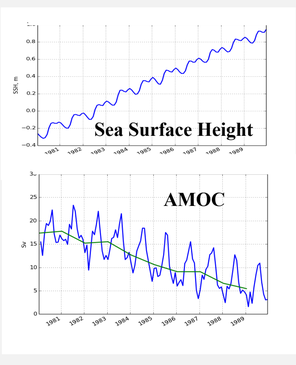
GEOS-S2S-2 – MERRA-2 Latent Heat



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

GEOS-S2S-2 – WOA Surface Salinity

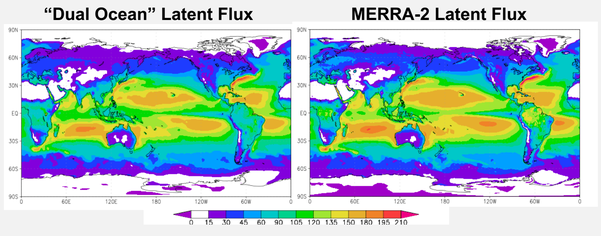




Reduced Latent Heat Resulted In:
Freshened Ocean, Sea Level Rise, Weakened AMOC

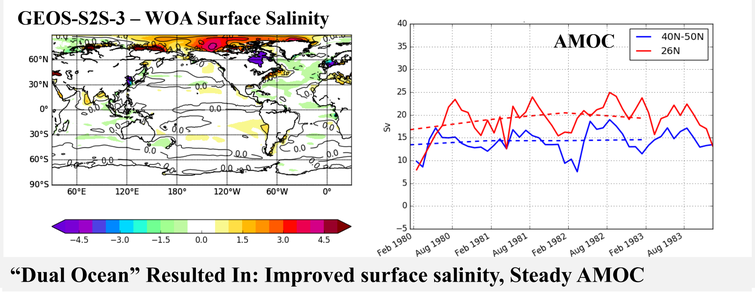
GEOS-S2S-3 Solution - "Dual Ocean": Compute near surface stability and latent heat flux (bulk formulae) using the SST that the data assimilation (MERRA-2) "saw"

"Dual Ocean" Latent Flux **MERRA-2 Latent Flux**



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

GEOS-S2S-3 – WOA Surface Salinity



"Dual Ocean" Resulted In: Improved surface salinity, Steady AMOC

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