Impact of Satellite Sea Surface Salinity Observations on ENSO Predictions from the NASA/GMAO Seasonal Forecast System

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ABSTRACT

We assess the impact of satellite sea surface salinity (SSS) observations on dynamical ENSO forecasts. Assimilation of SSS improves the mixed layer depth (MLD) and modulates the Kelvin waves associated with ENSO. In column 2, the initialization differences between experiments that assimilate SSS minus those withholding SSS assimilation are presented. Column 3 shows examples of forecasts generated for the different phases of ENSO assimilating the different satellite SSS. In general, for all phases of ENSO, SSS assimilation improves forecasts. The far right column compares ensemble means for assimilation of individual and combined SMOS, Aquarius, and SMAP SSS forecasts. Finally, the latest forecasts are presented comparing assimilation versus no-assimilation of satellite SSS for single forecasts over the last year.

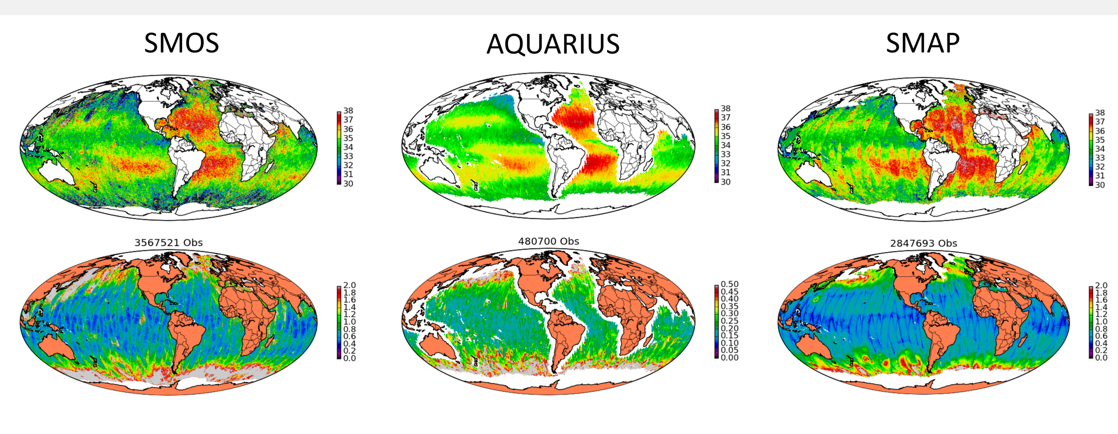
METHODOLOGY

The coupled model used in this project is the S2S_v2.1 that is the seasonal coupled forecast production model for NASA GMAO (NASA's NMME contribution). This version couples the 0.5° resolution, 72 level atmosphere (model version – Heracles-5_4_p3) with the Modular Ocean Model Version 5 (Griffies, 2012) with 0.5° resolution and 40 vertical levels. For all initialization experiments, all available along-track absolute dynamic topography (AVISO, 2013) and in situ observations (Argo, XBT, CTD, tropical moorings) are assimilated using a scheme similar to the LETKF of Penny et al., 2013. The process of forecast, ocean observer, and analysis is applied every 5 days using intermittent replay and 18 hour IAU. DA ensemble members come from monthly averaged anomalies of 20 freely coupled experiments re-centered around the background. In order to minimize the transition from the NASA GMAO atmospheric reanalysis, SST is relaxed to MERRA-2 (Gelaro et al., 2017). Note that the current system neither relaxes to nor assimilates observed SSS but does replay to MERRA2 precipitation.

EXPERIMENT DESIGN

Additional reanalysis experiments were executed that assimilate SSS along-track products (SMOS V3 – Boutin et al., 2018, Aquarius V5 - Lilly and Lagerloef, 2008, and SMAP V4._ - Fore et al., 2016). From these initialization reanalyses (along with the standard S2S experiment described above), 9 month coupled forecasts are initialized every 5-days spanning April 2015 (El Niño), May 2017 (La Niña) and April 2018 (weak El Niño). SMOS and Aquarius/SMAP data overlap so another set of forecasts are initialized to compare coupled experiments initialized from a combination of all these data. All results are then validated against observed NINO 3.4 values (SST – Reynolds et al., 2002).

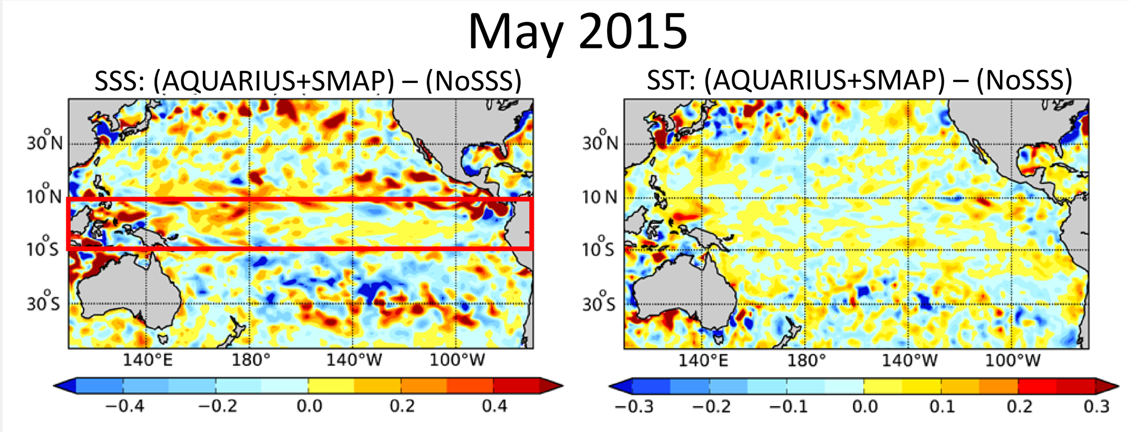
ASSIMILATION DATA



An example of May 15, 2015 assimilation data used in this study. Along-track SSS data are assimilated for 5 days. Note that SMOS and SMAP have the higher observation error than Aquarius due to different radiometer characteristics. Data are from SMOS V3 (Boutin et al., 2018), Aquarius V5 (Lilly and Lagerloef, 2008) and SMAP V4._ (Fore et al., 2016).

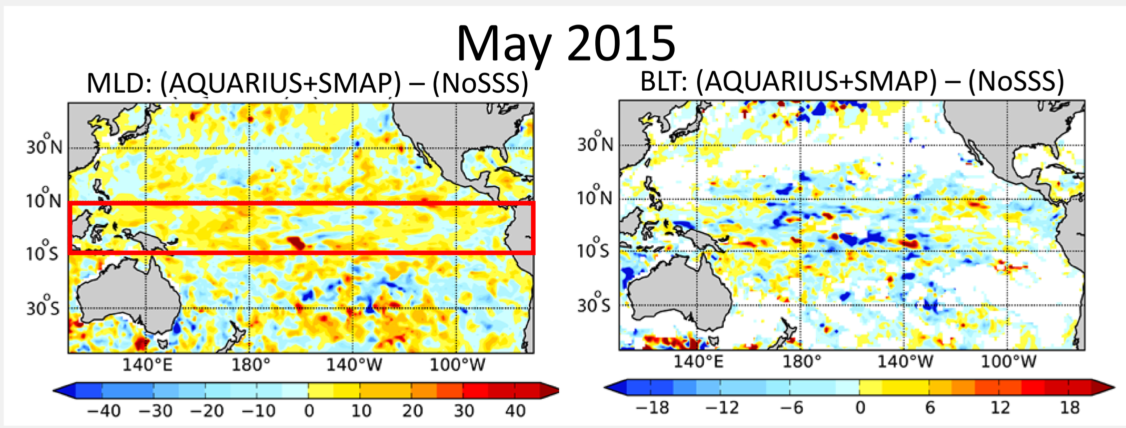
IMPACTS ON INITIAL CONDITIONS

Surface Differences



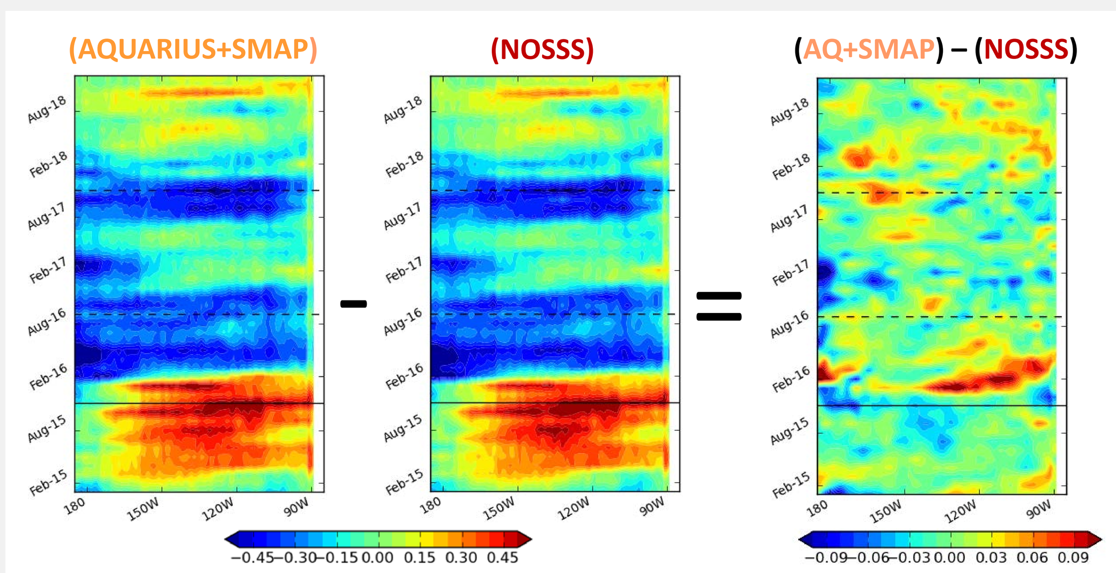
May 2015 differences between the experiment that assimilates both Aquarius and SMAP Sea Surface Salinity (SSS) minus the experiment that withholds SSS assimilation for (left) SSS and (right) SST. Improved (somewhat saltier) SSS, combined with SST, increase near-surface density within the equatorial waveguide (density plot essentially matches SSS, so it's not shown). Also, SMOS results look similar to these examples.

Mixed and Boundary Layer



Increased density near the equator leads to deeper MLD (left) and shoaling of the barrier layer thickness (BLT – right). Increased MLD leads to damped ENSO response due to reduced efficiency of wind forcing on a relatively deeper MLD. Mixed layer depth is defined as the depth where the surface density increases to a value that would equal a 0.2°C temperature change, keeping salinity the same as SSS. BLT is the difference between the isothermal depth (i.e. temperature within 0.2°C of the SST) minus the MLD. Thus, the BLT insolates the MLD from the deeper cooler ocean.

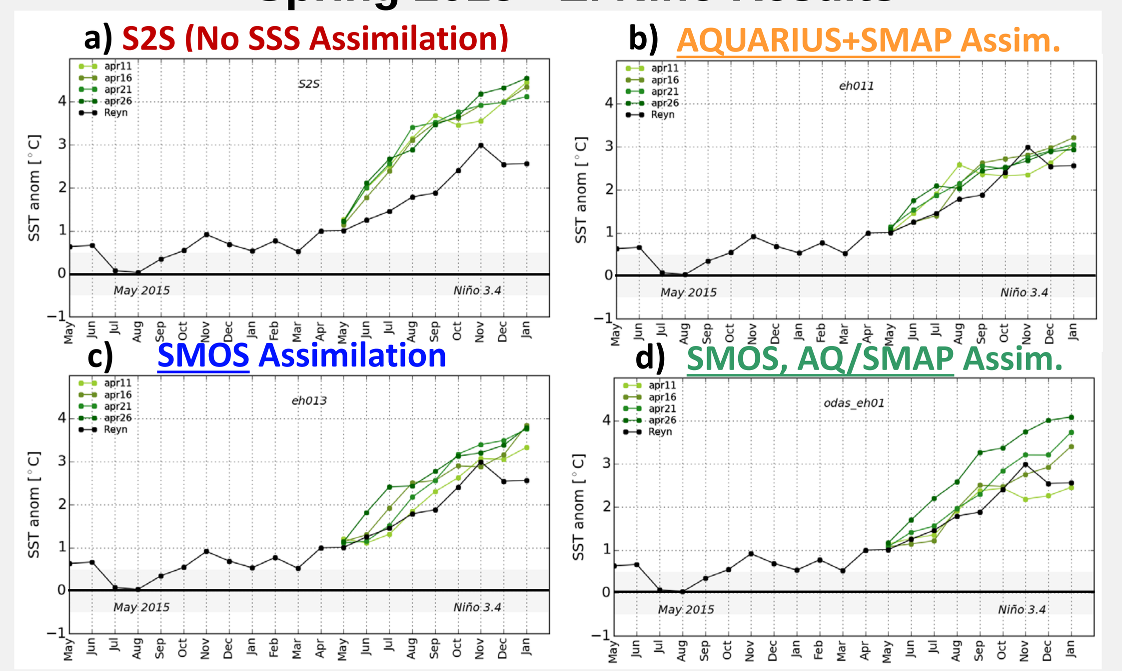
Kelvin Wave Amplitude



Using the technique of Delcroix et al., 1994, sea level anomalies can be decomposed into the Kelvin wave signal. Left panel shows the experiment that assimilates both Aquarius and SMAP, middle panel is the S2S experiment (i.e. with no SSS assimilation). The right panel shows the differences, SSS assimilation minus no-assimilation. Note that the ENSO signal is generally damped due to SSS assimilation (e.g. downwelling/upwelling Kelvin wave is damped during the 2015 El Niño/2016 La Niña). Correlation between right panel versus NINO3.4 SST' = -0.46 (signif. at 95%, SST' lag U'_{KEL} by 4 months).

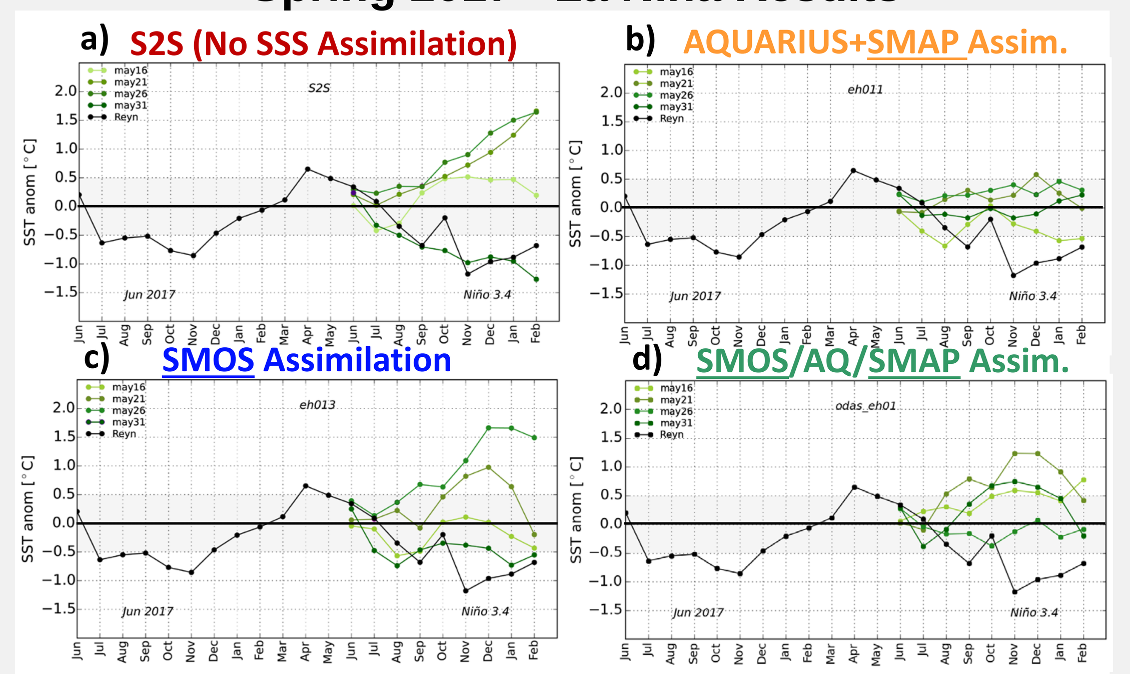
ENSO FORECASTS

Spring 2015 - El Niño Results



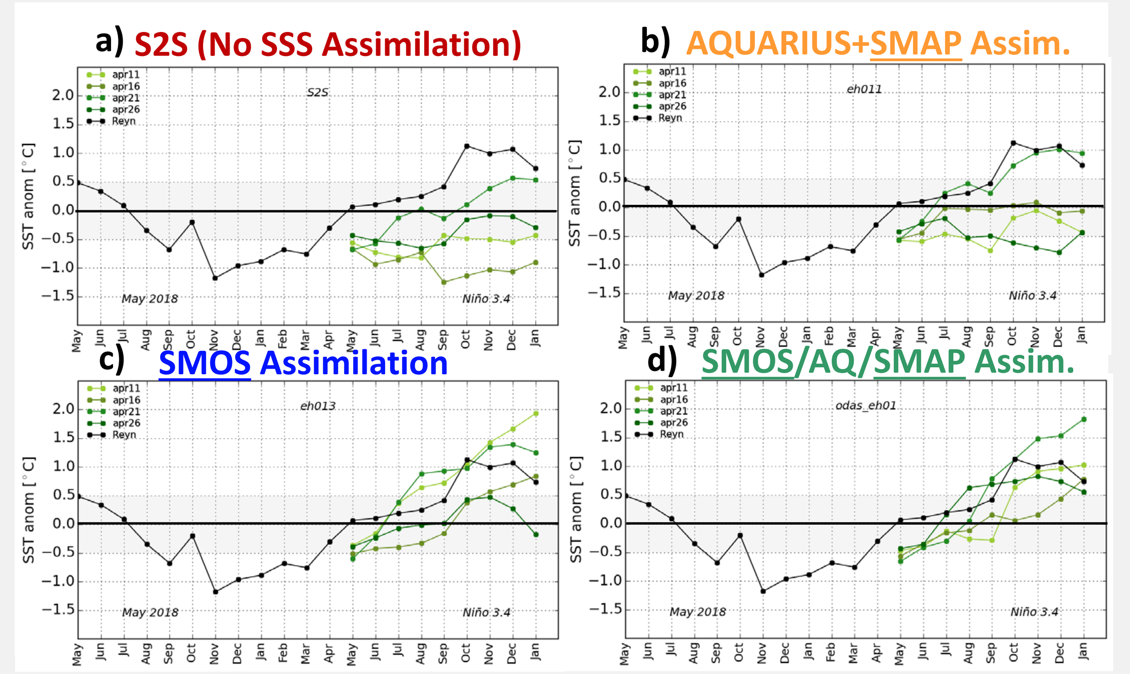
NINO3.4 forecast plume plots initialized from April 2015 for a) no SSS assimilation, b) AQ/SMAP c) SMOS, and d) SMOS/AQ/SMAP satellite SSS assimilation. Note that the thicker MLD from assimilation of SSS damps the warming of downwelling Kelvin waves for the big 2015 El Niño.

Spring 2017 - La Niña Results



Forecast plume plots for May 2017. The negative MLD differences and relative upwelling from SMAP SSS assimilation (b) acts to give a more realistic forecast for the 2017 La Niña. The wide spread of forecasts in c) and d) increases the uncertainty for the El Niño forecast of the NO SSS forecast (a).

Spring 2018 - Current ENSO Results



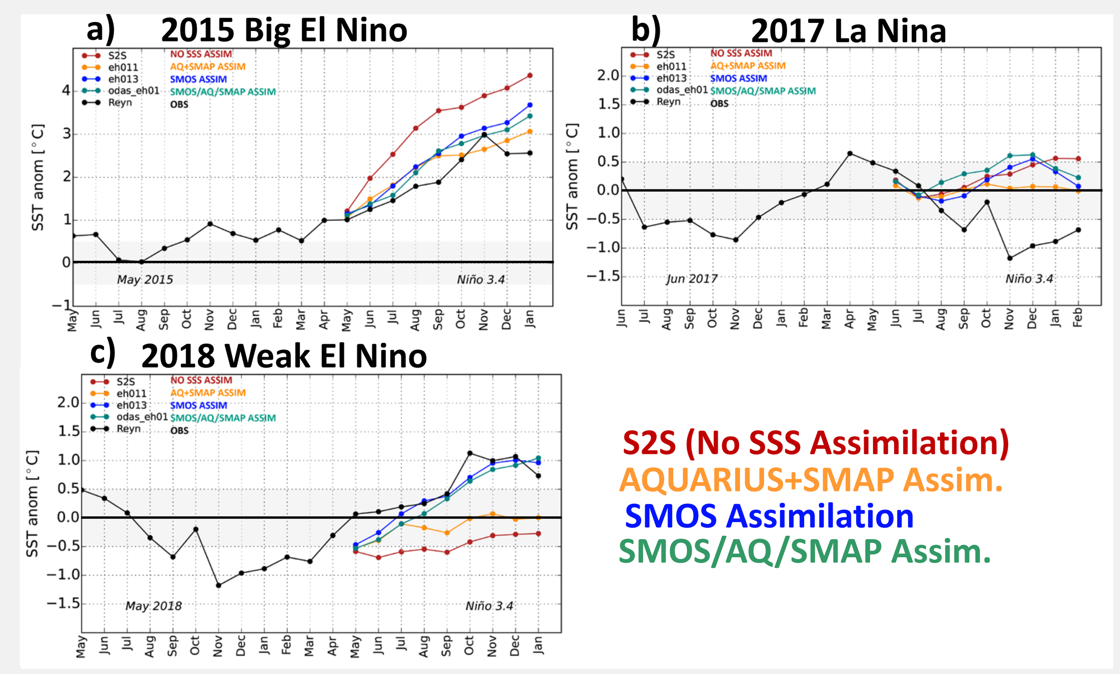
For April 2018, the NO SSS forecasts (a) completely missed the moderate El Niño. However, fresh SSS and shoaled (i.e. negative) MLD near the equator improved the NINO3.4 forecast to closely match observations. For this case, the impact of SMOS assimilation (c) and especially in combination with SMAP (d) flipped upwelling to downwelling and resulted in the improved forecasts.

CONCLUSIONS

1) ASSIM SSS ➡ changes in SSS ➡ changes in near-surface density ➡ modifies MLD and BLT.
2) Improved MLD acts to modify ENSO (Kelvin) signal to a) dampen the 2015 El Niño b) neutralize the 2017 erroneous El Niño, and c) change upwelling (La Niña) to downwelling (El Niño) in 2018.
3) Assimilating satellite SSS ➡ improved ENSO forecasts. Often multiple satellite SSS outperform single satellite results.
4) For 2019, SSS assimilation has better represented the forecast trend from a weakening El Niño to neutral conditions

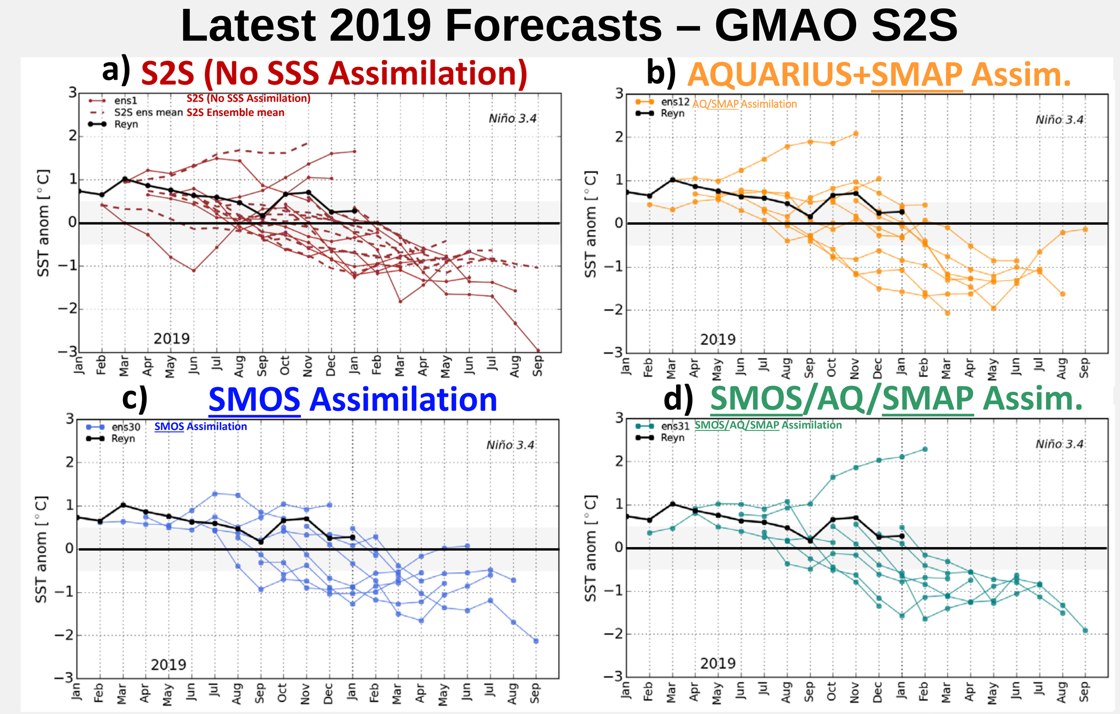
TAKE HOME RESULT – Assimilation of satellite SSS improves ENSO Forecasts

Ensemble Mean Results for Different ENSO Stages



Summary of column 3 results: The ensemble mean for a) 2015 and c) 2018 El Niño forecasts shows the clear improvement due to SSS assimilation. For 2018, SMOS and SMOS+SMAP improves the forecasts significantly. For b) the 2017 La Niña the improvement is less dramatic. However, the SMAP forecast is an improvement over the NO SSS forecast over the entire 9-months.

Latest 2019 Forecasts – GMAO S2S



For all forecasts, the general trend is towards neutral then La Niña conditions. The single-forecast, NO SSS ASSIM, spread (solid in a) is generally greater than the SSS experiments spread (b-d) especially in early 2019 and SSS experiments appear to be coming to the consensus cooling sooner. If our S2S ensemble average of 10 forecasts (dashed lines in a) is to be believed, then the few SSS experiments better represent the S2S predictions (especially in c and d).

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