Impact of Satellite Sea Surface Salinity Observations on ENSO Predictions from the GEOS GMAO S2S 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 initialisation 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. From March to June 2015, the availability of two overlapping satellite SSS instruments, Aquarius and SMAP, allows a unique opportunity to compare and contrast coupled forecasts generated with the benefit of these two satellite SSS observation types. The right column compares assimilation of Aquarius, SMAP, and combined Aquarius and SMAP on forecasts for the 2015 El Niño.

METHODOLOGY
The coupled model used in this project is the S2S_v2.1 that has recently become 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 (Griffies, 2012) with no SSS assimilation (i.e. downwelling/upwelling Kelvin wave is damped during the La Niña). The short period of April to June 2015 of overlapping SSS satellite coverage allows comparison of the impact of Aquarius versus SMAP. Independent experiments are initialized from May 2015 for Aquarius, SMAP and the combination of AQUARIUS+SMAP assimilation.

EXPERIMENT DESIGN
Additional reanalysis experiments were executed that assimilate SSS gridded products (Aquarius V5 - Lilly and Lagerloef, 2008, and SMAP V4 - Fore et al., 2016). From these initialization experiments (along with the standard S2S experiment described above), 9 month coupled experiments are initialized every 5 days spanningApril 2015 (El Niño), April 2016 (La Niña) and April 2014 (neutral). Both Aquarius and SMAP data are available for May 2015 so another set of forecasts is initialized to compare coupled experiments initialized from these data. All results are then validated against observed NINO3.4 values (IST – Reynolds et al., 2002).

ASSIMILATION DATA
An example of May 1, 2015 assimilation data used in this study. Gridded SSS L3 data are assimilated every 6 hours resulting in a saturation of data similar to the coverage of 24 satellites. Also note that SMAP has the same observation error as Aquarius (SMAP is more like 4x greater observation error). Data are from Aquarius V5 Lilly and Lagerloef, 2008 and SMAP V4.0 (Fore et al., 2016).

Using the technique of Delcroix et al., 1994, sea level anomalies can be deconstructed 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 (i.e. downwelling/upwelling Kelvin wave is damped during the 2015 El Niño). However, the S2S did a reasonable job of forecasting a weak El Niño (top left). Assimilation of SSS further modulated the NINO3.4 forecast to more closely match observations out to 5 months (bottom).

NINO3.4 forecast plume plots for experiments initialized in May 2015 for (top left) no SSS assimilation, (top right) assimilation of satellite SSS and (bottom) ensemble mean of Apr forecasts. Note that the thicker MLD from assimilation of SSS damps the warming of downwelling Kelvin waves for the big 2015 El Niño.

CONCLUSIONS
1) ASSIM SSS changes in SSS improves near-surface density; deepens MLD and shoals BLT
2) Deeper MLD acts to dampen ENSO (Kelvin) signal
3) Dampened ENSO cooling too warm El Niño and warming too cool La Niña
4) For the short overlapping period (Mar to Jun 2015) a) Any assimilation improves El Niño forecast b) Both maturity of algorithm and quantity of data impact forecasts (in order - SMAP, Aquarius, Aquarius + SMAP assimilation improves forecasts)

TAKING HOME RESULT – Assimilation of satellite SSS improves ENSO Forecasts

IMPACT OF AQUARIUS VERSUS SMAP 2015 Background and Experiment Design
The short period of April to June 2015 of overlapping SSS satellite coverage allows comparison of the impact of Aquarius versus SMAP. Independent experiments are initialized from May 2015 for Aquarius, SMAP and the combination of AQUARIUS+SMAP assimilation.

May 2015 El Niño Forecasts

NINO3.4 forecast plume plots for experiments initialized in May 2015 for (top left) no SSS assimilation, (top right) assimilation of a combination of Aquarius and SMAP, (bottom left) Aquarius, and (bottom right) SMAP assimilation. Note that any assimilation of SSS improves forecasts of the 2015 El Niño. Aquarius slightly outperforms SMAP, and the experiment that combines Aquarius and SMAP data give the best overall results.