The Impact of Satellite Sea Surface Salinity for Prediction of the Coupled Indo-Pacific System

E. Hackert, R. Kovach, J. Ballabrera-Poy, A.J. Busalacchi, and G. Vernieres

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ABSTRACT

Here we assess the impact of satellite sea surface salinity (SSS) observations on seasonal to interannual variability of tropical Indo-Pacific Ocean dynamics as well as on dynamical ENSO forecasts. The baseline experiment assimilates satellite sea level (SL), sea surface temperature (SST), and in situ subsurface temperature and salinity observations (T_z, S_z). These baseline experiments are then compared with experiments that additionally assimilate Aquarius (version 5.0 *Lilly and Lagerloef, 2008*) and SMAP (version 2.0 *Meissner and Wentz, 2016*) SSS. Twelve-month forecasts are initialized for each month from September 2011 to September 2017. We find that including satellite SSS significantly improves NINO3.4 sea surface temperature anomaly validation over 0-8 month forecast lead-times and removing the salty bias from SMAP data helps to extend useful forecasts out to 12 month lead-times.

METHODOLOGY

Our intermediate-complexity coupled model uses the anomaly coupling technique (e.g. *Kroeger and Kucharski, 2011*) and is comprised of the reduced-gravity, primitive equation, sigma-coordinate ocean model (*Gent and Cane, 1989*) that is coupled with the global SPEEDY atmospheric model (*Molteni, 2003; Kucharski et al., 2006*). The Ensemble Reduced Order Kalman Filter (EROKF) assimilates observations to constrain dynamics and thermodynamics for initialization of the coupled system.

Ocean Model – Encompasses the tropical Indo-Pacific (33ºE-76ºW, 30ºN-30ºS), resolution of 1ºx1/3º stretched, 20 layers (~1500 m), includes river contribution [*Dai and Trenberth, 2002*]. Forcing by MERRA2 reanalysis [*Gelaro et al., 2017*].

Atmospheric Model – SPEEDY (for Simplified Parameterizations, primitivE-Equation Dynamics) Version 4.1 (*Molteni 2003, Kucharski et al., 2006*) - 3.8º resolution, 8 levels (925-30mb). Winds improved using convective momentum transport of *Kim et al., 2008.* SST' is supplied by the model within Indo-Pacific region and by HadISST (*Rayner et al., 2003*) outside.

EROKF Data Assimilation Technique - Assimilate SL (Multi-satellite product of *Aviso, 2013*), SST (*Reynolds et al., 2002*) and T_z, S_z (GTSPP *NODC 2006*). Additionally assimilate satellite gridded SSS of Aquarius V5.0 (*Lilly and Lagerloef, 2008*) and SMAP V2 (*Meissner and Wentz, 2016*).

EXPERIMENT DESIGN

	Experiment Name	Period	Assimilation Variables
Columns 2,3	ASSIM_SL_SST_T_z_S_z "Control"	Jan 1993 – Sep 2017	SL, SST, T_z and S_z
	ASSIM_SL_SST_SSS_T_z_S_z Known as "SSS Assimilation"	Sep 2011 – Sep 2017*	SSS from Aquarius Version 5.0 combined with SMAP Version 2.0 Level 3 data and SL, SST, T_z, and S_z
Columns 4	ASSIM_SL_SST SSS(AQ/SMAP_mod)_T_z_S_z "AQ/SMAP MODIFIED"	Sep 2011 – Sep 2017*	Level 3 SSS data from Aquarius /SMAP with (AQ–SMAP) added and SL, SST, T_z, and S_z

*NOTE – spin up of SSS Assimilation experiments assimilate an OI of near-surface in situ observations from Jan 1993-Aug 2011

E-mail: eric.c.hackert@nasa.gov
Web: gmao.gsfc.nasa.gov

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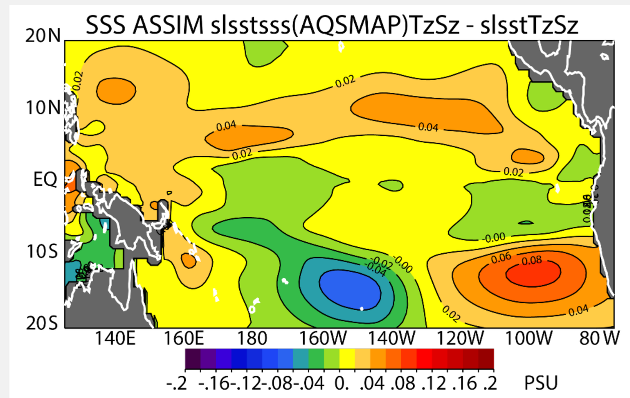
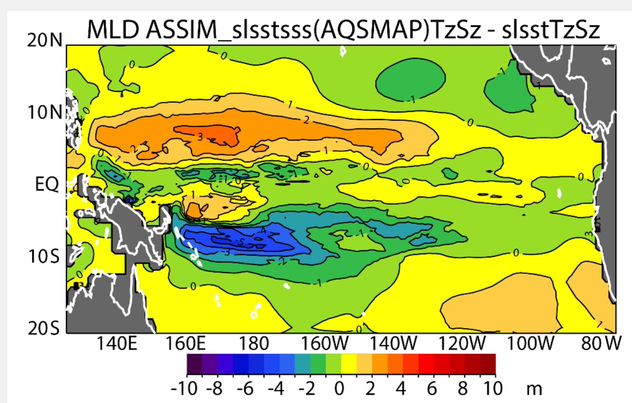
INITIALIZATION DIFFERENCES

SSS (SSS ASSIM – CONTROL)



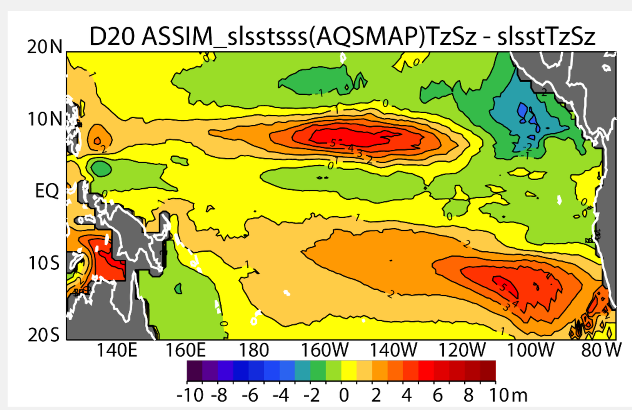
Data assimilation differences over 9/11-9/17 for SSS. SSS is fresher over warm/fresh pool in the western Pacific, equatorial waveguide, and SPCZ and saltier over ITCZ. SSS impacts density directly and near-surface density differences match this plot (but not shown).

Mixed Layer Depth (SSS ASSIM – CONTROL)



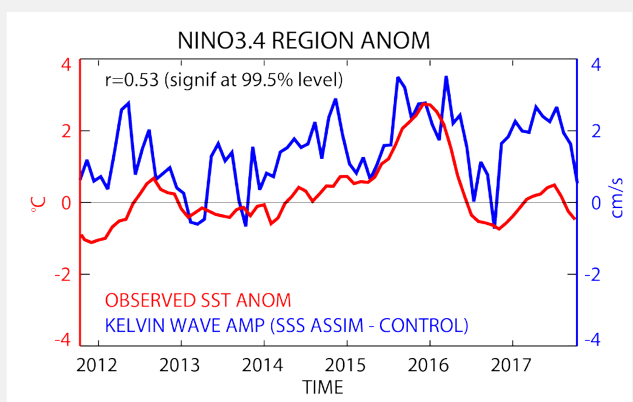
MLD responds to density changes and shoals throughout the equatorial waveguide (15ºS-5ºN) and deepens along the ITCZ. Shallower MLD couples more efficiently to atmospheric forcing and amplifies equatorial Kelvin waves associated with ENSO.

Depth of 20ºC Isotherm (SSS ASSIM – CONTROL)



Depth of 20ºC isotherm represents the depth of the thermocline. The thermocline shoals along the equator further enhancing the impact of air/sea coupling on equatorial Kelvin waves.

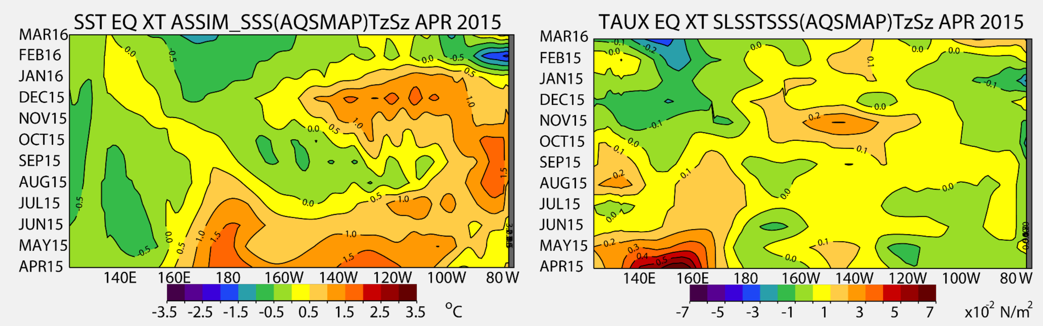
Kelvin Wave (SSS ASSIM – CONTROL) versus SST'

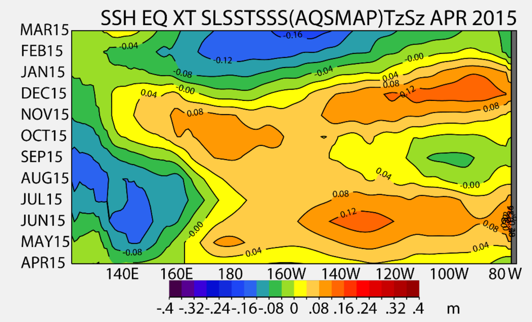


Index of the Kelvin wave amplitude of ASSIM SSS – CONTROL (blue curve) versus SST anomaly (red) in the NINO3.4 region. Significant correlation between the two shows that Kelvin wave amplitude (and ENSO signal) is enhanced due to SSS ASSIM. Kelvin Amplitude from technique of Delcriox et al., 1994

FORECAST DIFFERENCES AND VALIDATION

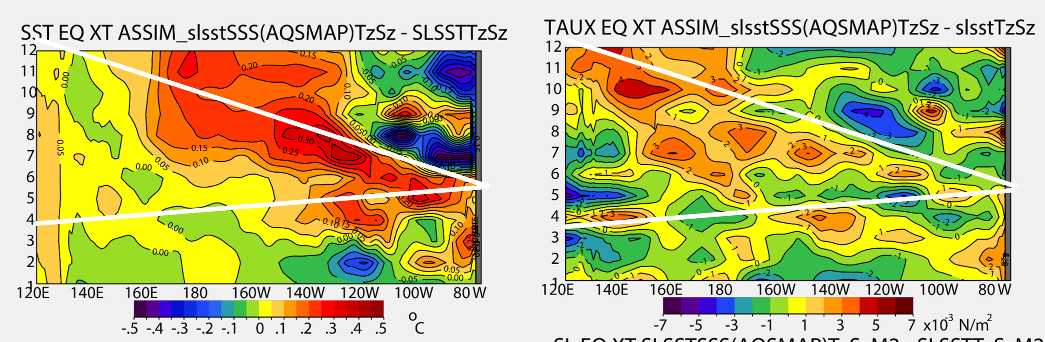
Example of April 2015 Forecast

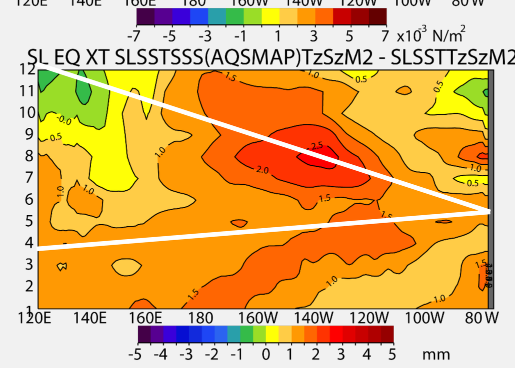




Example of April 2015 forecast Using equatorial Hovmöller diagrams. Warming near the dateline propagates eastward building warm SST in the eastern Pacific (upper left). Anomalous westerlies (upper right) follow the SST' and easterlies fill in the western basin from Oct 2015 on. Downwelling Kelvin waves (bottom right) are clearly initiated from Apr and Aug Westerly Wind Bursts (WWB). Later upwelling Kelvin waves set the stage for demise of the 2015 El Nino.

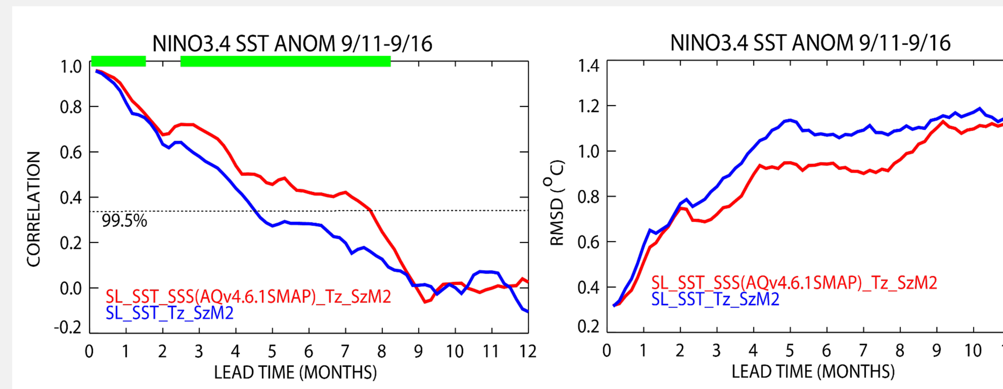
Mean Forecast Differences (SSS ASSIM – CONTROL)





Mean equatorial Hovmöller diagrams of forecast differences (SSS ASSIM-CONTROL) for 9/11-9/17. SST evolution (upper left) is governed by the big 2015 El Nino development. Zonal wind stress (upper right) follow the SST with westerlies to the west and easterlies to the east of the warmest SST'. Sea level (bottom right) is dominated by downwelling Kelvin and Rossby waves (wave speed is indicated by positive and negative sloped lines, respectively).

Coupled Model Validation



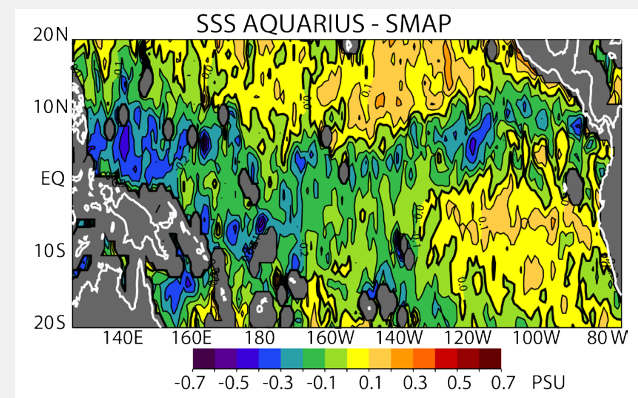
Validation of the coupled results using observed NINO3.4 SST'. Correlation is significantly higher with SSS assimilation from 0-8 months and RMSD is lower for all lead forecasts for the ASSIM SSS (red) versus CONTROL (blue). Useful forecasts are extended from 4 to 8 months due to SSS assimilation (e.g. follow along thin dash line). Green line at top indicates where the differences exceed the 95% significance using the Steiger Z test. Thus, SSS assimilation significantly improves long-lead coupled forecast statistics

CONCLUSIONS

1) Including satellite SSS significantly improves NINO3.4 sea surface temperature anomaly validation out to ~8 month forecast lead-times.
2) For initialization of the coupled forecast, the positive impact of SSS assimilation is brought about by surface freshening near the eastern edge of the western Pacific warm pool and density changes that lead to shallower mixed layer between 10ºS-5ºN. In addition, salting near the ITCZ leads to a deepening of the mixed layer and thermocline near 8ºN. These patterns together provide the background state to amplify equatorial Kelvin waves and ENSO signal.
3) Additional experiments are presented that demonstrate the impact of the SMAP versus Aquarius. This preliminary version of SMAP data shows a salty bias over the entire warm/fresh pool and within the equatorial wave-guide stretching just north of the equator into the eastern Pacific.
4) Removing this bias leads to significantly improved coupled forecasts after 8 month lead-times extending useful ENSO forecasts out to 12 month lead-times.
5) These results have relevance in the context of combining Aquarius and SMAP SSS as a continuous climate data record.

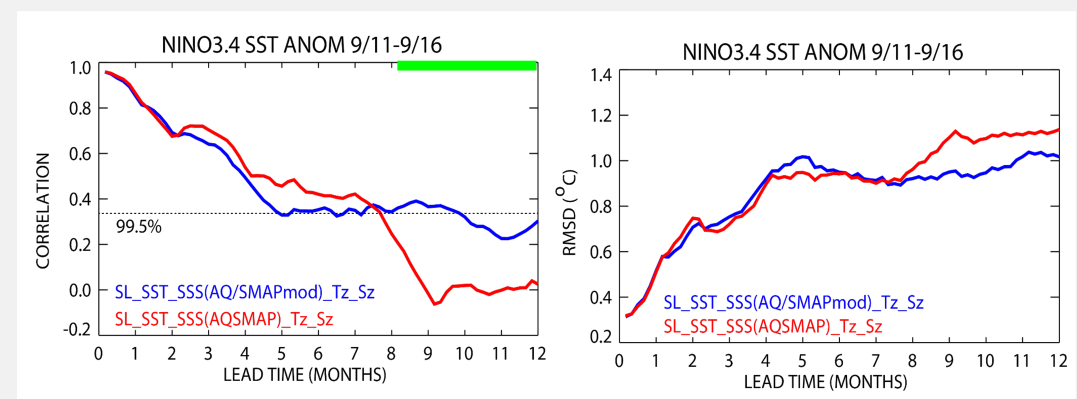
IMPACT OF SMAP/AQUARIUS BIAS

Bias Between Aquarius and SMAP



Short overlap period between SMAP and AQUARIS (Apr 6 – May 26, 2015) indicates a strong salty bias of up to 0.4 PSU for SMAP V2 versus Aquarius V5. Using this bias, the Aquarius/SMAP bias was removed from SMAP and coupled experiments were rerun (i.e. the AQ/SMAP modified experiments).

Coupled Model Validation



ASSIM SSS (red line) results are reproduced from the slides to the left. The blue line is now the NINO3.4 observed SST' validation of the experiment that has de-biased the SMAP data using the Aquarius/SMAP overlap (depicted above). Salty biased SMAP data is responsible for degradation of the model for 8-12 month lead times. In this case the Steiger Z test (thick green line) is for AQ/SMAPmod versus AQ/SMAP

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