Assessment of Sea Surface Salinity Products Using a Coupled ENSO Prediction Model

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ABSTRACT

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. Twelve-month forecasts are initialized for each month from September 2011 to September 2017. All experiments assimilate satellite sea level (SL), sea surface temperature (SST), and in situ subsurface temperature and salinity observations (T_z, S_z). Additionally various satellite, blended, and in-situ SSS products are assimilated. Using our intermediate-complexity coupled model as a transfer function, we test if more mature SSS model algorithms actually improve ENSO forecast skill. **We find that including satellite SSS significantly improves Niño3.4 sea surface temperature anomaly validation, more mature SSS model algorithms are generally improving ENSO forecasts over time, and more satellite SSS helps to extend useful forecasts.**

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 (33°E-76°W, 30°N-30°S), resolution of 1°x1/3° 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*) - 3.8° 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, blended and in situ gridded (L3) SSS products described in the table below.

EXPERIMENT DESIGN

Category	Experiment Shorthand	Experiment Name
NO SSS ASSIM	NO SSS ASSIM	ASSIM_SL_SST_T_z_S_z
IN SITU SSS	GMAO OI	SL_SST_SSS(GMAO_OI)_Tz_Sz
	CORA5	SL_SST_SSS(CORA5)_Tz_Sz
BLENDED SSS	SMOSISOI	SL_SST_SSS(SMOSISOI)_Tz_Sz
	BASS	SL_SST_SSS(BASS)_Tz_Sz
SATELLITE SSS	SMOSv2.1	SL_SST_SSS(SMOSv2.1)_Tz_Sz
	SMOSv3	SL_SST_SSS(SMOSv3)_Tz_Sz
	AQ+SMAPv3	SL_SST_SSS(AQSMAPv3)_Tz_Sz
	AQ+SMAPv4	SL_SST_SSS(AQSMAPv4)_Tz_Sz
	AQ+SMAPv4.1	SL_SST_SSS(AQSMAPv4.1)_Tz_Sz
	AQ+SMAPv4.2	SL_SST_SSS(AQSMAPv4.2)_Tz_Sz
MULTI-SATELLITE SSS	SMOSv3+AQ+SMAPv4.2	SL_SST_SSS(SMOSAQSMAPv4.2)_Tz_Sz

All examples of SMAP are combined with Aquarius v5.
All experiments are run from September 2011 to September 2017.

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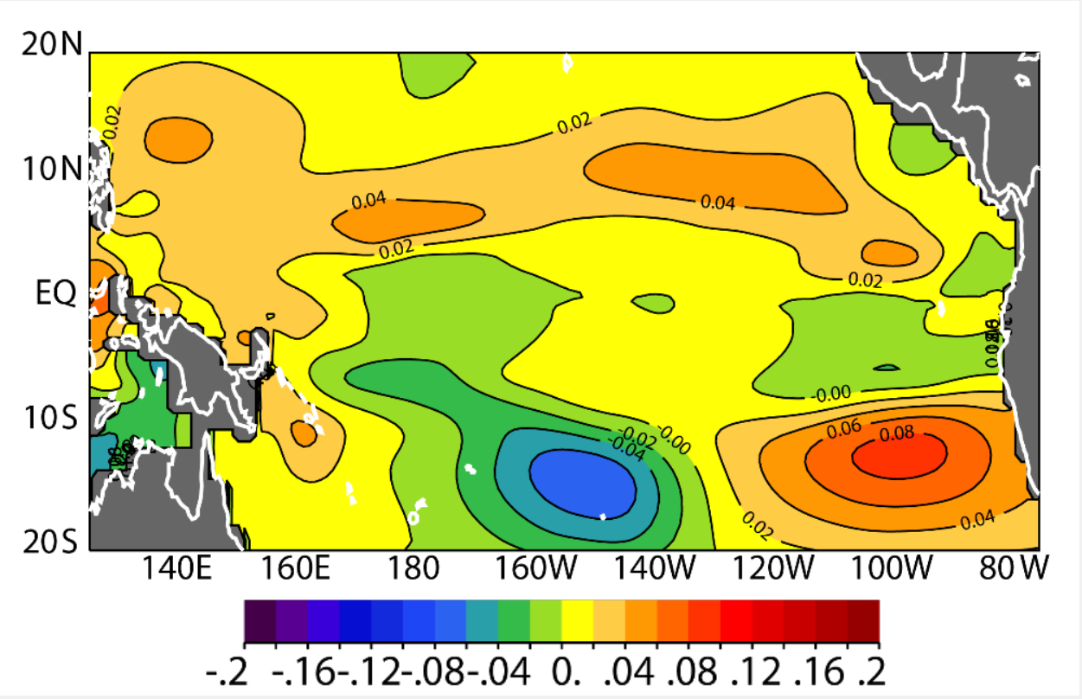
Work Supported by GMAO and OSST Grant NNX16ZDA001N-OSST

Motivation- Why SSS Assimilation Improves ENSO Forecasts

from Hackert et al., 2019 JGR Oceans (https://doi.org/10.1029/2019JC015130)

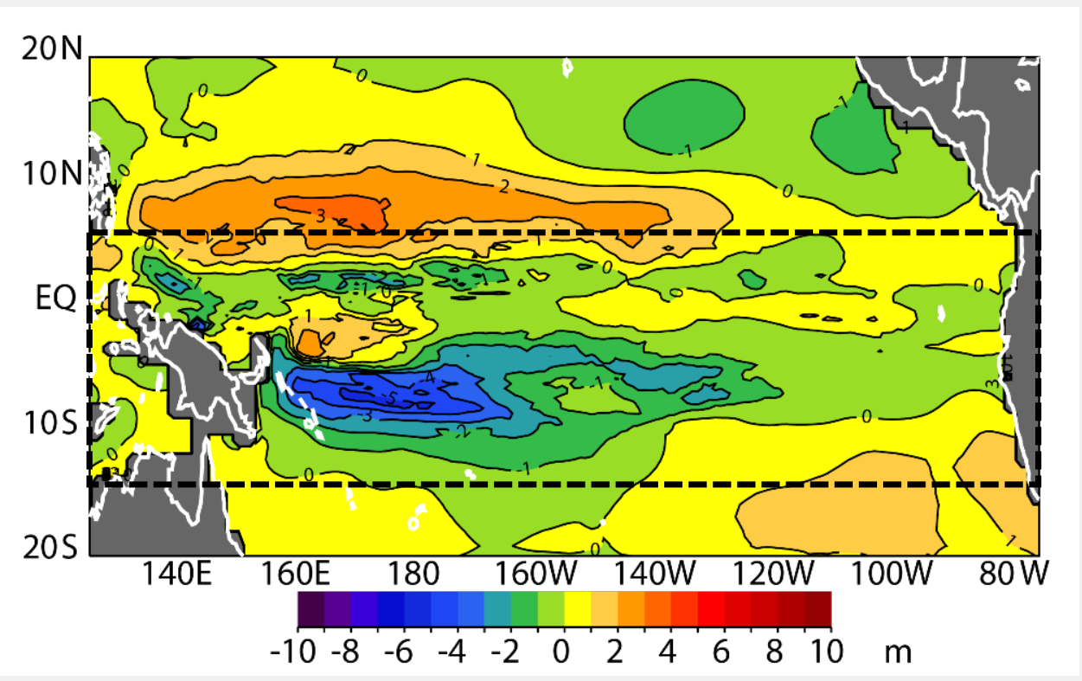
SSS (SSS ASSIM – NO SSS ASSIM)



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 are not shown).

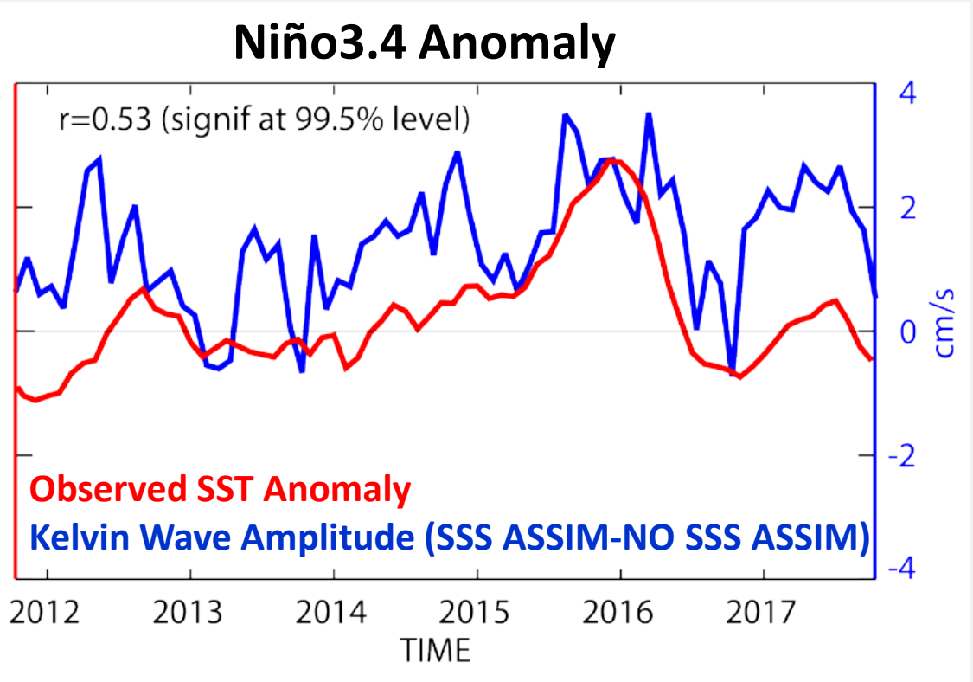
Mixed Layer Depth (SSS ASSIM – NO SSS ASSIM)



Data assimilation differences over 9/11-9/17 for MLD.

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

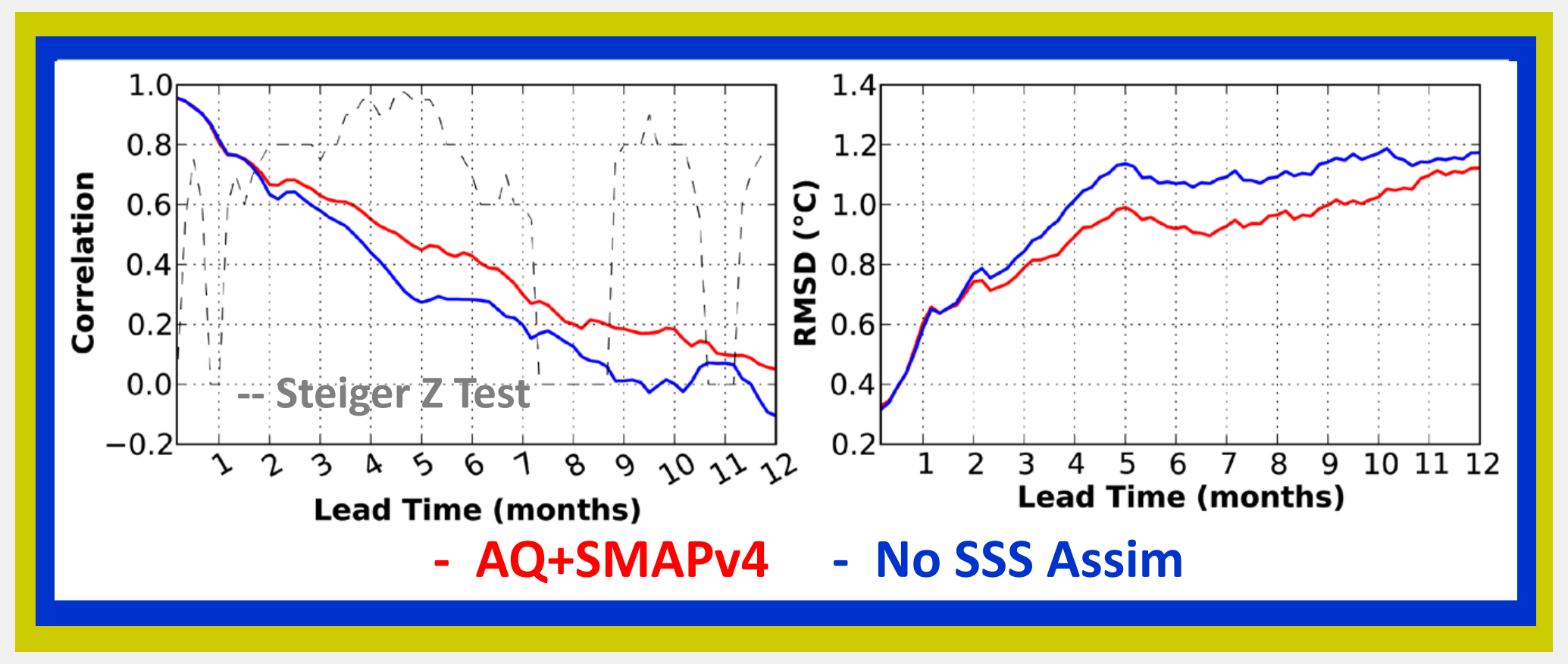
Kelvin Wave (SSS ASSIM – NO SSS ASSIM) versus SST'



Index of the Kelvin wave amplitude of ASSIM SSS – NO SSS ASSIM versus SST anomaly over the Niño3.4 region.

Significant correlation between the two shows that the Kelvin wave amplitude (and ENSO signal) is **enhanced due to SSS ASSIM**. Kelvin amplitude from technique of *Delcriox et al., 1994*.

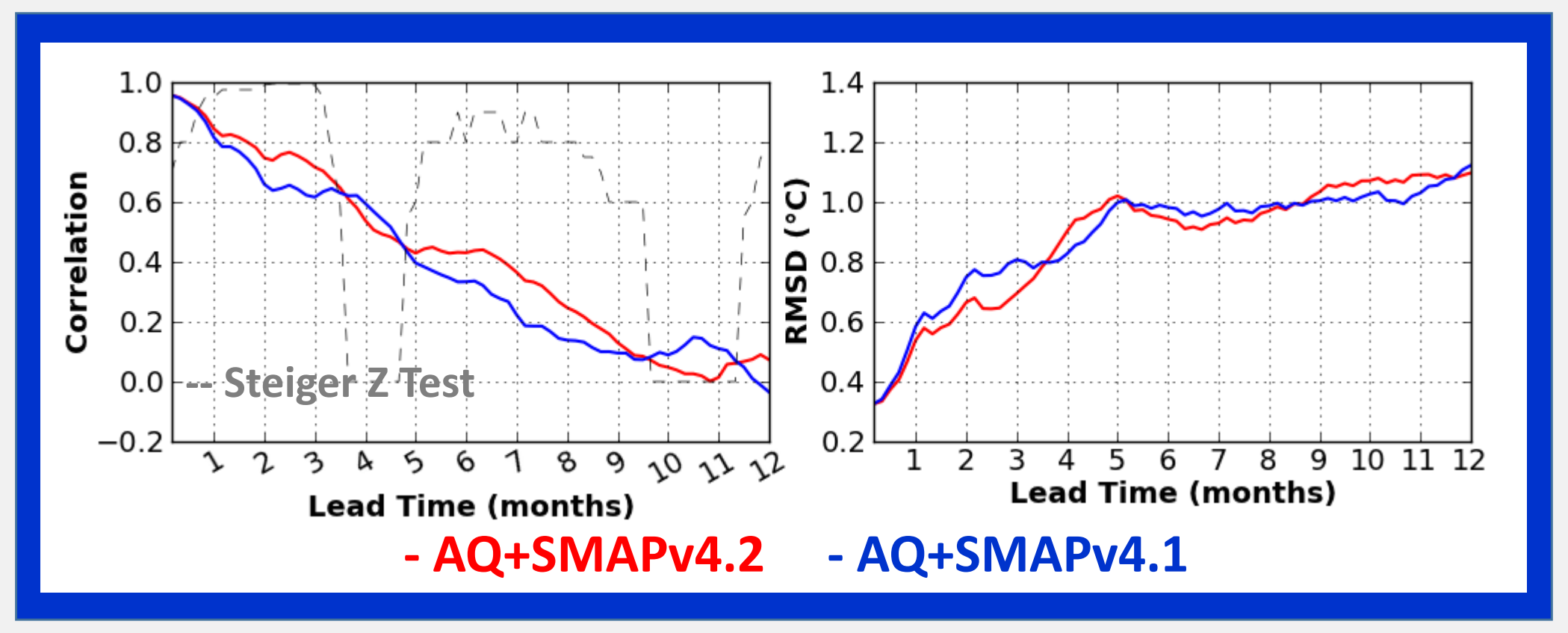
Coupled Model Validation



Validation of the coupled results using observed Niño3.4 SST'. Correlation (left) is significantly higher and RMSD (right) is lower for **SSS assimilation** versus **No SSS assimilation.** The relative low-cost of our intermediate-complexity coupled model allows us to use this as a transfer function to test SSS model algorithm developments. *(Correlation measured by the Steiger's Z statistic – dashed line.)*

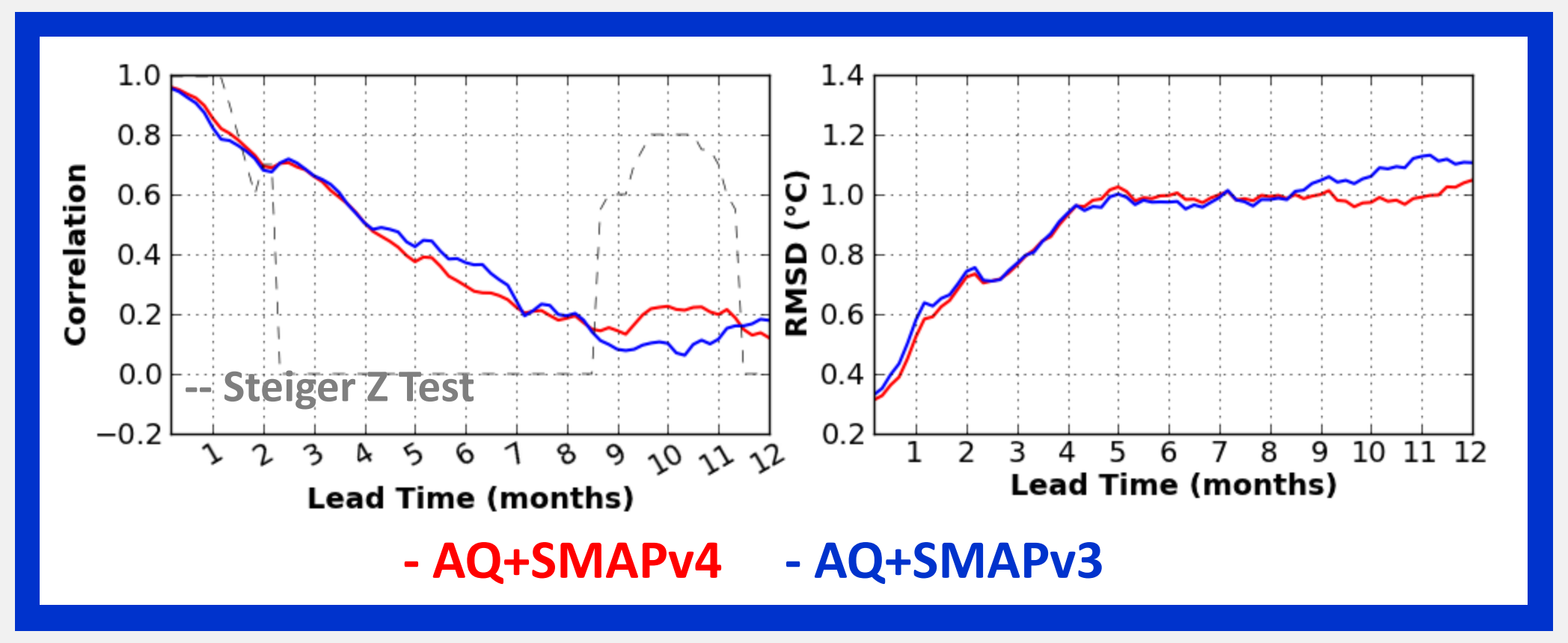
SALINITY MODEL VALIDATION

AQ/SMAPv4.2 versus AQ/SMAPv4.1



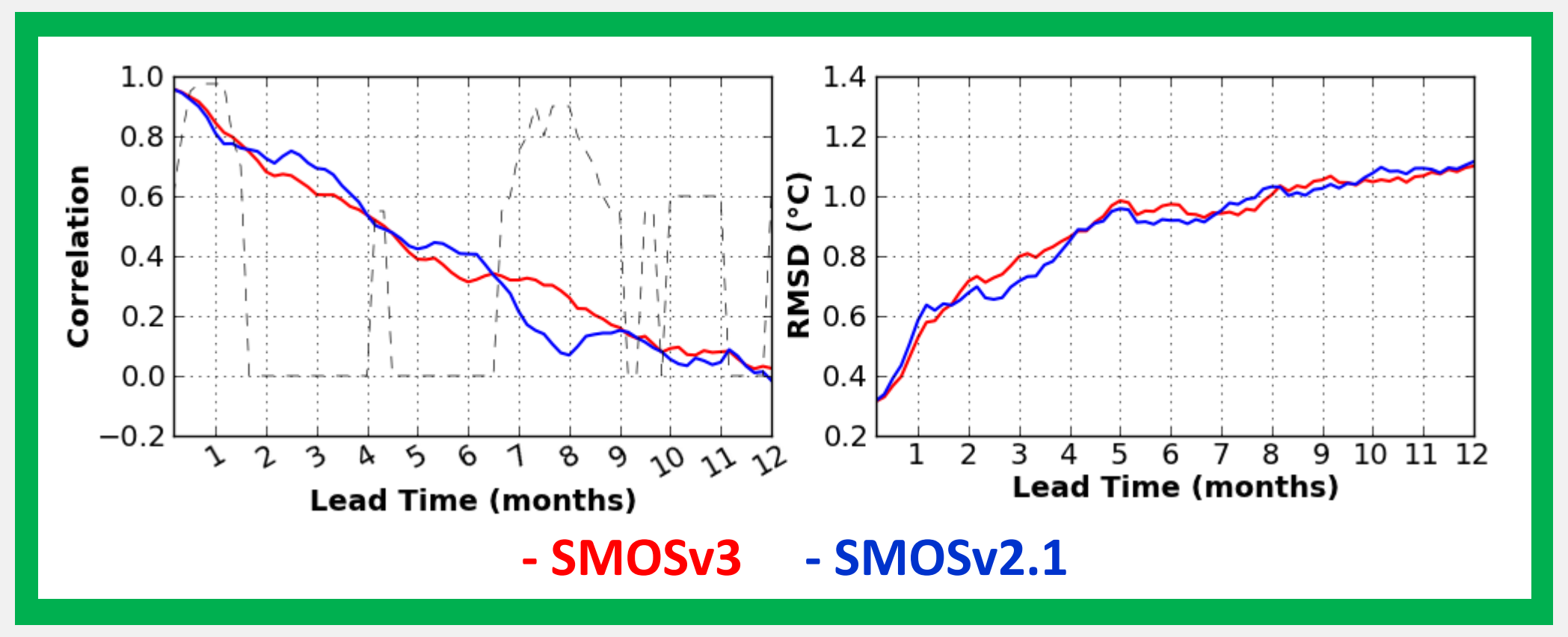
Comparison of gridded SSS fields are presented for **Aquarius v5** combined with **SMAPv4.2** versus **SMAPv4.1** (*Fore et al., 2016*). Note that the new **SMAPv4.2** is an improvement upon **SMAPv4.1** at 2 to 3 month and 6 to 9 month forecasts.

AQ/SMAP v4 versus AQ/SMAP v3



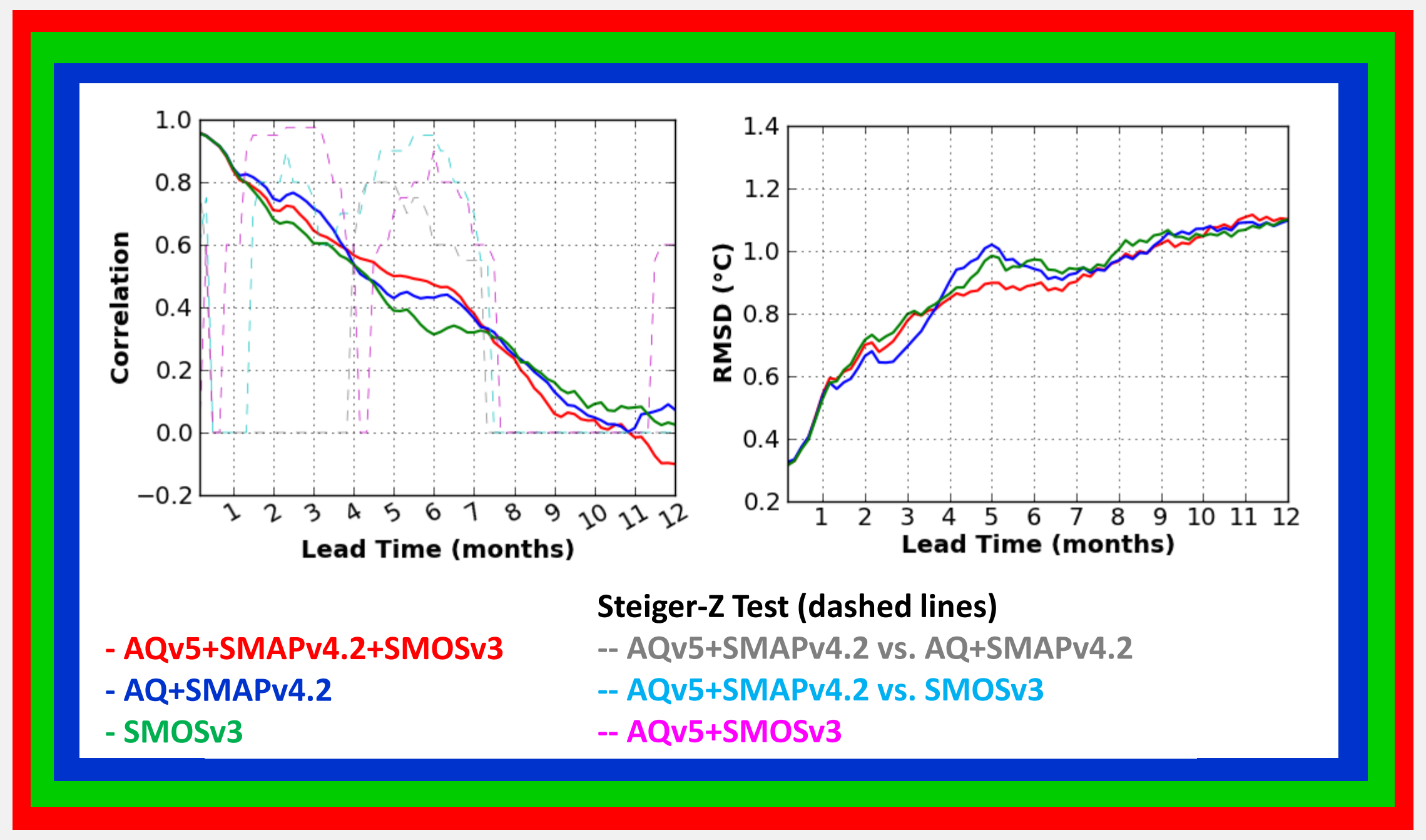
Aquarius+SMAP V4 (*Meissner et al., 2018*) is an improvement upon **AQ+SMAP V3** only after 8 month forecasts. The improvement is probably due to Rossby wave processes and salinity improvements in the western Pacific.

SMOS v3 versus SMOS v2.1



The new **SMOSv3** SSS model algorithm is tested against **SMOSv2.1.** (*Boutin et al., 2017*). Both have relatively similar validation statistics.

Impact of Data Coverage

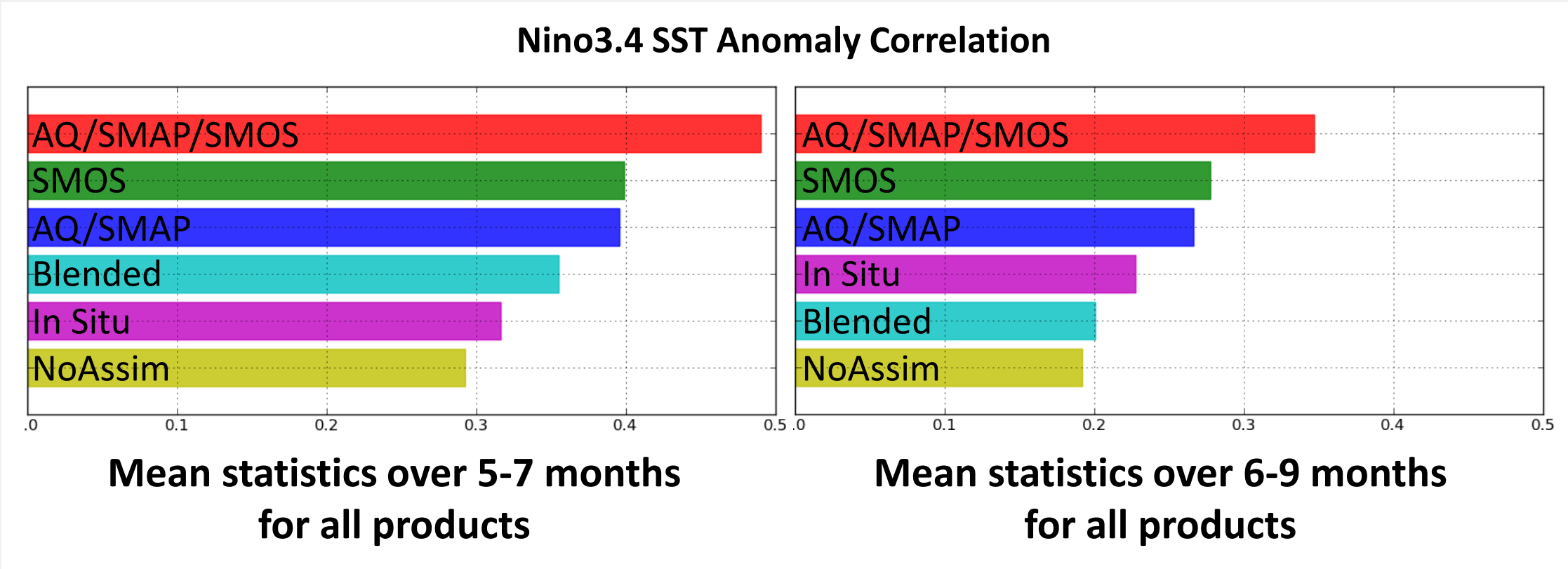


- **The more satellite SSS data, the better for prediction of ENSO.**
- The combination of **AQv5+SMAPv4.2+SMOSv3** outperforms **AQv5+SMAPv4.2** and **SMOSv3** for 4 to 7 month forecasts.
- **Aquariusv5+SMAPv4.2** performs the best from 1 to 4 months.
- Note that the differences between all combinations are not significant from 8 to 11 months.

CONCLUSIONS

1) Including satellite SSS significantly improves Niño3.4 sea surface temperature anomaly validation.
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 10°S-5°N. In addition, salting near the ITCZ leads to a deepening of the mixed layer and thermocline near 8°N. These patterns together provide the background state to amplify equatorial Kelvin waves and ENSO signal.
3) Our intermediate complexity coupled model is routinely used as a transfer function to test SSS model and product development.
4) Additional experiments are presented that demonstrate that more mature SSS algorithms lead to better ENSO predictions. In addition, the more satellite SSS data, the better the ENSO forecasts.

Impact of Satellite Versus In Situ



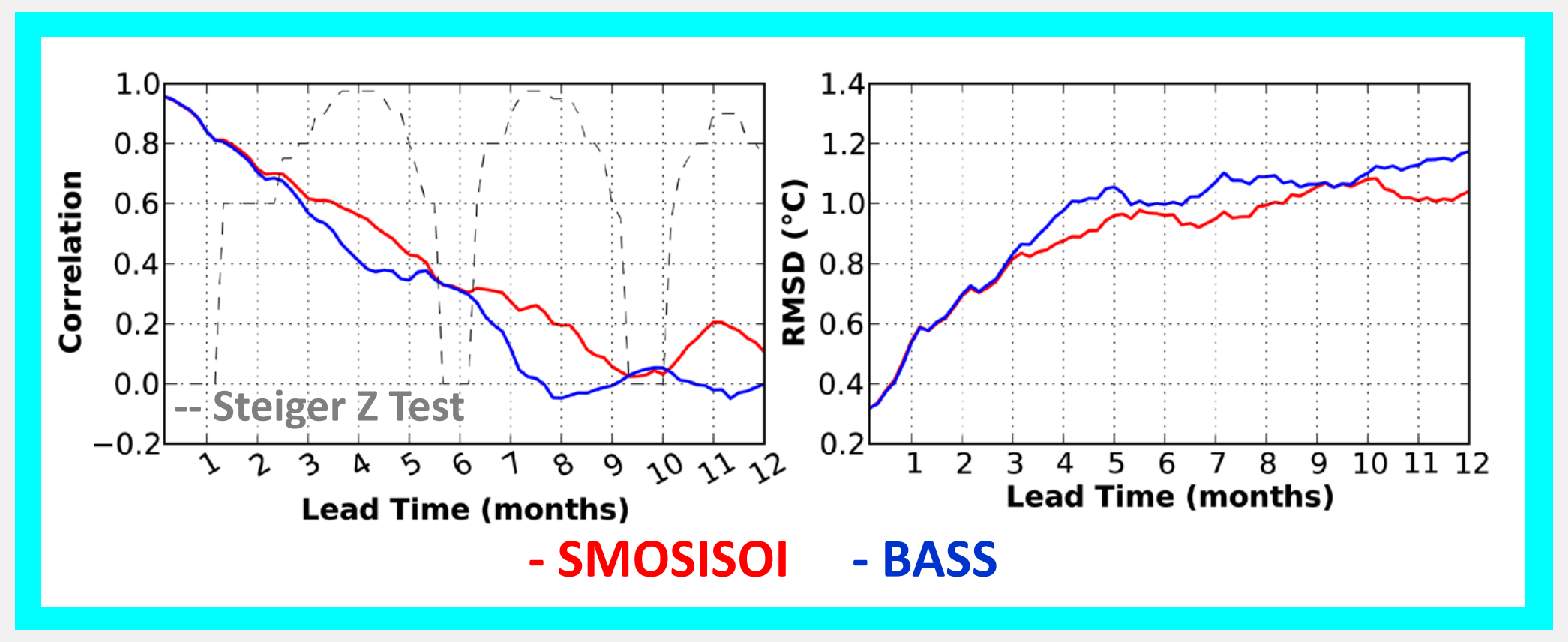
Mean statistics over 5-7 months for all products

Mean statistics over 6-9 months for all products

Mean statistics for all satellite **AQ+SMAP+SMOS**, **SMOS**, **AQ/SMAP**, **in situ**, **blended**, and **No SSS assimilation**.
Note that the more satellite SSS data, the better the ENSO forecast.

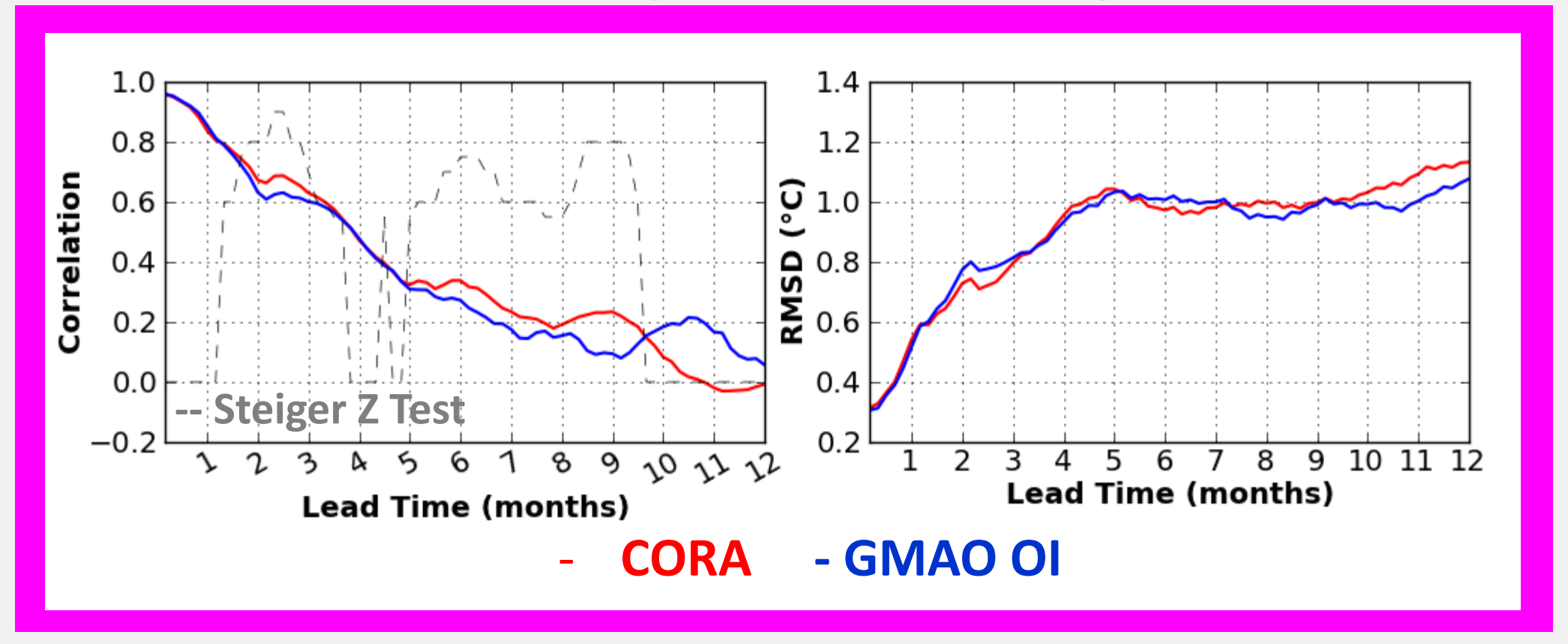
Blended (Satellite with In Situ) and In Situ Product Validation

BASS versus SMOSISOI



BASS blends **in situ** with **Aq/SMAP** (*Xie et al, 2014*) and **SMOSISOI** blends **SMOS** and **in situ** (*Nardelli et al., 2016*). Improved response of **SMOSISOI** is likely due to increased reliance upon satellite SSS and higher temporal resolution (7-day) as compared to **BASS** (monthly).

In Situ (No Satellite SSS)



GMAO OI (*Hackert et al., 2011*) and **CORA5** (*Cabanes et al., 2012*) are included as examples of in situ products. Note that the spin-up for all experiments used **GMAO OI**.

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OceanObs'19 Conference - Sep 16-20, 2019