Impact of Satellite Sea Surface Salinity Observations on ENSO Predictions from the 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 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. 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 far right column compares assimilation of Aquarius, SMAP and combined Aquarius and SMAP on forecasts for the 2015 El Niño.

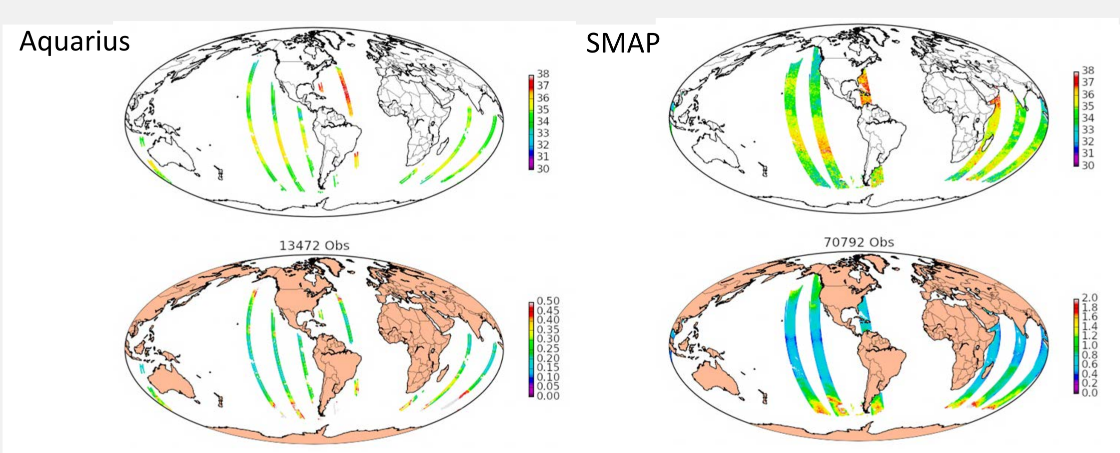
METHODOLOGY

The coupled model used in this project is the S2S_v2.1 that 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 (column 2,3) and gridded (column 3) 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 spanning April 2015 (El Niño), May 2017 (La Niña) and April 2018 (weak El Niño). Both Aquarius and SMAP data are available for May 2015 so another set of forecasts are initialized to compare coupled experiments initialized from these data. All results are then validated against observed NINO 3.4 values (SST – Reynolds et al., 2002).

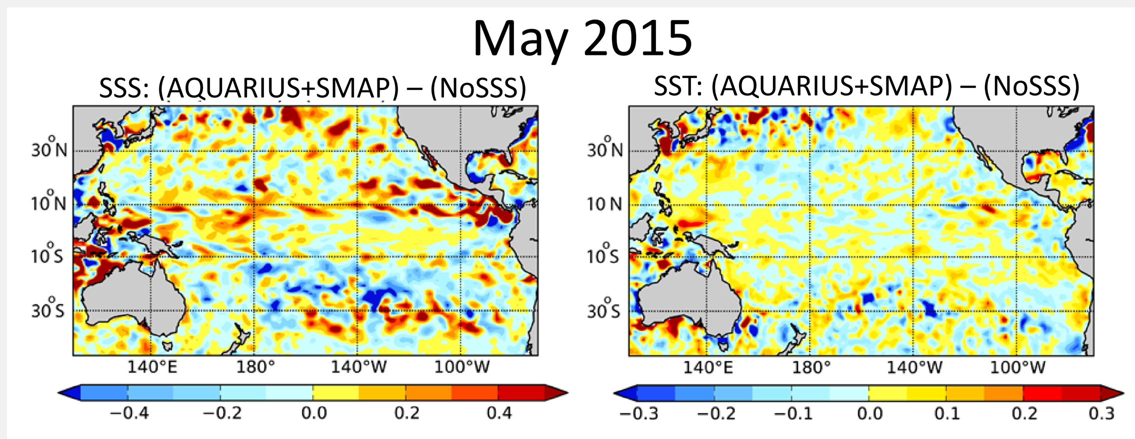
ASSIMILATION DATA



An example of May 15, 2015 assimilation data used in this study. Along-track SSS L2 data are assimilated every 6 hours. Note that SMAP has the higher observation error than Aquarius (SMAP has 4x greater observation error) due to the immaturity of the product. Data are from Aquarius V5 (Lilly and Lagerloef, 2008) and SMAP V4.0 (Fore et al., 2016).

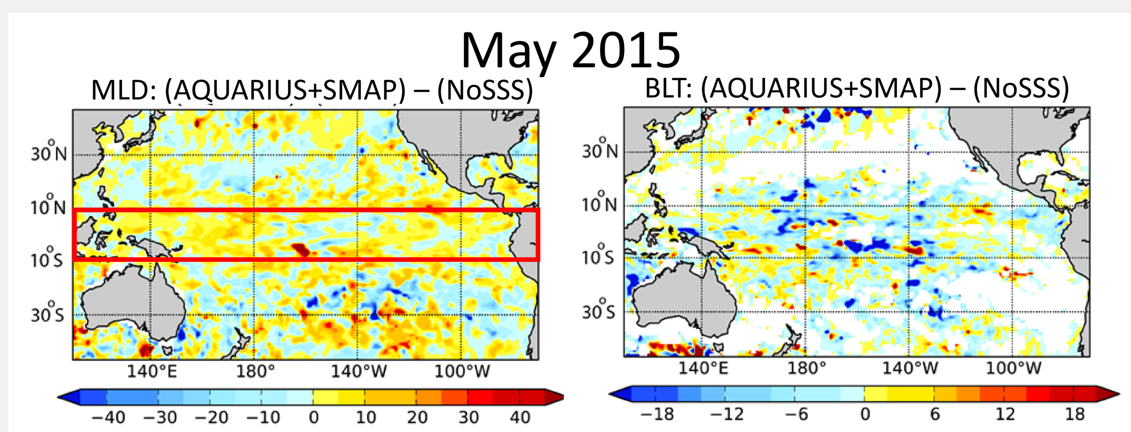
IMPACTS ON INITIAL CONDITIONS

Surface Differences



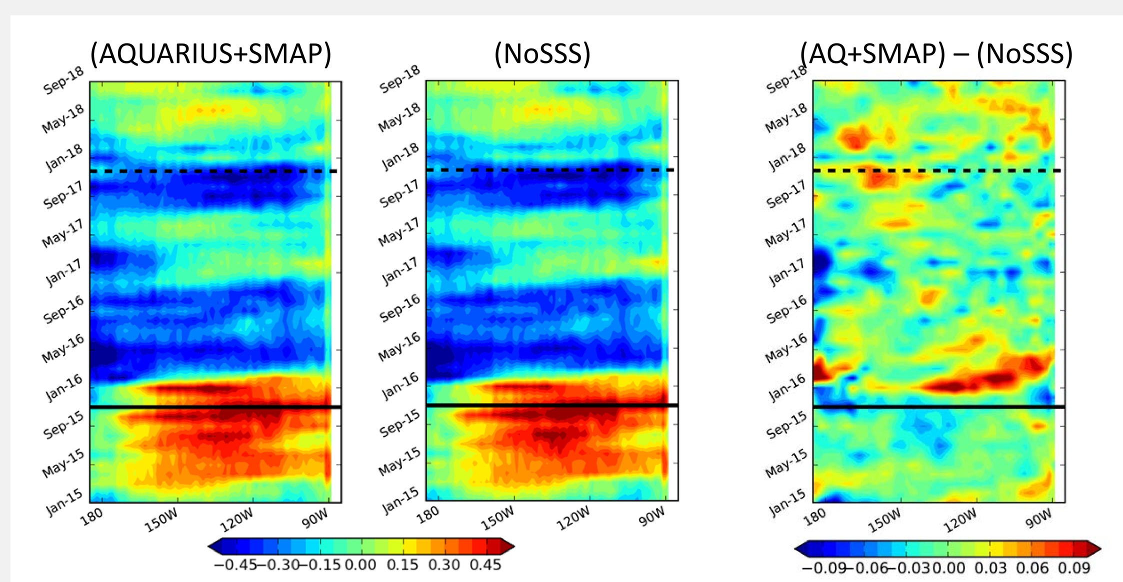
May 2015 differences between the experiment that assimilates both Aquarius and SMAP Sea Surface Salinity (SSS) minus the experiment that withholds SSS assimilation for (left) SSS and (right) SST. Improved (somewhat saltier) SSS, combined with SST, increase near-surface density within the equatorial waveguide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

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.

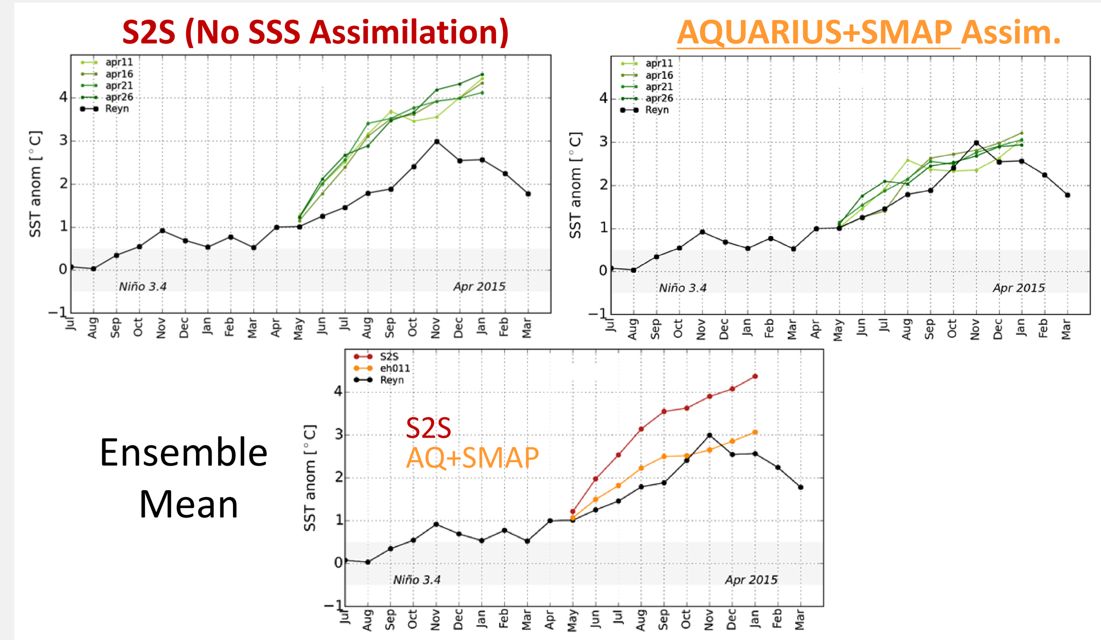
Kelvin Wave Amplitude



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 (i.e. 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).

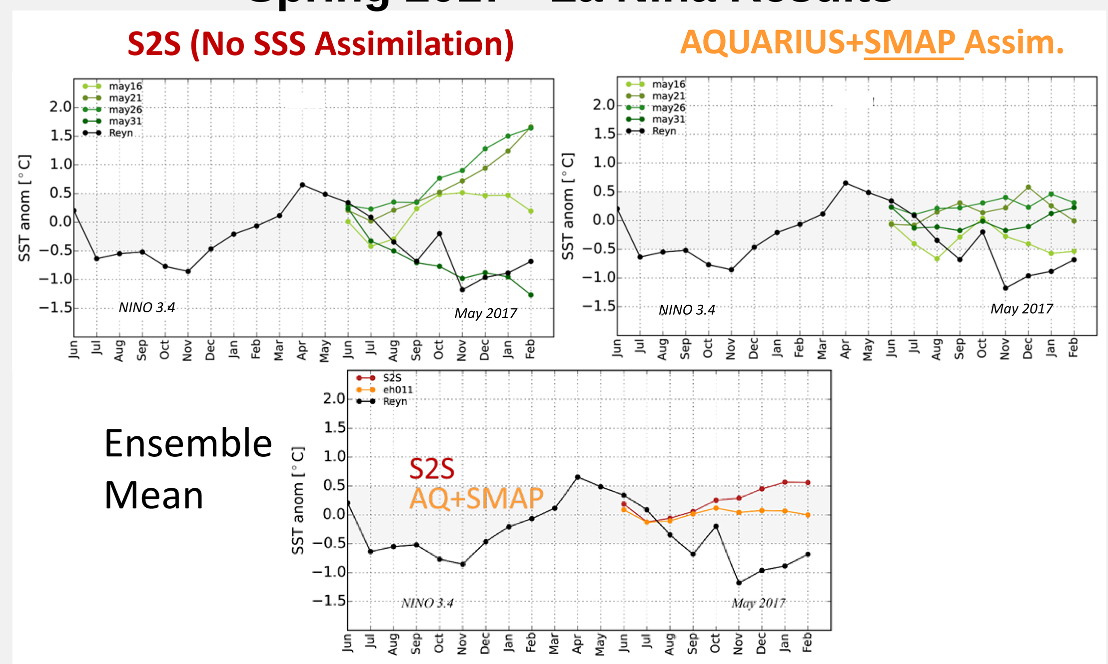
ENSO FORECASTS

Spring 2015 - El Niño Results



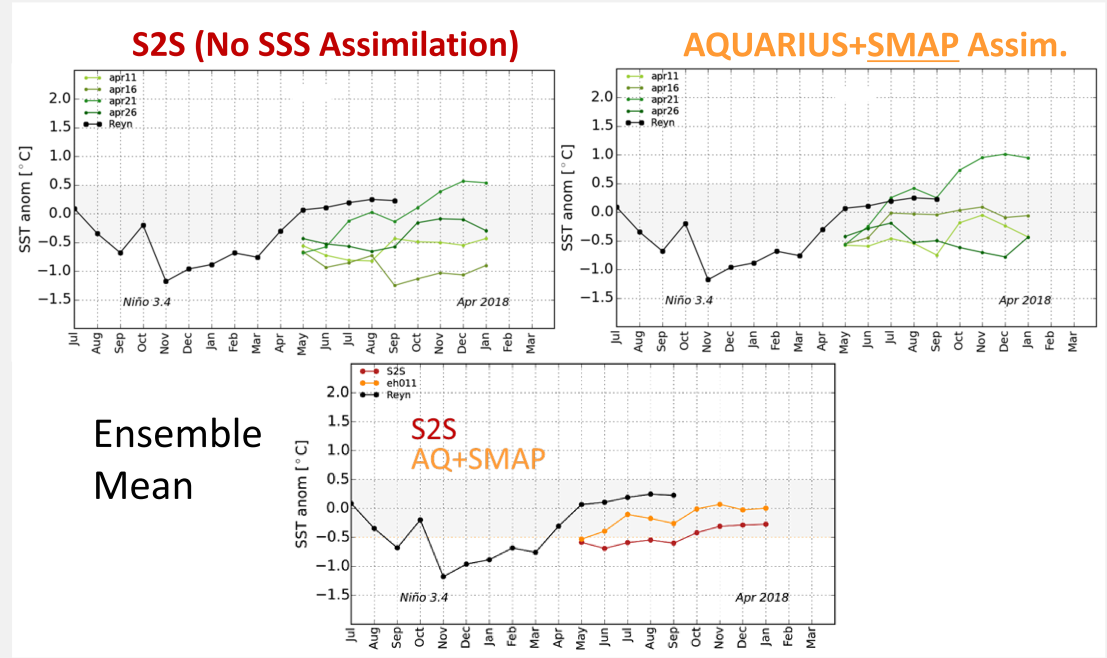
NINO3.4 forecast plume plots initialized from April 2015 for (top left) no SSS assimilation, (top right) assimilation of satellite SSS and (bottom) ensemble mean of Apr forecasts. Note that the thicker MLD from assimilation of SSS damps the warming of downwelling Kelvin waves for the big 2015 El Niño.

Spring 2017 - La Niña Results



Forecast plume plots for May 2017. Here the deeper MLD from SSS assimilation (top right) acts to give a more realistic forecast for the 2017 La Niña. In this case, the improvement brought about by SSS increases out to 9 month forecasts (bottom).

Spring 2018 - Current ENSO Results



For April 2018, many models over-forecast this event as a moderate El Niño. However, the S2S did a reasonable job of forecasting neutral ENSO conditions (top left). Assimilation of SSS further modulated the NINO3.4 forecast to more closely match observations out to 9 months (bottom).

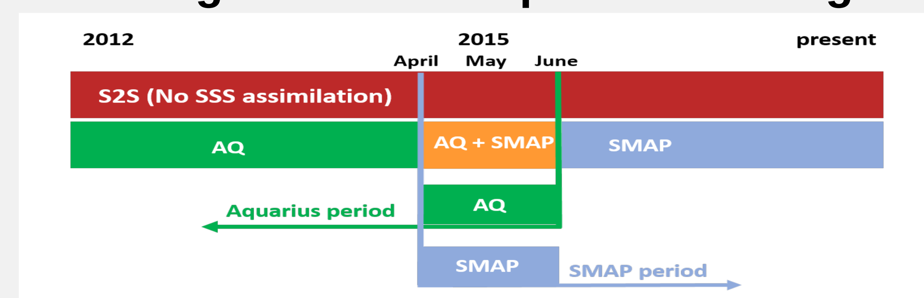
CONCLUSIONS

1) ASSIM SSS ➡ changes in SSS ➡ changes in 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)

TAKE HOME RESULT – Assimilation of satellite SSS improves ENSO Forecasts

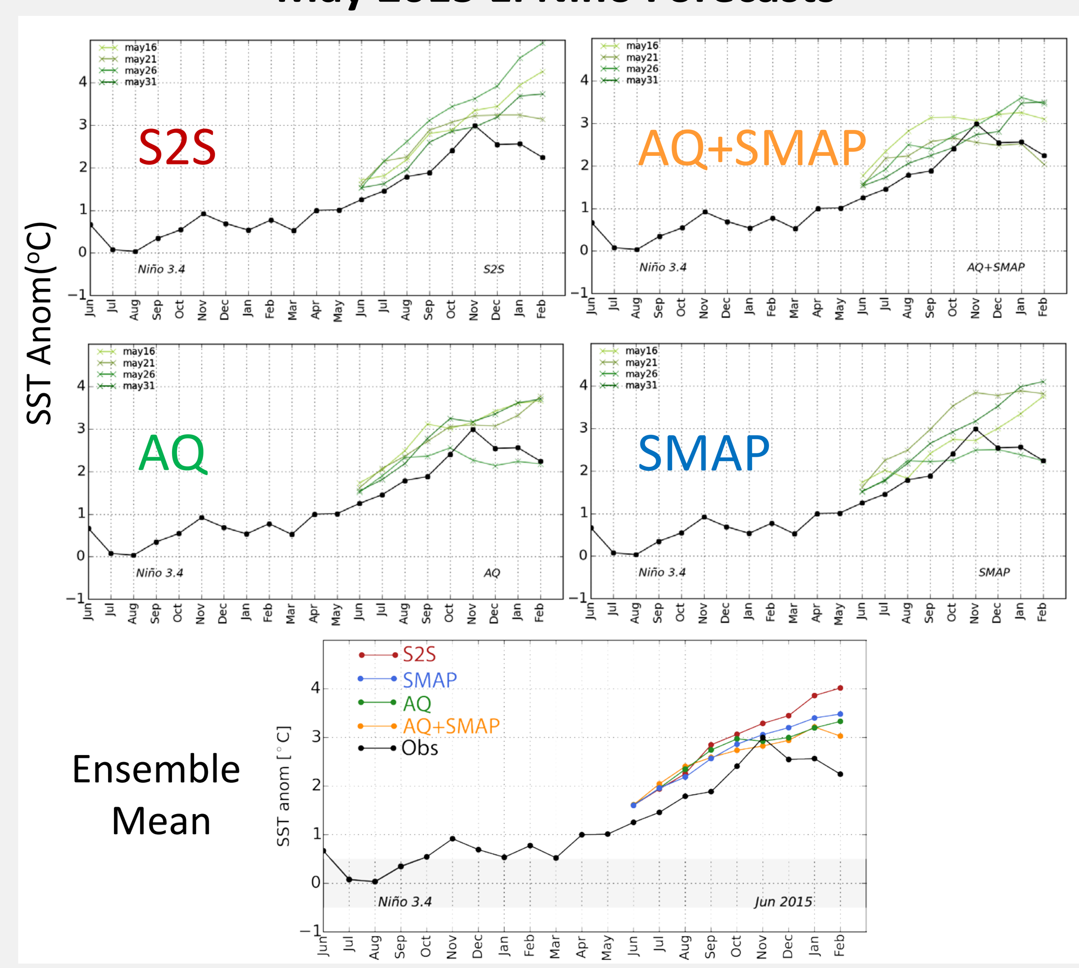
IMPACT OF AQUARIUS VERSUS SMAP 2015

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 using L3 gridded fields and an idealized Aquarius gridded observation error.

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, (middle left) Aquarius, and (middle right) SMAP gridded SSS. 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.

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