Impact of Satellite SSS on ENSO Forecasts for the Tropical Indo-Pacific

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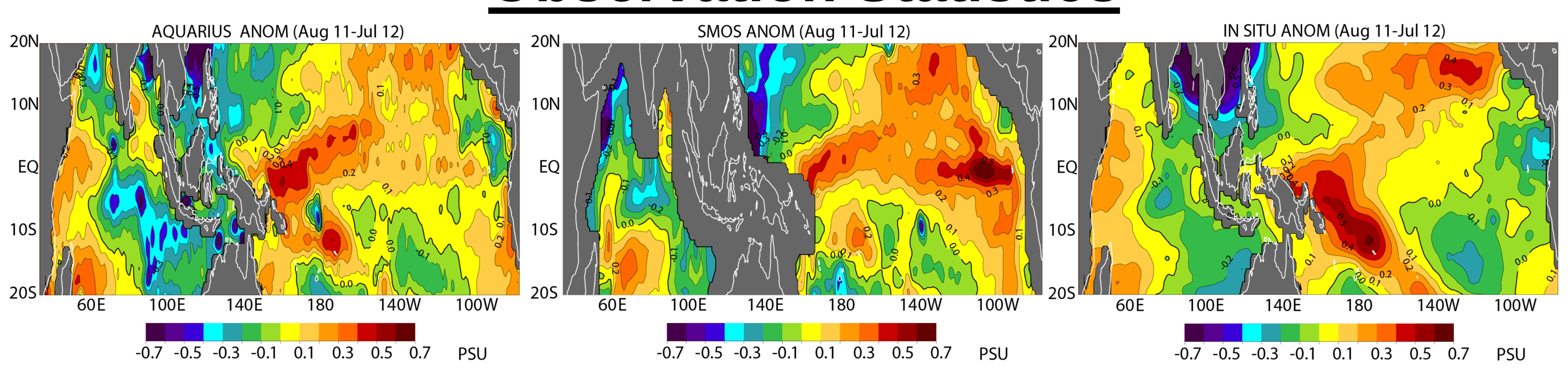
ABSTRACT

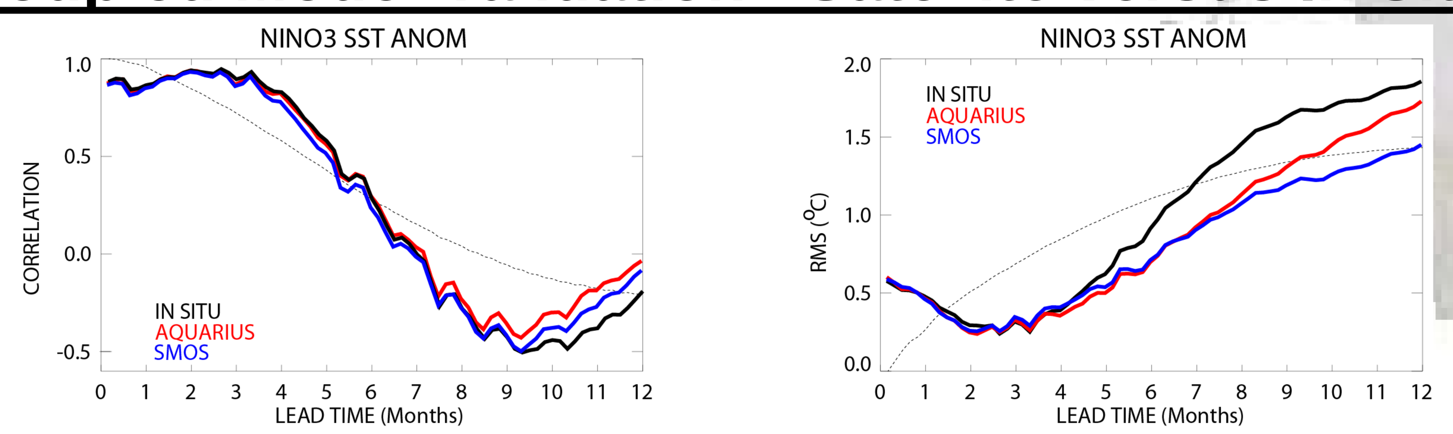
In earlier work we have demonstrated that assimilation of gridded fields of sea surface salinity (SSS), derived from in situ salinity observations, has led to significantly improved coupled forecasts for lead times greater than 6 months (*Hackert et al., 2011*). We found that the positive impact of SSS assimilation is brought about by surface freshening in the western Pacific that led to increased barrier layer thickness (BLT) and shallower mixed layer depth. Thus, the net effect of assimilating SSS is to increase stability, reduce mixing, and shoal the thermocline which amplifies the wind component of ENSO coupling. Here we test the impact of Aquarius and SMOS SSS assimilation by comparing coupled experiments initiated from satellite versus in situ SSS assimilation and run for 12 months for each month August 2011 to July 2012. Although there is not enough data to rigorously validate any conclusions, we show preliminary results highlighting the potential positive impact of satellite SSS assimilation on ENSO forecasts.

Observation Statistics



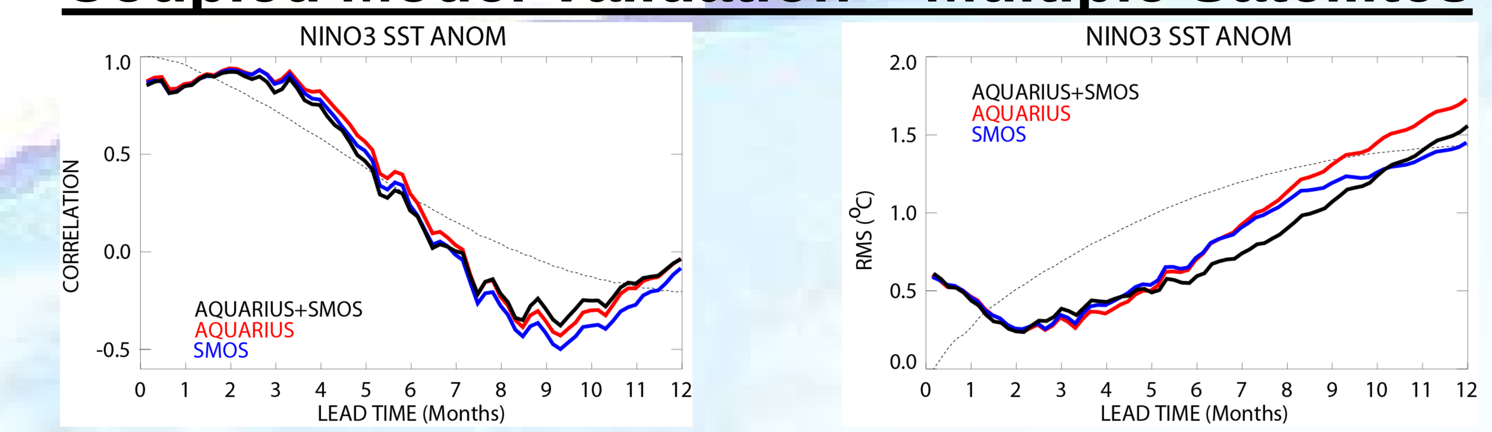
SSS Observations - These 3 panels show the SSS anomaly mean over August 2011 to July 2012 for Version 1.3.5 Aquarius (left), CATDS SMOS Version 1.0 (middle), and our OI In Situ SSS (right). Monthly anomalies are first formulated with respect to WOA09 and also the 1993-2011 bias between in situ product and WOA09 (OIBIAS). Note the overall correspondence between satellite and in situ values. However, satellite products (SMOS and to a lesser degree Aquarius) differ with the in situ product with high SSS anomaly in the eastern equatorial Pacific and lower values in the SPCZ region. The in situ product is thought to be reliable in these regions due to good data coverage for this period.

Coupled Model Validation - Satellite versus In Situ



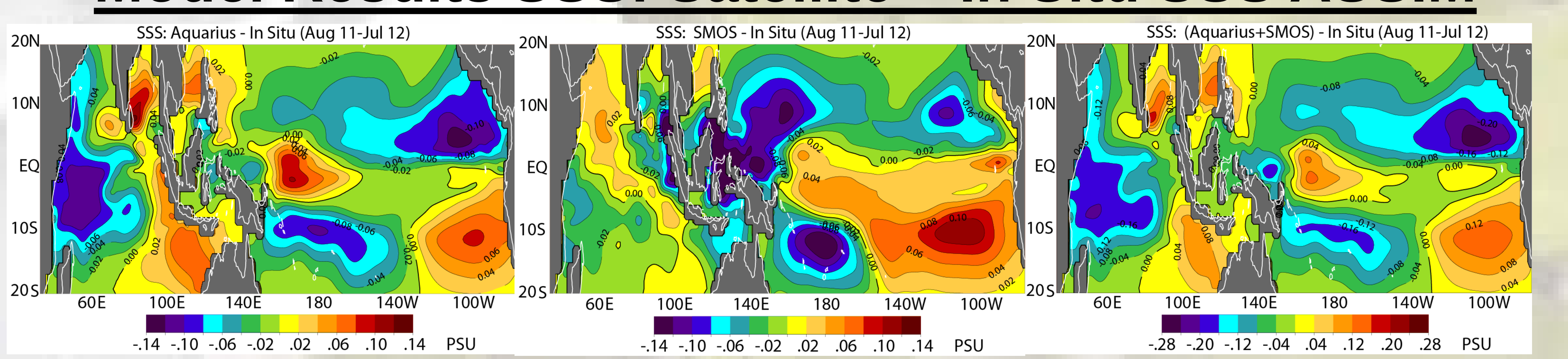
Our hybrid coupled ocean-atmosphere model is initialized using in situ (black), Aquarius (red) and SMOS (blue) SSS assimilation results along with subsurface temperature. These experiments are then run for 12 months for each month August 2011-July 2012. Although there are not enough satellite SSS data to rigorously validate these correlation (left) and RMS differences (right) with observed NINO3 SST anomalies, these results foreshadow the potential for improved correlation assimilating satellite SSS after 8 month and RMSD after 4 month lead times. Note that satellite coupled forecasts only outperform observations persistence (thin dotted line) for 1-5 and 12 month for correlation and 1-9 month lead times for RMS.

Coupled Model Validation – Multiple Satellites



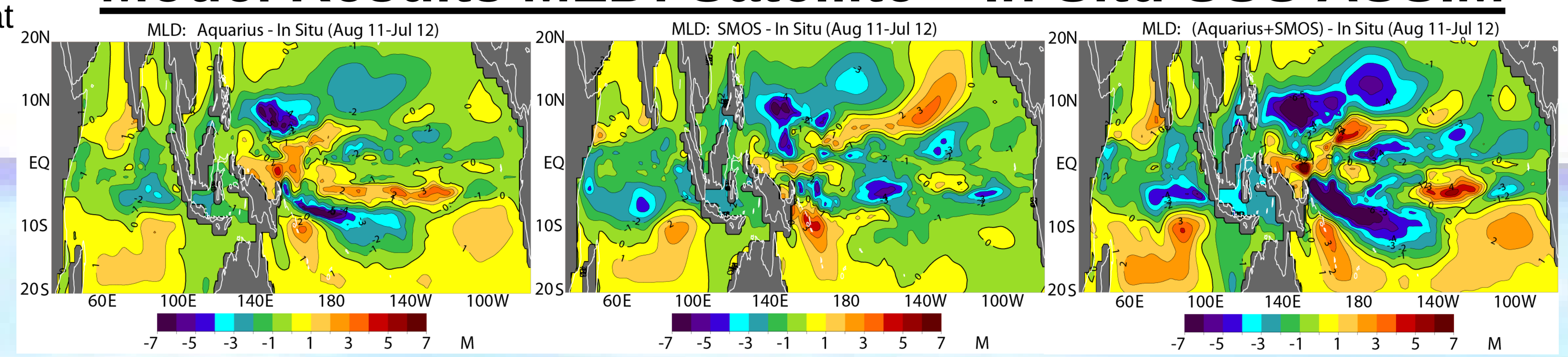
Plots of coupled forecast statistics are repeated from above for Aquarius (red) and SMOS (blue) satellite SSS assimilation and validated against observed SST NINO3 anomalies. In addition, results of the coupled experiment initialized using both Aquarius and SMOS SSS assimilation is shown (black). The combination of assimilating Aquarius and SMOS slightly improves the temporal signal after 8 months (left) but the RMS difference (right) is noticeably improved after 5 month lead times. SMOS and combined Aquarius+SMOS RMSD statistics beats persistence (thin dotted black line) for all lead times from 1-12 months.

Model Results SSS: Satellite – In Situ SSS ASSIM



Model Mean IC SSS – We assimilate each SSS product along with subsurface temperature into our OGCM using the EROKF technique. Mean differences between the satellite minus in situ SSS assimilation results are presented to highlight the impact of Aquarius (left), SMOS (middle) and combined Aquarius + SMOS assimilation (right). Relative freshening occurs in the ITCZ and SPCZ for both products whereas salting can be seen at the eastern edge of the warm pool region and in the southeast Pacific with respect to in situ SSS assimilation. (Model, data, and assimilation technique are described in the "Model and Data Processing" section in the lower right corner of this poster.)

Model Results MLD: Satellite – In Situ SSS ASSIM

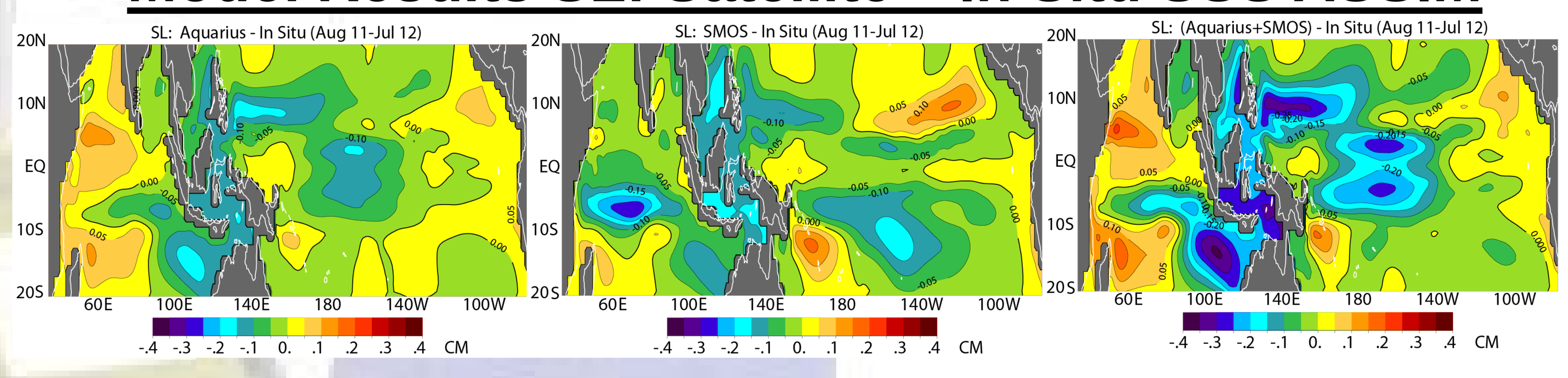


Model Mean IC MLD - Mixed Layer Depth (MLD) mean differences between assimilation of Aquarius (left), SMOS (middle), and Aquarius + SMOS (right) minus in situ SSS assimilation are shown above. MLD is defined using density criteria. For all examples above, a shallower MLD (i.e. cool shading) is present throughout most of the entire wave-guide with the exception of the far western Pacific. Within 5º of the equator SSS differences directly impact MLD. Freshening west of 160ºE corresponds to deeper MLD and salting to the east is related to shallower MLD. Since most of the basin shows shallower MLD within the waveguide, any atmospheric coupling will be more efficient due to satellite SSS assimilation presumably leading to better long-lead coupled forecasts. (Note that BLT pattern matches MLD in the western Pacific – not shown.)

CONCLUSIONS

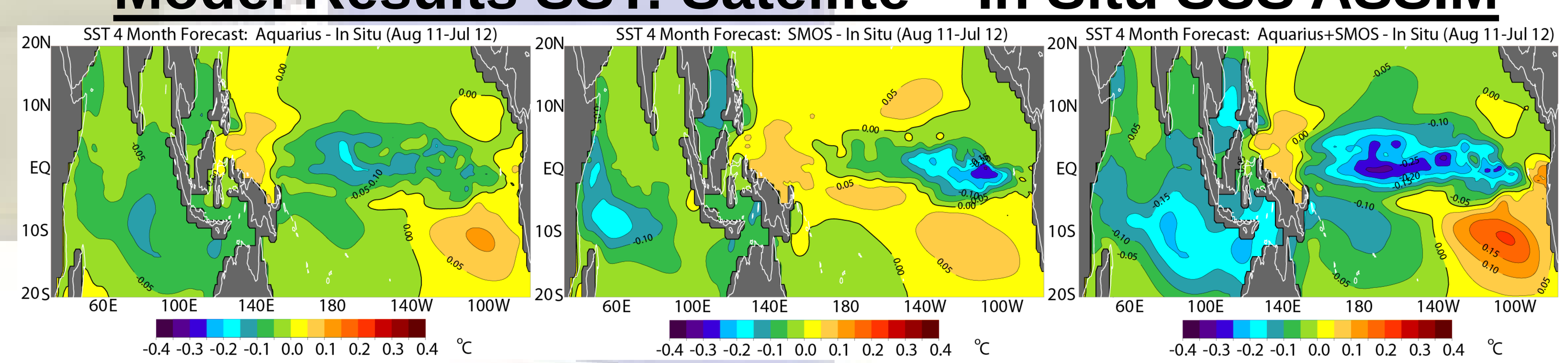
- **Coupled experiments initialized from assimilation of satellite SSS outperform in situ SSS assimilation, with satellite correlation slightly higher than in situ (from 9-12 months) and especially lower RMSD from (5-12 months) when validated against observed NINO3 SST anomalies.**
- **Combining satellite SSS (Aquarius + SMOS) outperforms either Aquarius or SMOS initialization especially when validated with RMSD statistics.**
- **Satellite SSS assimilation serves to reduce the MLD with respect to in situ SSS product leading to more efficient ocean/atmosphere coupling near the equator.**
- **Relatively fresh satellite SSS throughout the ML adds an equatorial upwelling signal that propagates to the NINO3 region leading to reduction of positive SST anomaly-biased forecasts for this particular period.**
- **Although only one year of satellite SSS observations are available, this work foreshadows the potential improvement in coupled forecasts due to assimilation of Aquarius and SMOS satellite SSS.**

Model Results SL: Satellite – In Situ SSS ASSIM



Model Mean IC SL – Negative values of Sea Level (SL) are seen for all SSS assimilation scenarios at roughly 160ºW within 10º of the equator corresponding to the salinity-forced upwelling signal. The combined impact of upwelling (negative SL) Kelvin wave and the western boundary-reflected upwelling Rossby wave starts to impact the Nino3 region after about 4 months corresponding to the satellite SSS improvements seen in RMS lead time statistics in 1st column.

Model Results SST: Satellite – In Situ SSS ASSIM



Model Mean Forecast SST – The Sea Surface Temperature (SST) 4 month forecast mean differences between coupled experiments initiated using Aquarius (left), SMOS (middle) and combined Aquarius+SMOS (right) minus the in situ SSS product for all initialization times, August 2011-July 2012. On average, after 4 month forecasts, the combined impacts of the relative upwelling Kelvin and Rossby signals have arrived in the eastern Pacific as is demonstrated by the negative SST in the NINO3 region. Thus, the impact of satellite SSS assimilation is to mitigate the tendency for warm-biased coupled forecasts typical of La Nina initial conditions (as were present in the equatorial Pacific observations from June 2011 to approximately April 2012).

Model and Data Processing

- Ocean Model - Reduced-gravity, primitive equation, sigma coordinate model [*Gent and Cane, 1989*]. Hybrid variable depth mixed layer [*Chen et al., 1994*] (wind stirring, shear instability, conv. overturning). Advective AML coupled to OGCM [*Seager et al., 1995*]. SSS, SST natural boundary condition [*Huang, 1993*]. Realistic coastlines for tropical Indo-Pacific (33ºE-284ºE, 30ºN-30ºS), 20 layers with 1/3º equatorial stretched grid. Forcing: ECMWF analysis wind stress, GPCP rainfall, NCEP reanalysis cloud anomalies added to ISCCP seasonal cycle, ERBE solar radiation.
- Data Assimilation - Ensemble Reduced Order Kalman Filter (EROKF) uses MEOF of long model run (1985-2004) to formulate basis, impacts entire state vector (SL, H, T, S, U, V).
- Hybrid Coupled Model – statistical atmospheric model (SAM) SVD between ECHAM 4.5 Ensemble and observed SSTA, 1950-1999. Separate SAM for each month.
- NINO3 SST Anomaly - NOAA_OI_SST_V2 data [*Reynolds et al.,* 2002] provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/ are used to validate the coupled model results from August 2011 – October 2012.
- In situ SSS product - Only highest quality salinity observations from all sources* were combined to include data within 10m of surface for 1990-present. SSS anomalies were first formulated using WOA09 SSS seasonal cycle. These anomalies were binned onto 1ºx1ºx monthly grids and then were gridded using the OI technique of *Carton and Hackert, 1989* using 15º and 3º decorrelation scales (*Meyers et. al., 1991*) for each basin. At each grid point the long-term seasonal cycle bias with respect to WOA09 (referred to as OIBIAS) was removed prior to assimilation.
- SMOS –Level 3 (L3) SMOS SSS data were obtained from the "Centre Aval de Traitement des Données SMOS" (CATDS), operated for the "Centre National d'Etudes Spatiales" (CNES, France) by IFREMER (Brest, France) (ftp eftp.ifremer.fr). Data were averaged for 50 km x 10 days using the CATDS L3 OS Simple Mapping technique (Reanalysis Version 1.0) for January 2010 to April 2012. Starting in May 2012, the resolution drops to 200 km x monthly mean and these were renormalized using the Reanalysis May-July mean. Both ascending and descending orbits have been included with full polarization. Maps with excessive 'trackiness" were removed (~8%), and data within 6º of land were removed (> 2 PSU fresher than surrounding data).
- Aquarius – L3 global gridded data were furnished through the NASA/CONAE Aquarius/SAC-D Project. The version V1.3.5 1ºx1º mapped data cover the period August 27, 2011 until September 23, 2012. For both SMOS and Aquarius the anomaly is formulated using WOA09 + OIBIAS as the seasonal cycle.

* GTSPP – mixed data sources including Argo, starting in 1990, ftp.nodc.noaa.gov; WOD09 – World Ocean Database 2009 CD (1990-2008) combined with www.nodc.noaa.gov/OC5/WOA09/pr_woa09.html update (to 2011). Research quality individual observations on standard levels, TAO/RAMA – tropical mooring data, acquired from http://www.pmel.noaa.gov/tao/data_deliv/, daily mean data, these are included due to inconsistent handling by GTSPP and WOD09.

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