Investigating the Physical Basis of Aquarius/SAC-D Salinity's Regional Biases

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AQUARIUS/SAC-D

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Introduction

Sea-surface temperature (SST) plays an important, and yet to be fully understood, role in sea-surface salinity (SSS) retrievals. The Version-3 release of Aquarius/SAC-D salinity retrievals applied an empirically derived adjustment to SSS that is a function of SST. This adjustment was derived after noticing regional salinity biases relative to modeled and *in situ* salinity observations. These SSS biases correlated well with climatological SST maps.

While the ΔSSS(SST) adjustment has already been implemented in the ADPS standard processing, there is great value in determining the physical basis of this adjustment. Understanding the root causes of this adjustment will enable improved Aquarius's salinity retrievals, as well as ensure that no true SSS-SST correlations or variability are being removed by the adjustment.

There are several factors that may contribute to the ΔSSS(SST) adjustment:

- The dependence of the sea-water dielectric constant on SST.
- The dependence of the roughness model on SST.
- Mis-modeling of the atmospheric oxygen absorption, which correlates with SST.

Note: Rain freshening and stratification may also contribute to a freshening signal, particularly in the tropics where rain correlates with SST. However, for this study, all rain-affected observations have been filtered out using SAC-D's MWR instrument's rain retrievals.

Data

-- Aquarius (SAC-D) V3.0 SSS retrieval
- L-band radiometer SSS retrieval via Aquarius Data Processing System (ADPS) at Goddard Space Flight Center (GSFC) [Lagerloef et al., 2008]
- Measure SSS at top 1 cm of ocean

-- HYCOM (Hybrid Coordinate Ocean Model)
- Global coupled ocean-atmosphere modeled SSS field at 1/12-degree resolution
- Provided by FSU COAPS, the NOPP, and US GODAE

-- ARGO (profiling & surface floats)
- Global *in situ* data product of SSS on a mean monthly 3-degree surface grid
- Provided by ADPRC (Asia-Pacific Data-Research Center) of the IPRC (International Pacific Research Center)

-- dSSS(x) = Aquarius SSS - SSS(x), where x can be HYCOM or ARGO, as noted
- For spatial and temporally collocated SSS measurements, with rain filtered out
- *in situ* adjusted to the surface

-- Reynold's daily OI SST [Banzon and Reynolds, 2013; Reynolds et al., 2007]
- NOAA Optimum Interpolation 1/4 Degree Daily Sea Surface Temperature Analysis, Version 2, final product.
- Collocated temporally and spatially to Aquarius's SSS retrievals for comparison

Regional Salinity Biases

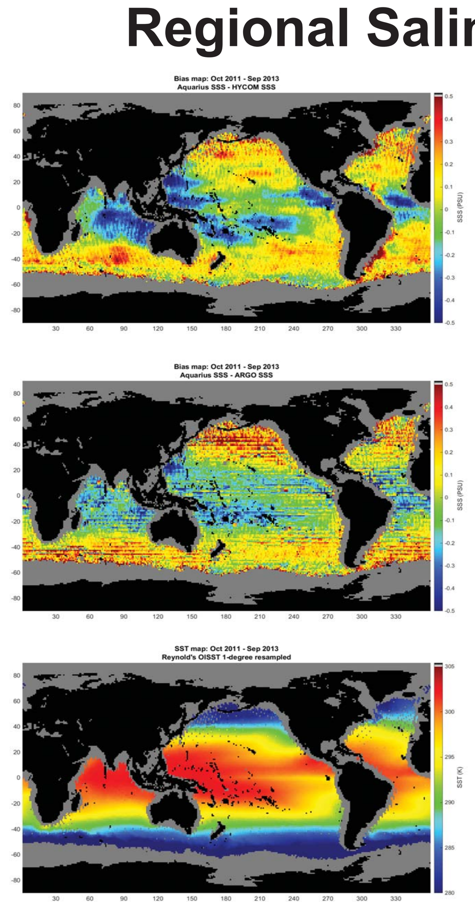

Figure 1. Regional SSS bias maps for the first two years of the Aquarius mission. The upper panel depicts Aquarius SSS less HYCOM SSS. The middle panel depicts Aquarius SSS less ADPRC ARGO SSS. The regional sea surface salinity bias patterns seen relative to both HYCOM and ARGO show regional similarity to the mean two-year Sea Surface Termperature (SST) global map from Reynold's OISST data product, depicted in the bottom panel.

References:

Banzon, V. F., and R. W. Reynolds (2013), Use of WindSat to extend a microwave-based daily optimum interpolation sea surface temperature time series, Journal of Climate, 26(8), 2557-2562.

Lagerloef, G. S. E., et al. (2008), The Aquarius/SAC-D Mission: Designed to meet the salinity remote-sensing challenge, Oceanography, 21, 68-81., http://dx.doi.org/10.5670/oceanog.2008.68

Liebe, H. J. (1985), An updated model for millimeter wave propagation in moist air, Radio Science, 20, 1069-1089.

Reynolds, R. W., T. M. Smith, C. Liu, D. B. Chelton, K. S. Casey, and M. G. Schlax (2007), Daily high-resolution blended analyses for sea surface temperature, Journal of Climate, 20(22), 5473-5496.

Regional SSS(SST) Bias Correction

Deriving the SSS Correction

- For the first two years of the Aquarius mission, we:
  - Computed dSSS = Aquarius - HYCOM
  - Collocated Reynold's OISST to the Aquarius observations
  - Conducted a polynomial regression of the dSSS to the SST
- Resulting curve [Figure 2] and equation:
  SSS_adj = -0.0019594 [SST]^2 + 1.1257 [SST] -161.4934
- Apply the bias adjustment to the current observations:
  SSS = SSS_aquarius - SSS_adj

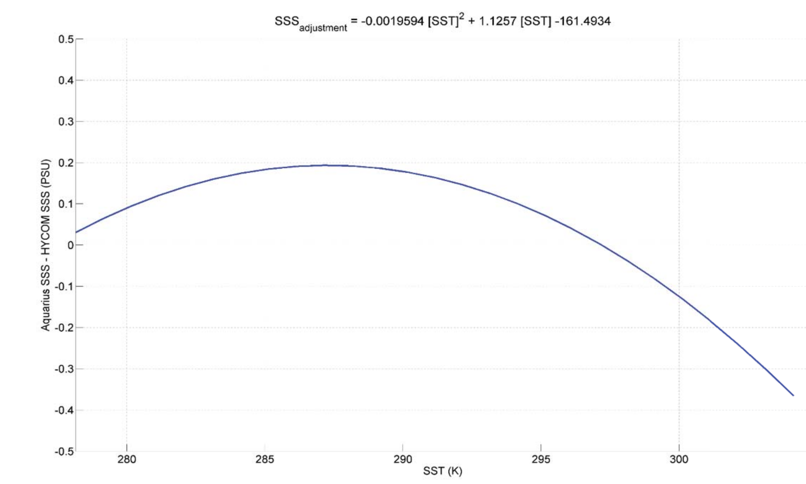

Figure 2. The blue curve is the polynomial regression of dSSS (Aquarius - HYCOM) with collocated Reynold's OISST. This curve's shape indicates that for warm water Aquarius has a salty bias and for cold water, a fresh bias, relative to HYCOM.

SST-based Bias Correction Applied

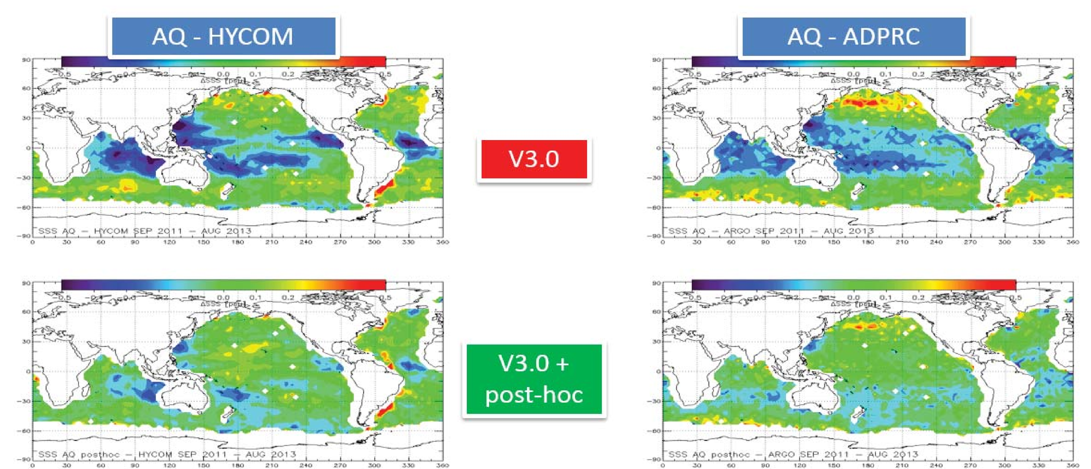

Figure 3A. The upper, left panel depicts the two-year global mean of the ADPS V3.0 Aquarius SSS retrieval bias relative to HYCOM without the SST-based bias correction. The lower, left panel shows the same plot, except with the SST-based bias correction applied. The right upper and lower panels show maps of the Aquarius biases relative to the ADPRC ARGO SSS data, with (lower) and without (upper) the SST-based bias correction.

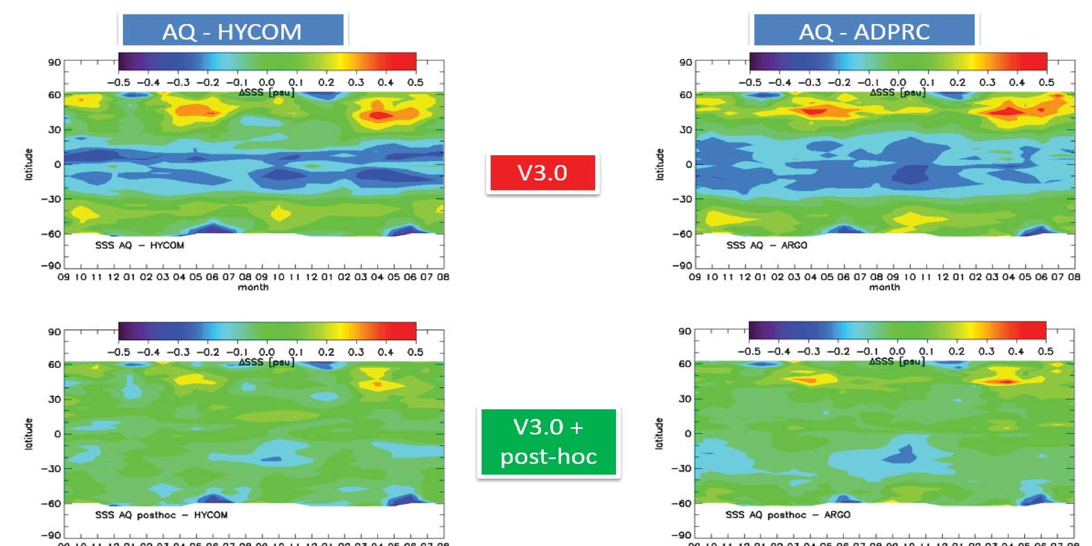

Figure 3B. The four panels of thie figure are similar to Figure 3A, but the quantity depicted is the longitudinal mean with latitude on the y-axis and time on the x-axis. This plot depicts the reduction in the SSS bias in time relative to both HYCOM and

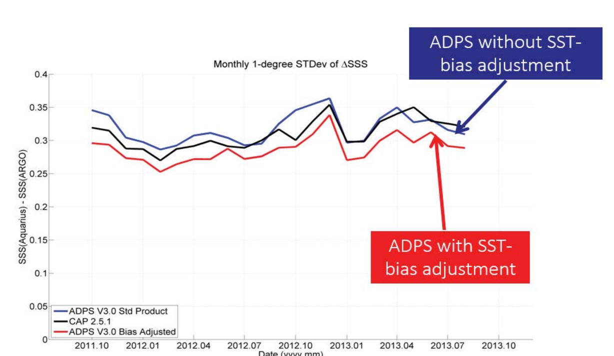

Figure 4. The monthly 1-degree standard deviations of of the difference (STD) of SSS (Aquarius minus ARGO) are shown here. The blue curve corresponds to the ADPS V3.0 data and has a higher STD than the red curve, which is the ADPS V3.0 SSS data with the SST-bias adjustment from Figure 2 applied.

Effects of the SST-based Bias Correction

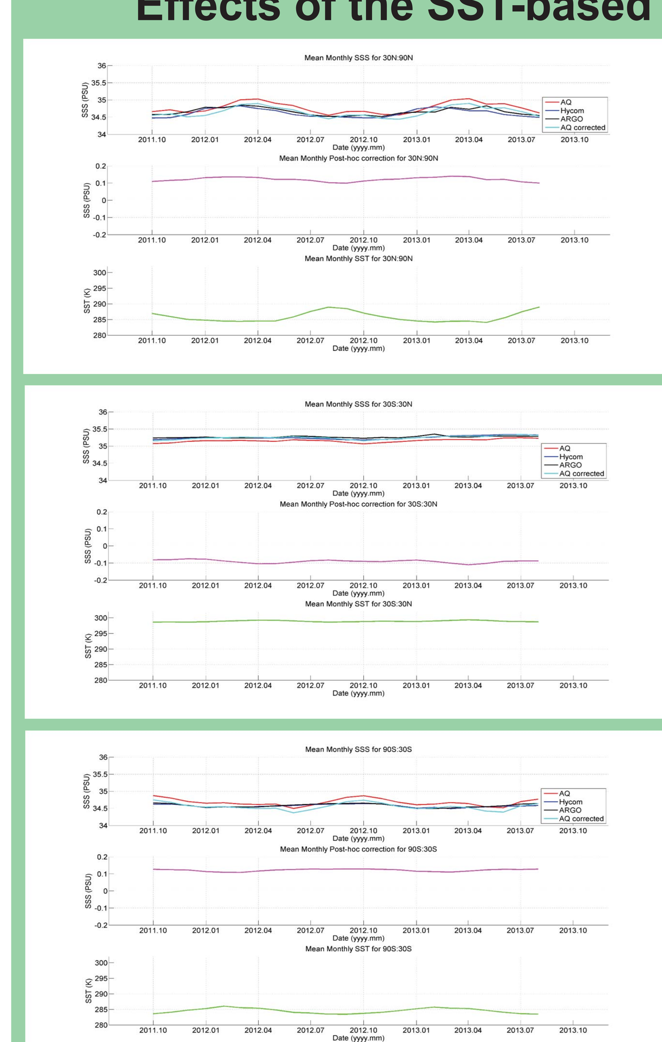

Figure 5. The three subpanels within each main panel depict mean monthly timeseries of various quantities. The three main panels of this figure correspond to different geographic regions.

The upper main panel shows the timeseries for 30N to 90N. The middle main panel shows the timeseries for 30S to 30N. And the lowest main panel shows the timeseries for 90 S to 30S.

The upper subpanels within each main panel depict the mean monthly SSS for four SSS values: Aquarius [red curve], HYCOM [blue curve], ARGO [black curve], and Aquarius with SST-based bias correction [teal curve].

The middle subpanel depicts the mean monthly SSS correction value, and lowest subpanel shows the mean monthly SST.

Effect of the SSS Correction's on the Seasonal Cycle

The biggest change cause by the SST-based adjustment is in the North Zone for which the adjustment slightly decreases the seasonal cycle by 0.012 psu. In this zone, the adjustment is resulting in better agreement with HYCOM and ARGO, both of which also show a smaller seasonal variation [Figure 5 and Table 1].

In the other two zones, the change in the seasonal amplitude due to the adjustment is less than 0.01 psu.

- For the South Zone the adjustment results in ever-so-slightly better agreement with HYCOM/ARGO.
- For the Tropics, the adjustment results in ever-so-slightly worse agreement with HYCOM/ARGO.

	South Zone	Tropics	North Zone
HYCOM	0.056	0.045	0.165
ARGO	0.070	0.014	0.137
AQUARIUS_Adj	0.111	0.054	0.181
AQUARIUS	0.116	0.045	0.193
Adjustment	-0.005	+0.009	-0.012

Table 1. This table shows the amplitude of the seasonal cycle in PSU for three zones: 90S to 30S, 30S to 30N, and 30N to 90N.

The amplitude is defined by:

$$y = a_0 + a_1 \cos\phi + a_2 \sin\phi$$

$$amplitude = \sqrt{a_1^2 + a_2^2}$$

where the a-coefficients are found from least-squares fit of the various parameters (HYCOM, ARGO, AQUARIUS) over two years.

SSS Regional Bias and Windspeed

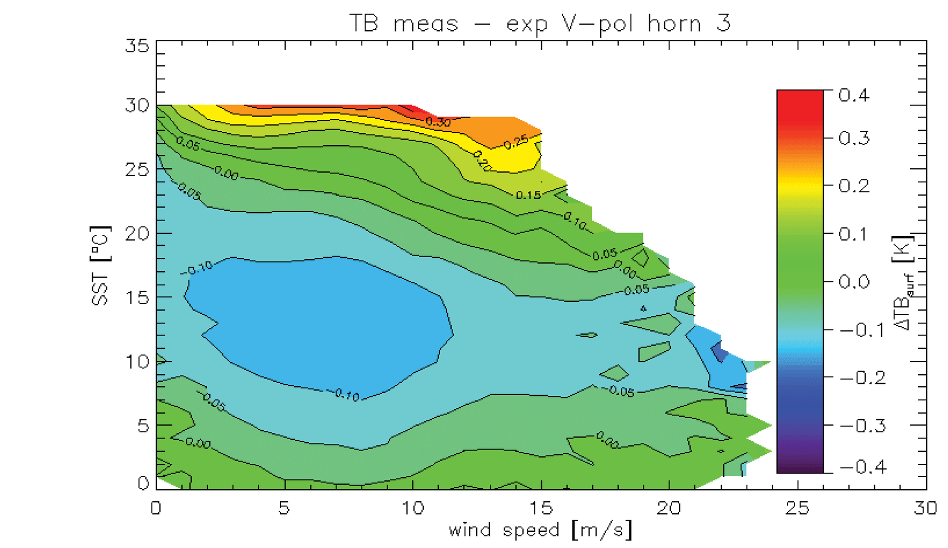

Figure 6. Brightness temperature (TB) difference contours are here shown between TB measured and TB expected for Aquarius's L-band radiometer's horn 3 V-pol channel. The TB difference contours are plotted as function of SST and wind speed. This plot indcates that for warm SST, the TB bias (and consequently, SSS bias) are also a dependent on wind speed.

- The SST-dependent regional biases in SSS are functions of both SST and windspeed, as seen in Figure 6.
- Wind speed contributes to these biases in two regimes:
  - Very low wind speeds (W < 2 m/s) [Figure 7]
    - The observed biases are on the order of ~0.1 K
    - Indicates biases from errors in the Geophysical Model Function (GMF)
  - Moderate to high wind speeds.
    - These biases are larger, up to 0.3K [Figure 6]
    - Causes fresh bias in the tropics, which increases with wind speed.
    - Indicates biases in surface roughness model.
- Possible Physical Causes in GMF (at low wind speeds)
  - Dielectric model (specular emissivity)
  - Oxygen absorption model [Figure 9]
  - Error in input SST
  - Combination of some or all of those
  - The causes have similar signature and are thus hard to separate [Figure 8].

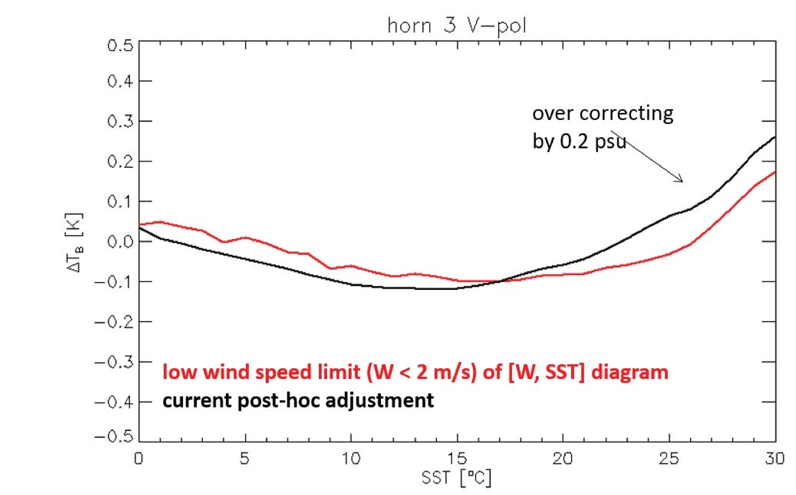

Figure 7. This is effectively a cross-section of the contour plot in Figure 6, taken at 2 m/s wind speed. The red curve is the TB difference between measured and expected (indicating +/- bias). And the black curve is the current SST-based bias adjustment, which for warm SSTs is over-correcting the SSS by ~0.2 PSU for warm SSTs.

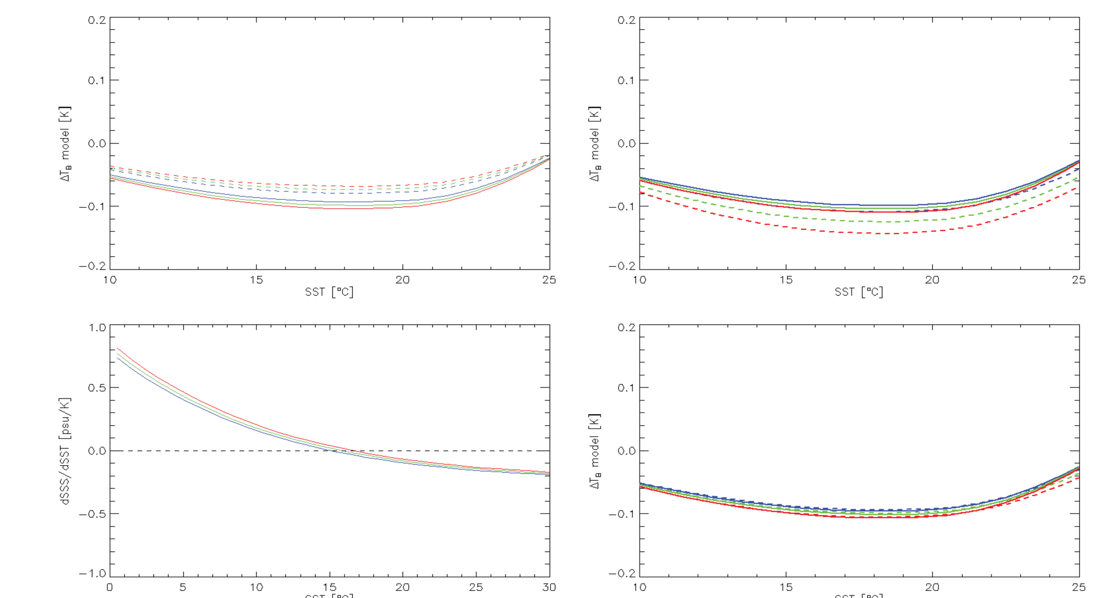

Figure 8. These four panels depict the effect the Dielectric model (upper left), the Oxygen Absorption model (upper right), the error in SST (lower left), and the combined Dielectric and Oxygen Absorption models (lower right) have on TB and consquently SSS, stratified here as a function of SST.
Note: The observed biases are small (~0.1 K) and each have similar signatures and are thus hard to separate.

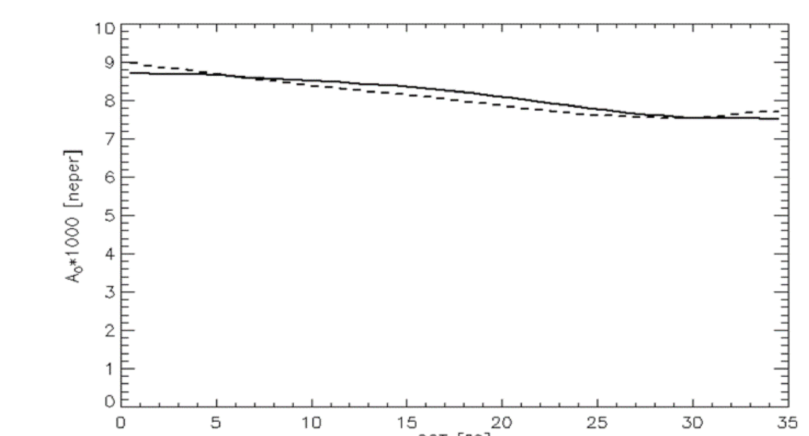

Figure 9. Oxygen absorption at L-band (solid curve) is due to non-resonant continuum term, based on Liebe (1985), with modification of the temperature dependence (dashed curve). This modification introducing 2% error in the oxygen absorption model.

Conclusions

- Regional SSS biases exist relative to *in situ* and modeled SSS fields.
  - A simple polynomial regression to collocated SST accounts much of the observed biases.
  - This adjustment was made part of GSFC/ADPS's V 3.0 release of the Aquarius L-band radiometer SSS data.
- Upon further investigation into the causes of the regional biases, we determined that wind speed is also a contributing factor to the regional biases.
  - There are a few sources of error that we have identified and are investigating further.
- Recommendation: Replace simple SST bias correction with a 2-dimensional (SST, Windspeed) correction table for each channel-horn combination [Figure 10].

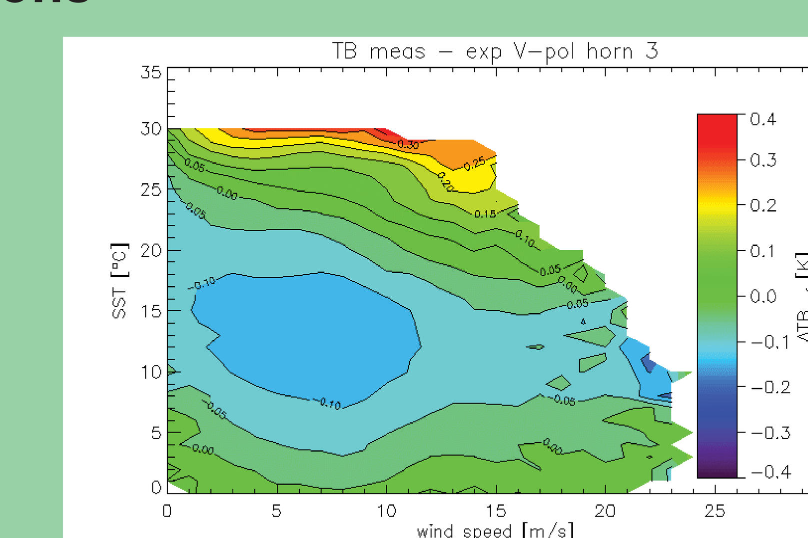

Figure 10. As seen in Figure 6, this is the proposed TB bias adjustment as a function of SST and windspeed. This specific plot is for Aquarius's L-band radiometer's horn 3 V-pol.