# EVALUATION OF AQUARIUS SSS SPACE/TIME VARIABILITY AND BIASES IN THE INDIAN OCEAN (Using Level 2 version 1.2.3 data)

**Aquarius/SAC-D Science Team Meeting**
**Buenos Aires, Argentina**
**11-13 April 2012**

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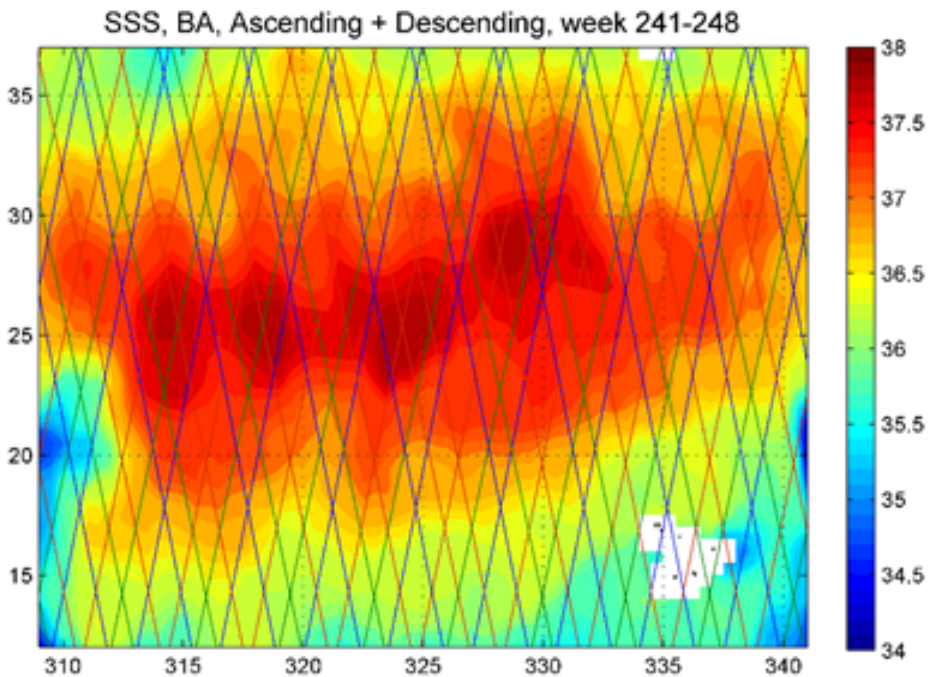
(Thanks to NASA Aquarius support)

# Motivation

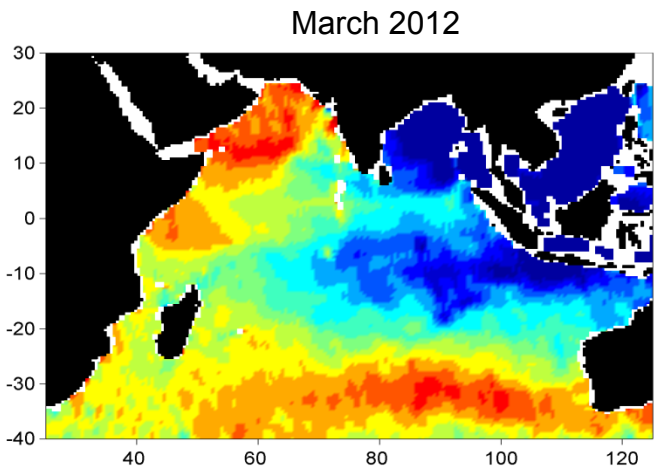
Working Hypothesis-
Satellite-based observations will (likely) revolutionize our ability to observe and characterize intermediate-scale (50-1000 km) space/time SSS structure and variability.
Project Goal-
To assist the Aquarius cal/val effort to strengthen the hypothesis.
Current Efforts-
To quantify and help remedy ascending/descending and inter-beam biases.

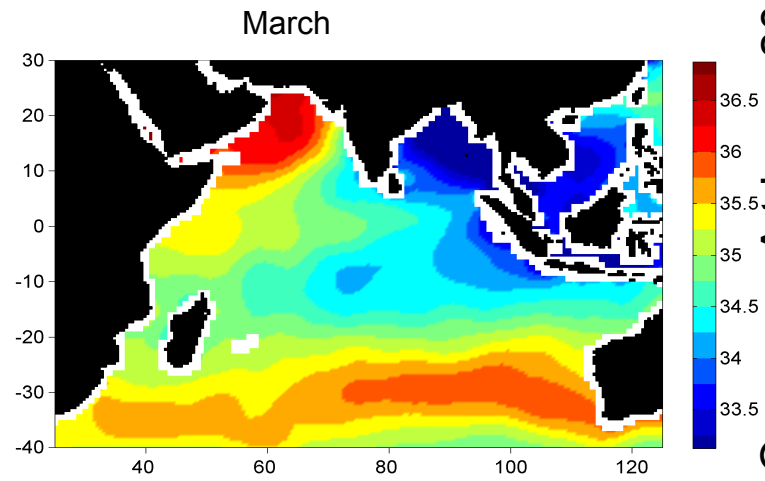



Map from the SPURS region-
To what degree are the observed salinity maxima real versus a result of biases.
Need to quantify “noise “ sources at these scales.

# Indian Ocean SSS
# from Aquarius and World Ocean Atlas 2009
# (March 2012 and Climatological March)

Aquarius SSS




World Ocean Atlas 2009

Outline-

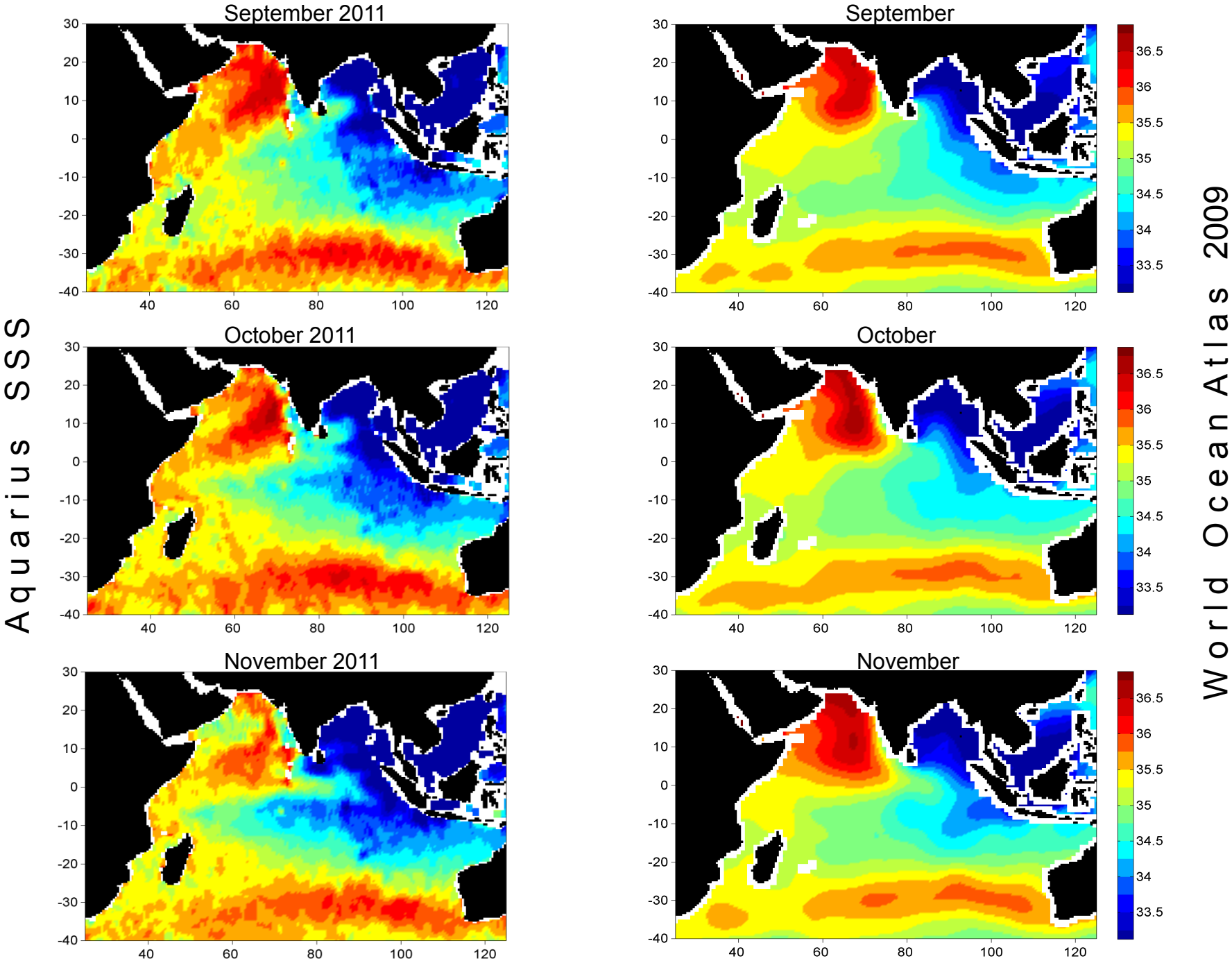
Space-time SSS variability at intermediate scales in the IO

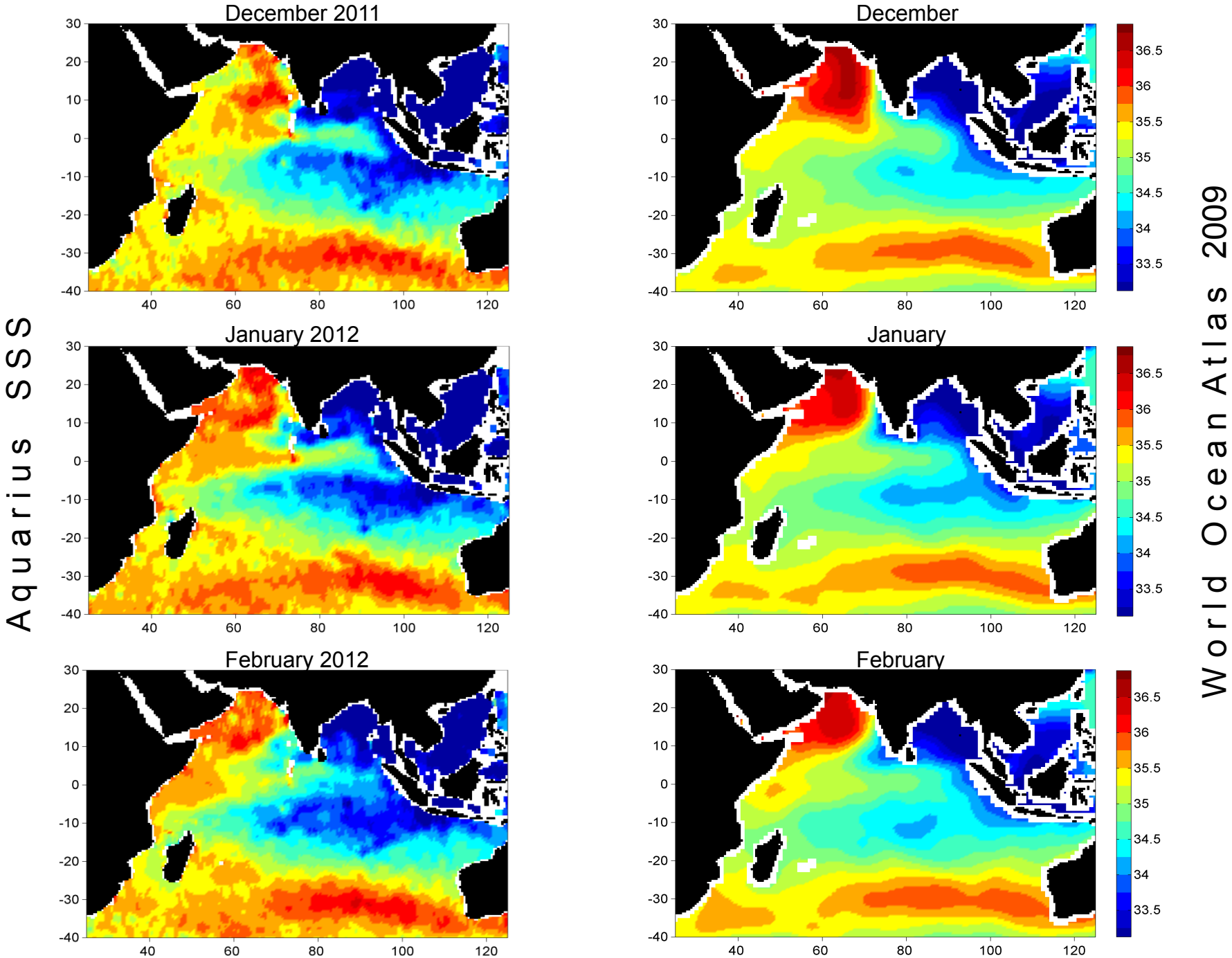
Ascending/descending biases

Inter-beam biases

Bay of Bengal

Sunda Strait


Aquarius SSS
September 2011
October 2011
November 2011
September
October
November
World Ocean Atlas 2009
30
20
10
0
-10
-20
-30
-40
40
60
80
100
120
36.5
36
35.5
35
34.5
34
33.5


Aquarius SSS
December 2011
January 2012
February 2012
December
January
February
World Ocean Atlas 2009
30
20
10
0
-10
-20
-30
-40
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60
80
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36.5
36
35.5
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34.5
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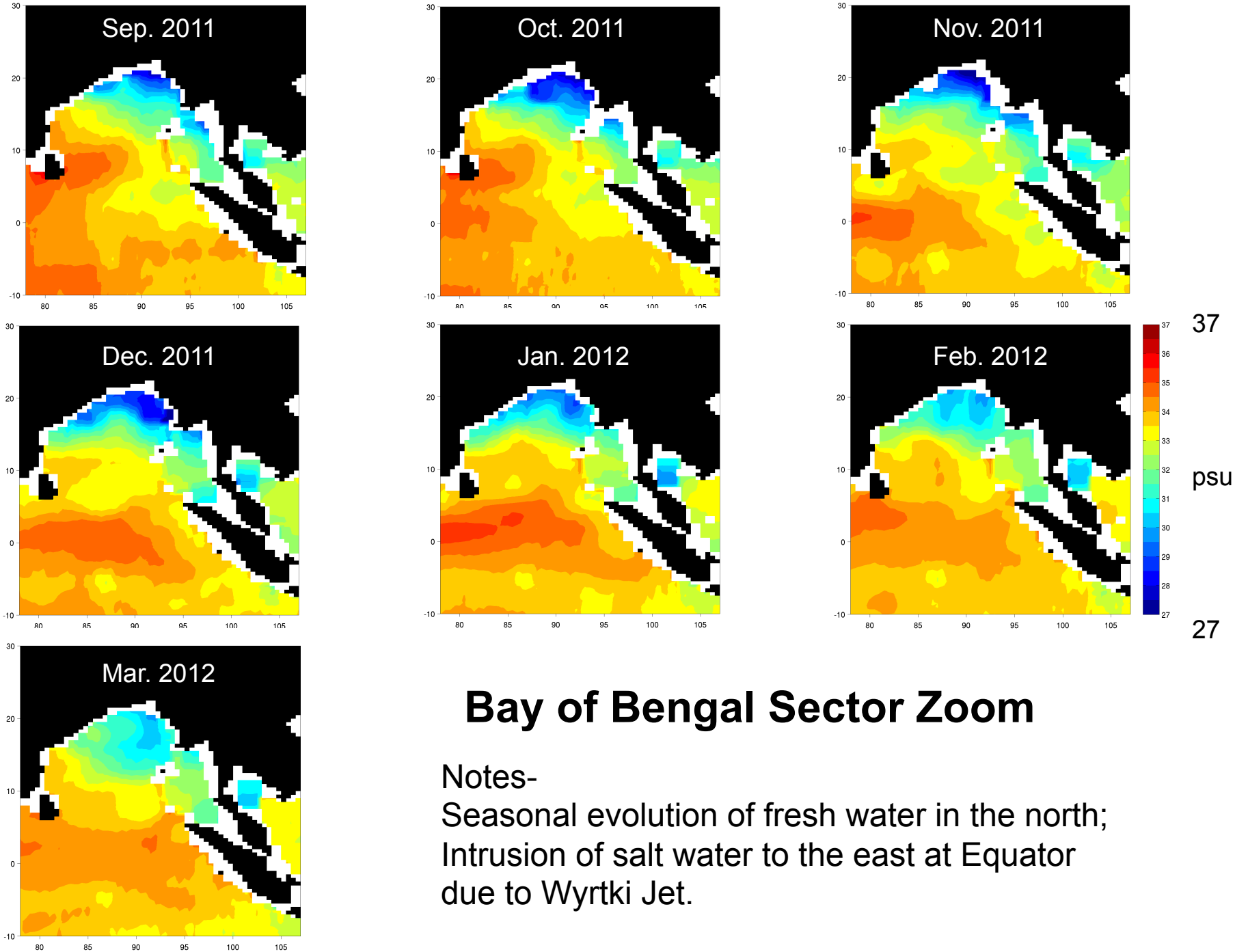
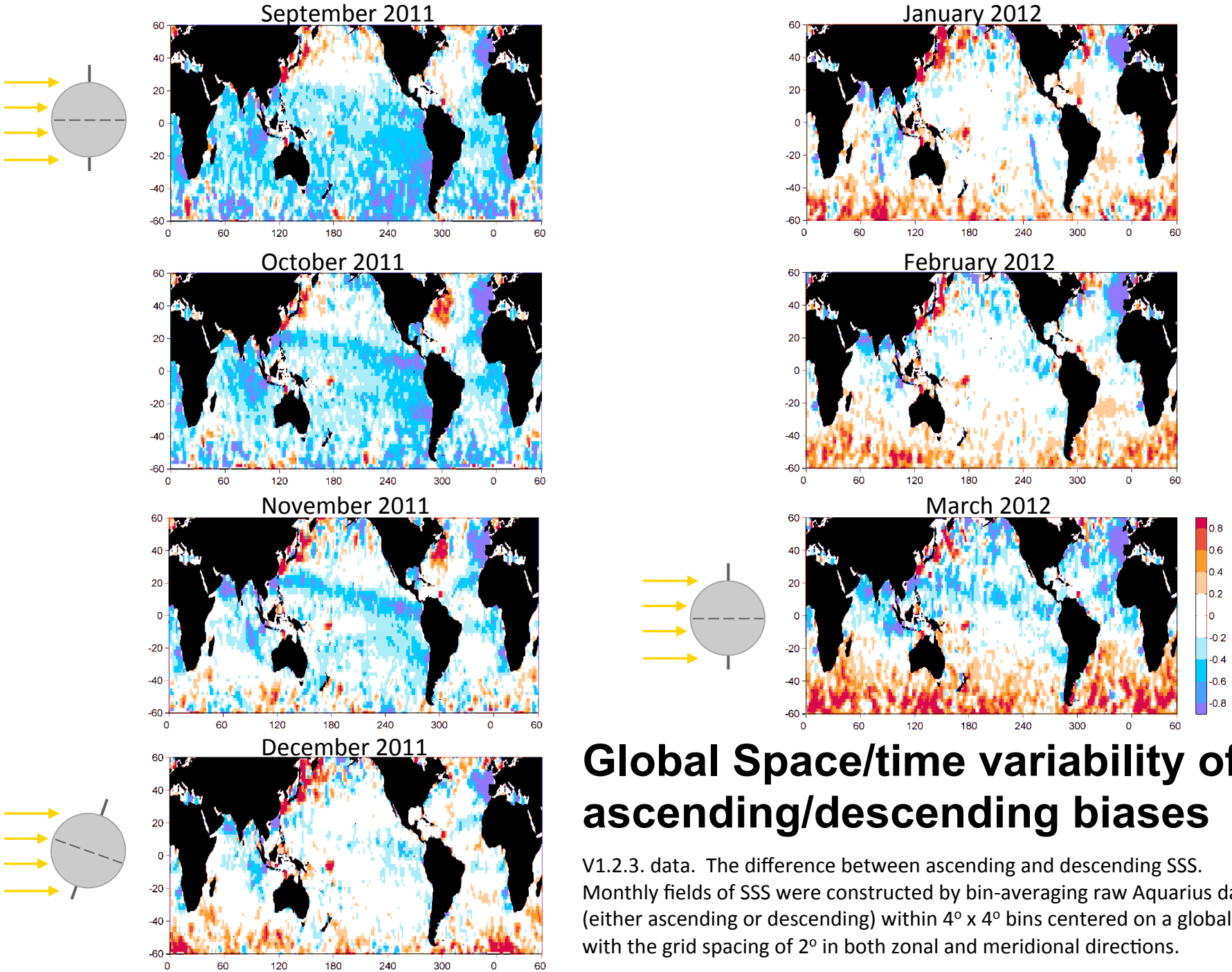
33.5




# Bay of Bengal Sector Zoom

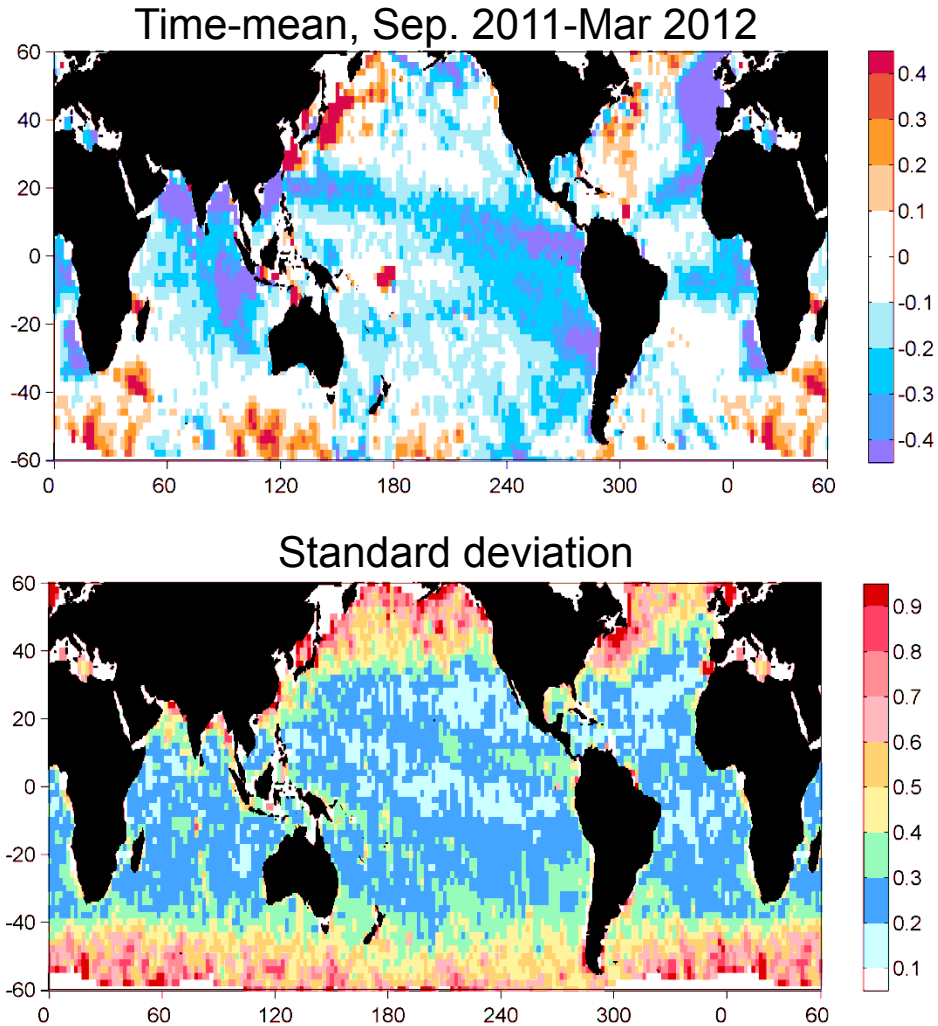
Notes-
Seasonal evolution of fresh water in the north;
Intrusion of salt water to the east at Equator due to Wyrtki Jet.




# Global Space/time variability of ascending/descending biases

V1.2.3. data. The difference between ascending and descending SSS. Monthly fields of SSS were constructed by bin-averaging raw Aquarius data (either ascending or descending) within 4° x 4° bins centered on a global grid with the grid spacing of 2° in both zonal and meridional directions.

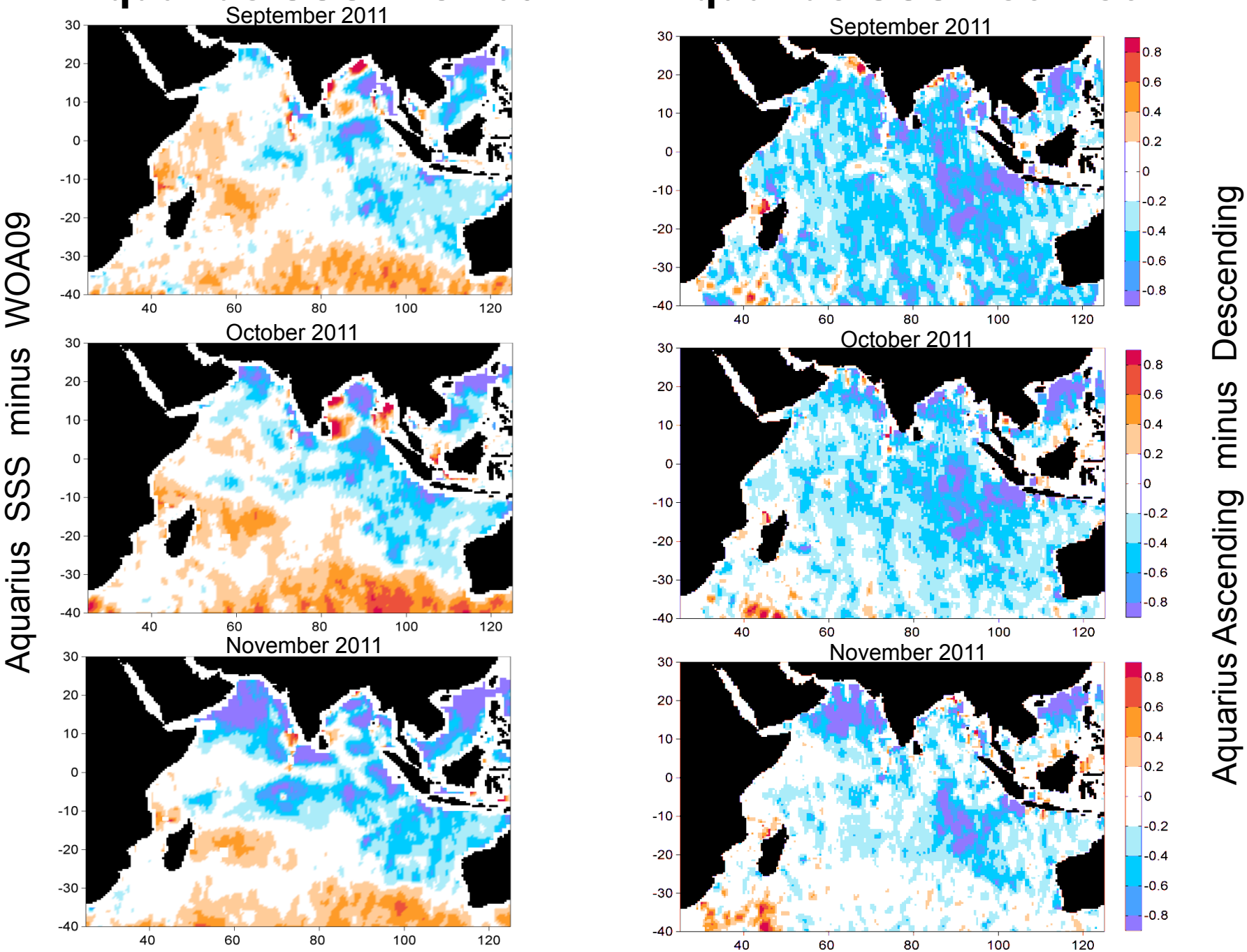
# Aquarius SSS, Ascending - Descending




The differences between ascending and descending SSS were computed using weekly maps. Weekly maps of SSS were constructed by bin-averaging raw Aquarius data (either ascending or descending) within $4^o$ x $4^o$ bins centered on a global grid with the grid spacing of $2^o$ in both zonal and meridional directions.

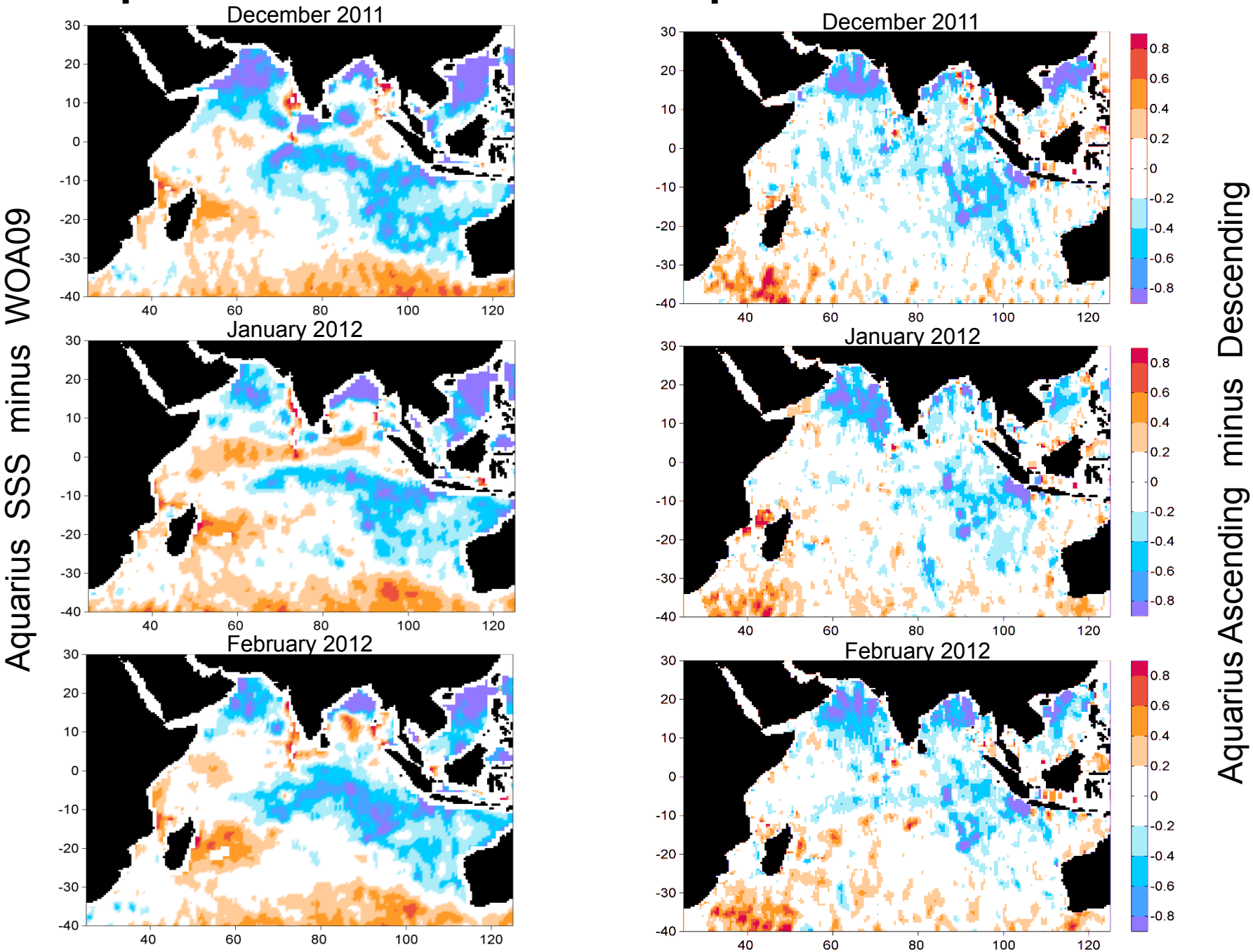
# Aquarius SSS-WOA09

# Aquarius SSS Asc-Dsc



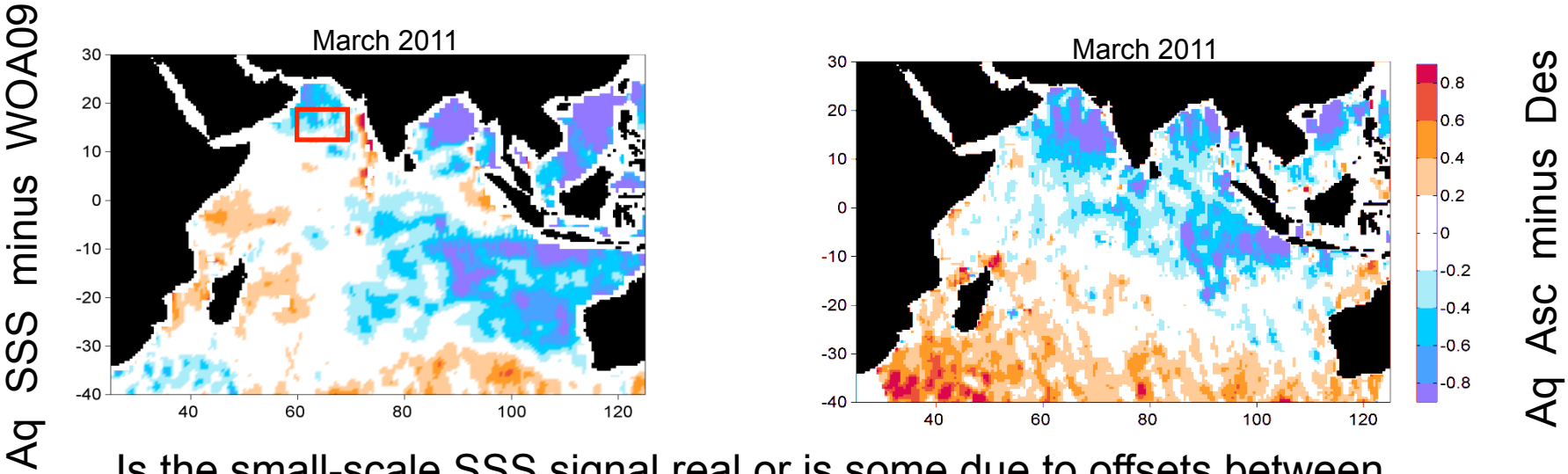
# Aquarius SSS-WOA09

# Aquarius SSS Asc-Dsc

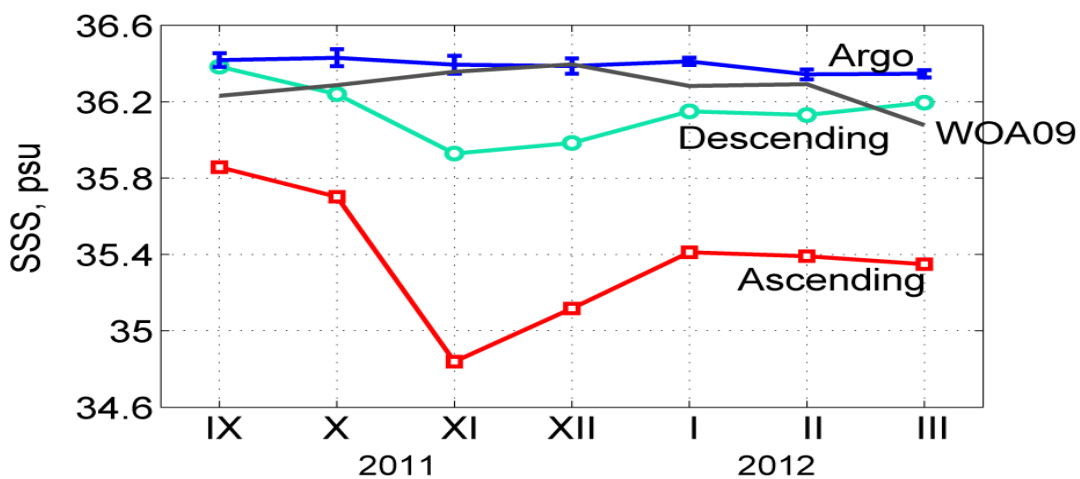


# Aquarius SSS-WOA09

# Aquarius SSS Asc-Dsc

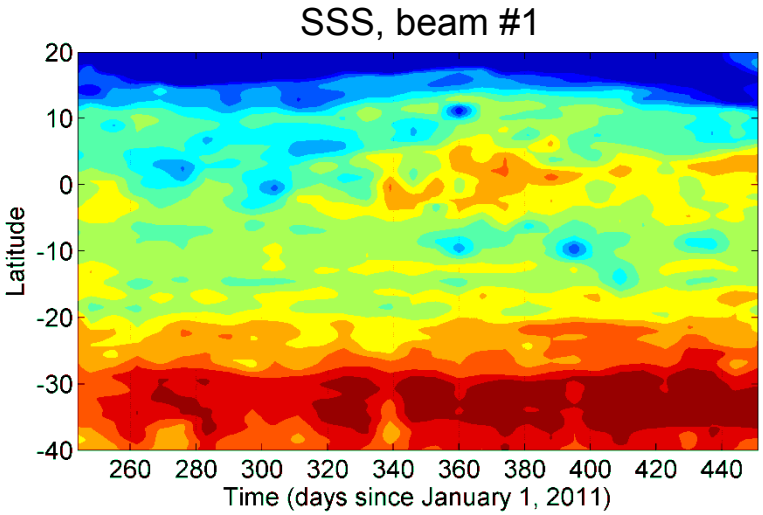


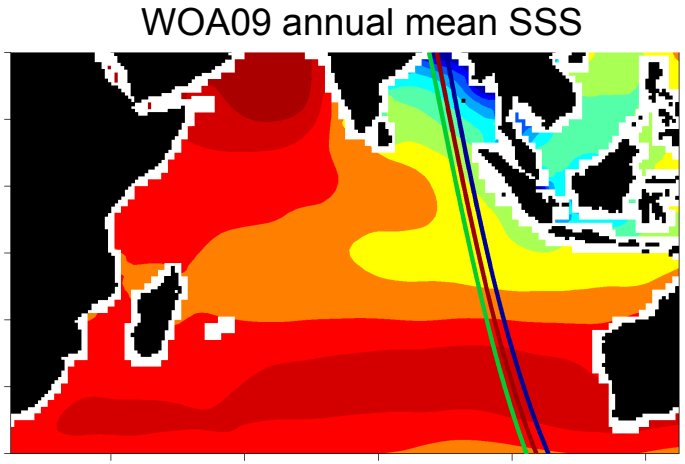

Is the small-scale SSS signal real or is some due to offsets between ascending and descending measurements? For instance, compare Aquarius SSS with Argo near-surface measurements in the Arabian Sea (red rectangle in the upper left panel).

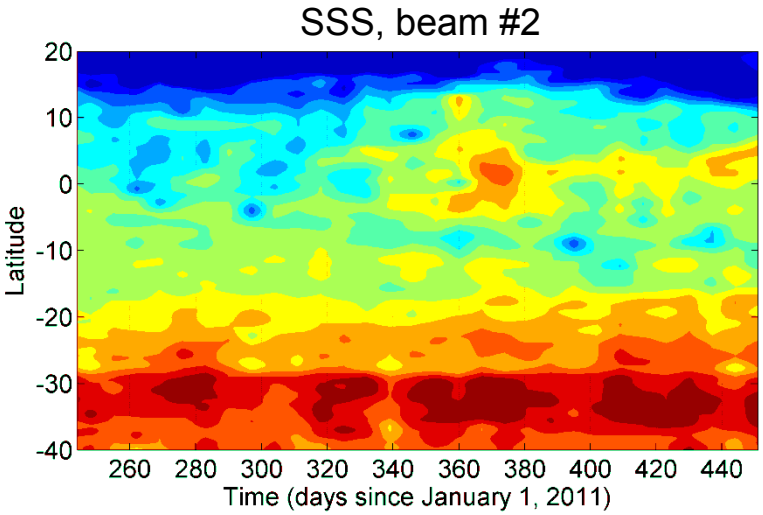


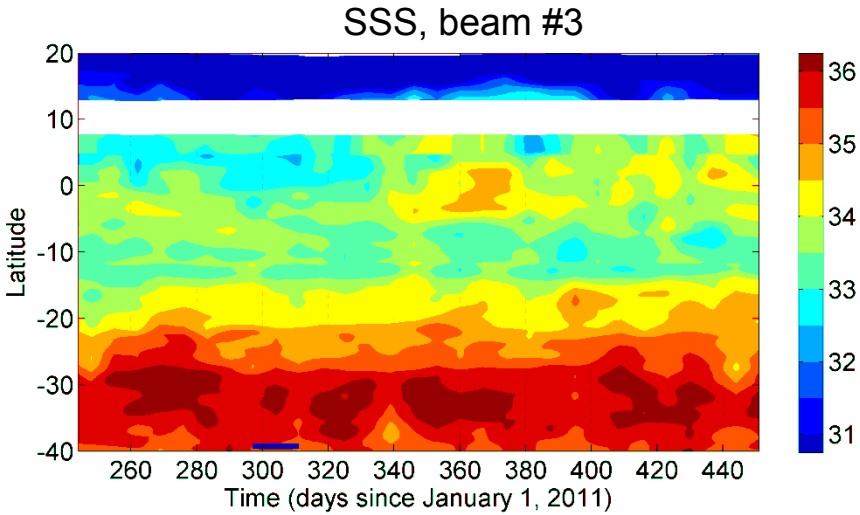

Notes-
Dsc agrees better with Argo but is about 0.3 psu too low;
Asc is about 0.9 psu too low;
Asc-Dsc difference seems to be increasing with time in the box.

# Lat/Time Plots of Aquarius SSS for 3 Beams, Ascending

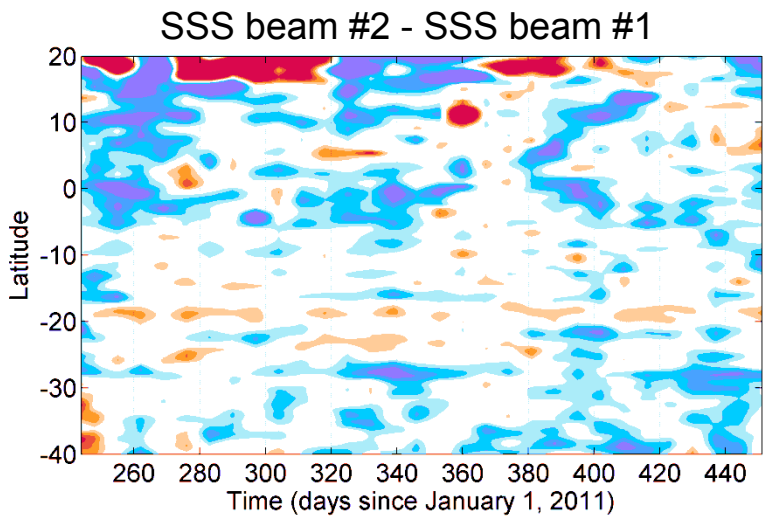


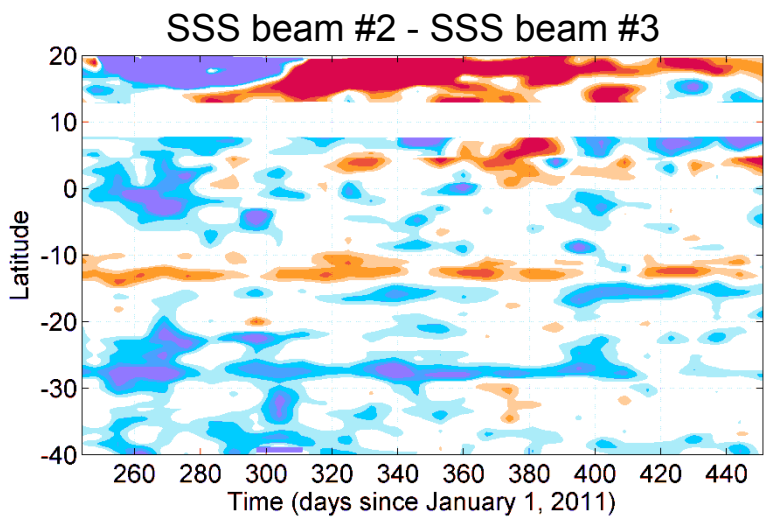



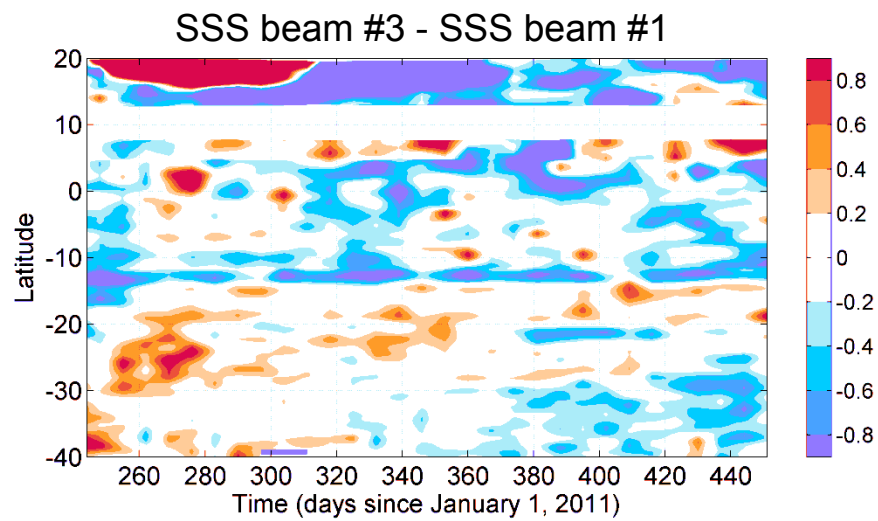



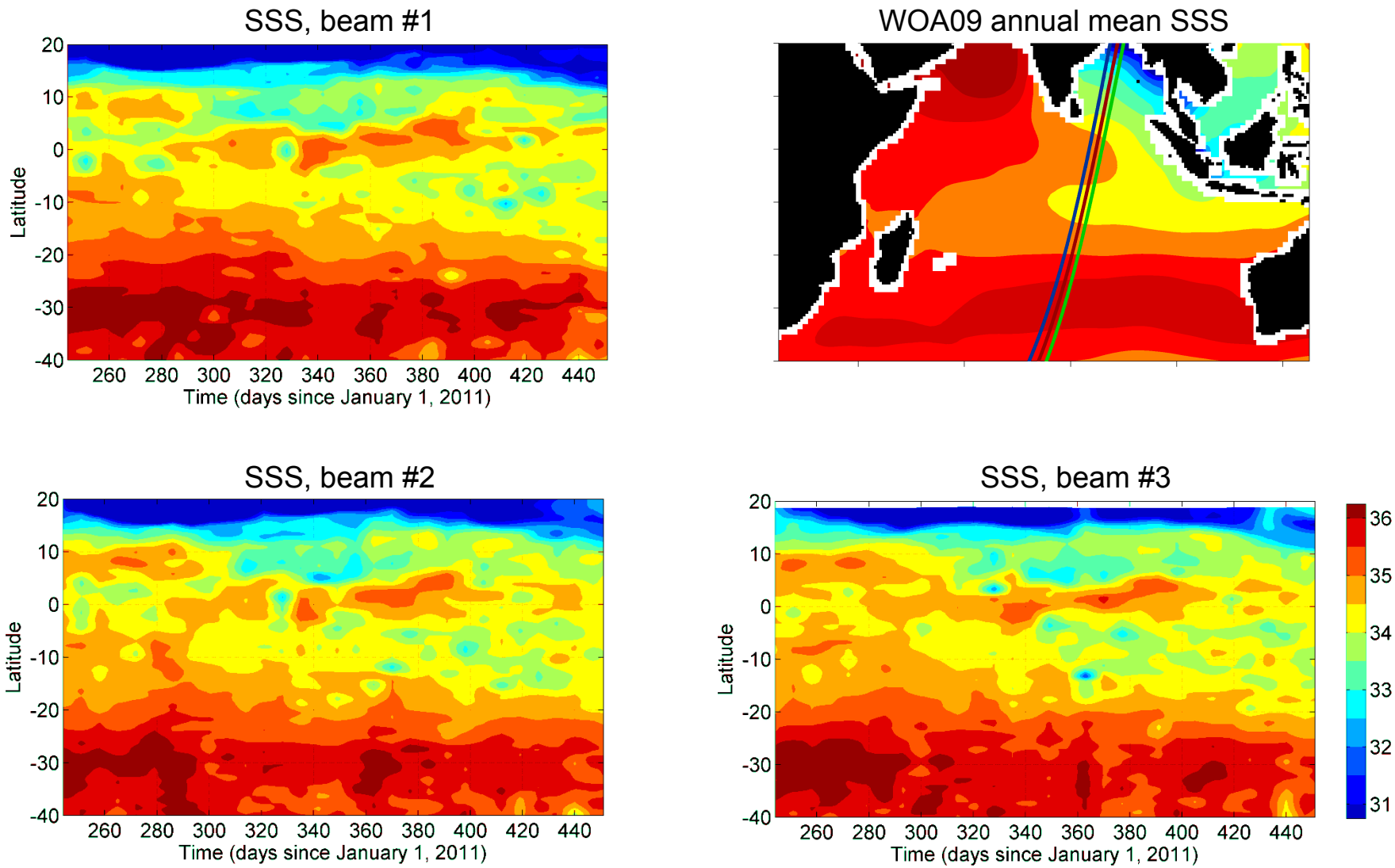
# Lat/Time Plots of Aquarius SSS, Asc., Beam Differences



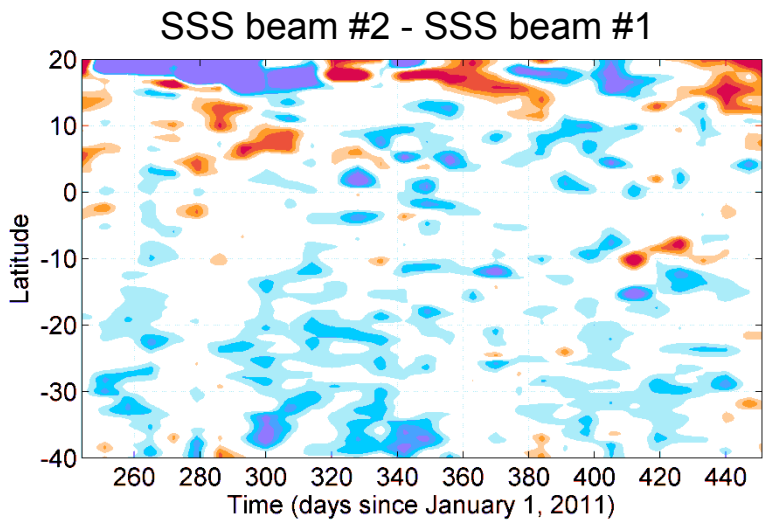



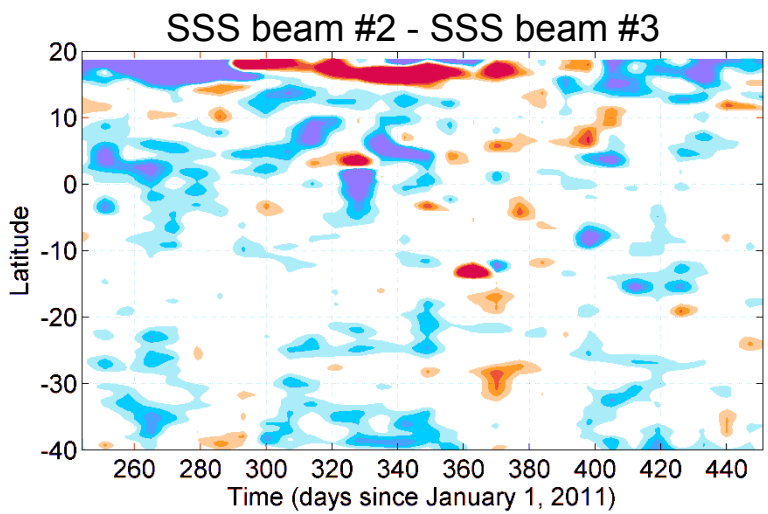



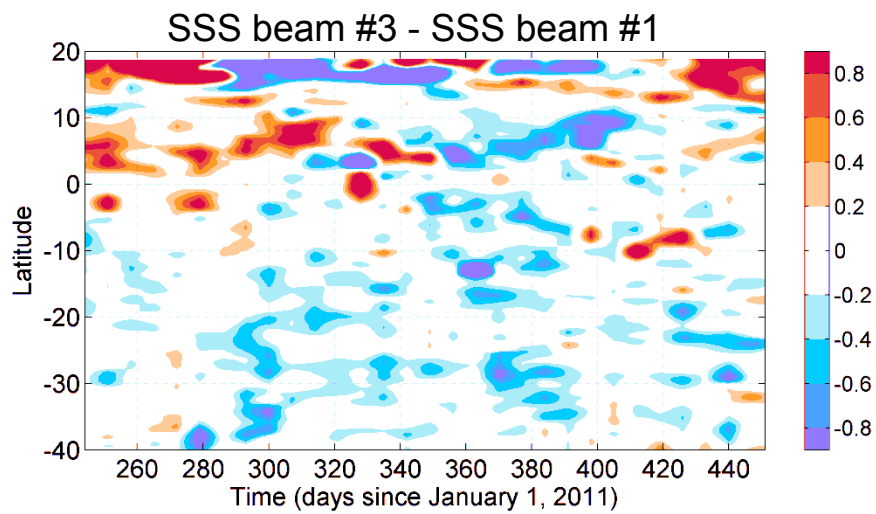
# Lat/Time Plots of Aquarius SSS for 3 Beams, Descending



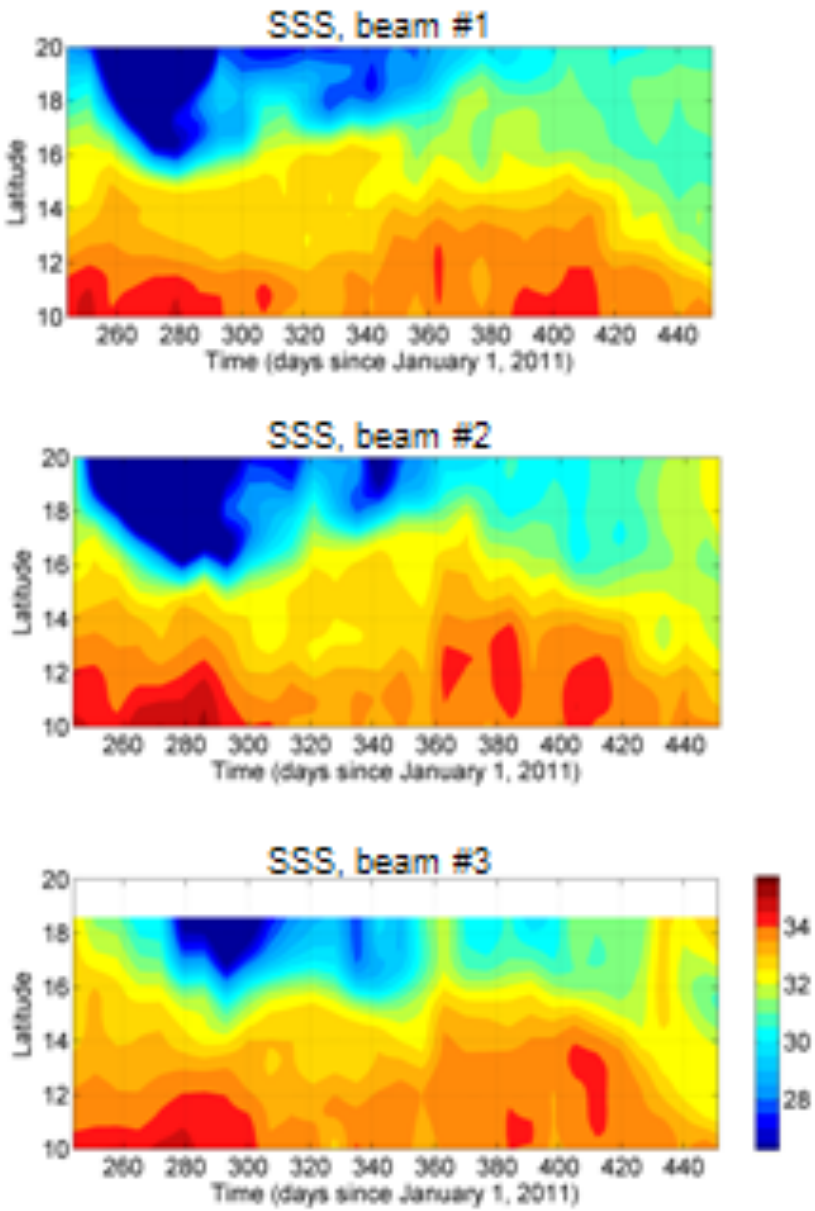
# Lat/Time Plots of Aquarius SSS, Dsc., Beam Differences

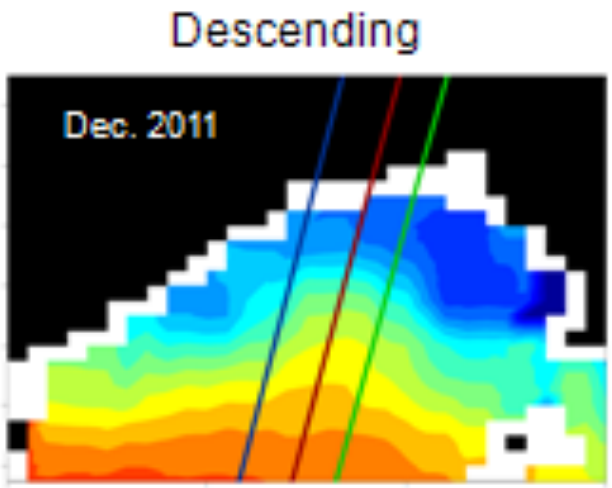


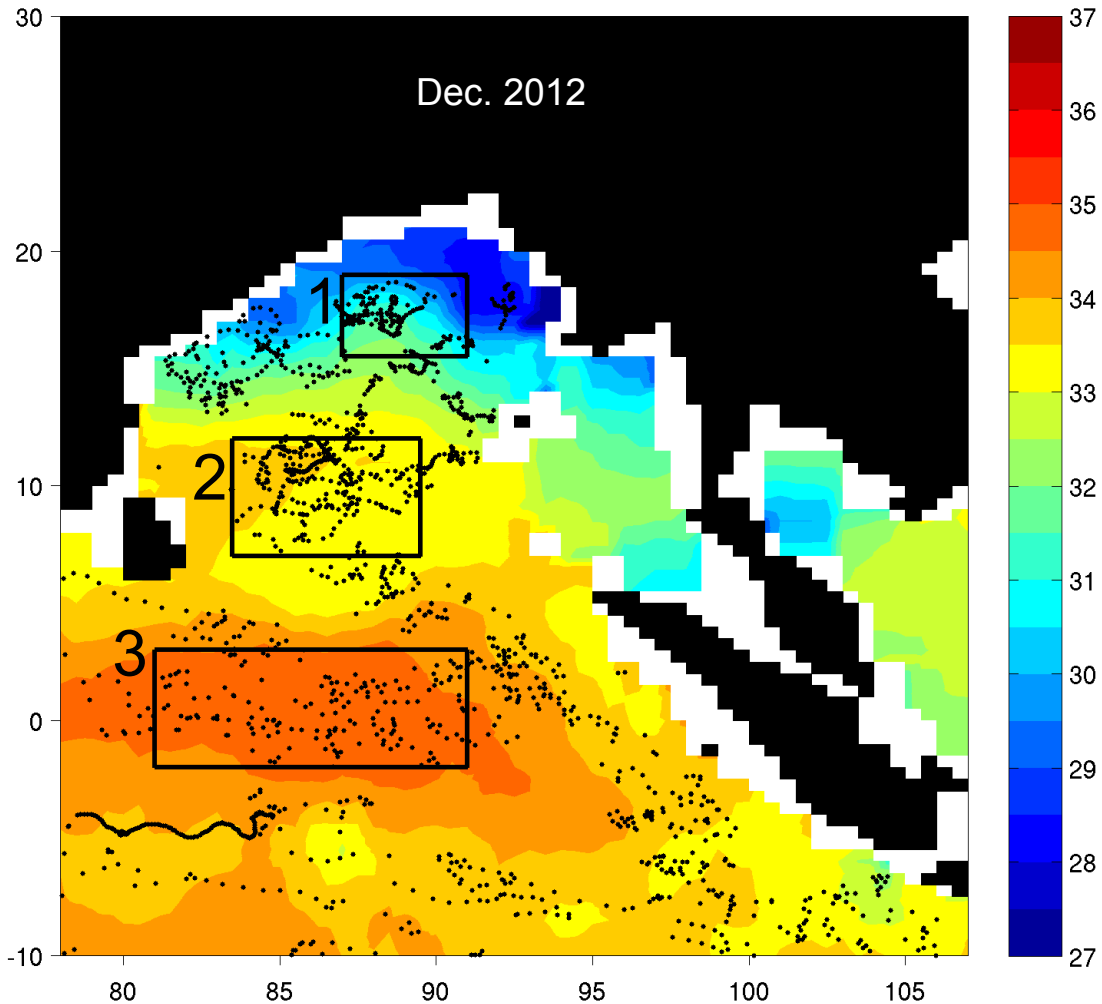
# Bay of Bengal SSS Lat/Time Plots, Descending Tracks



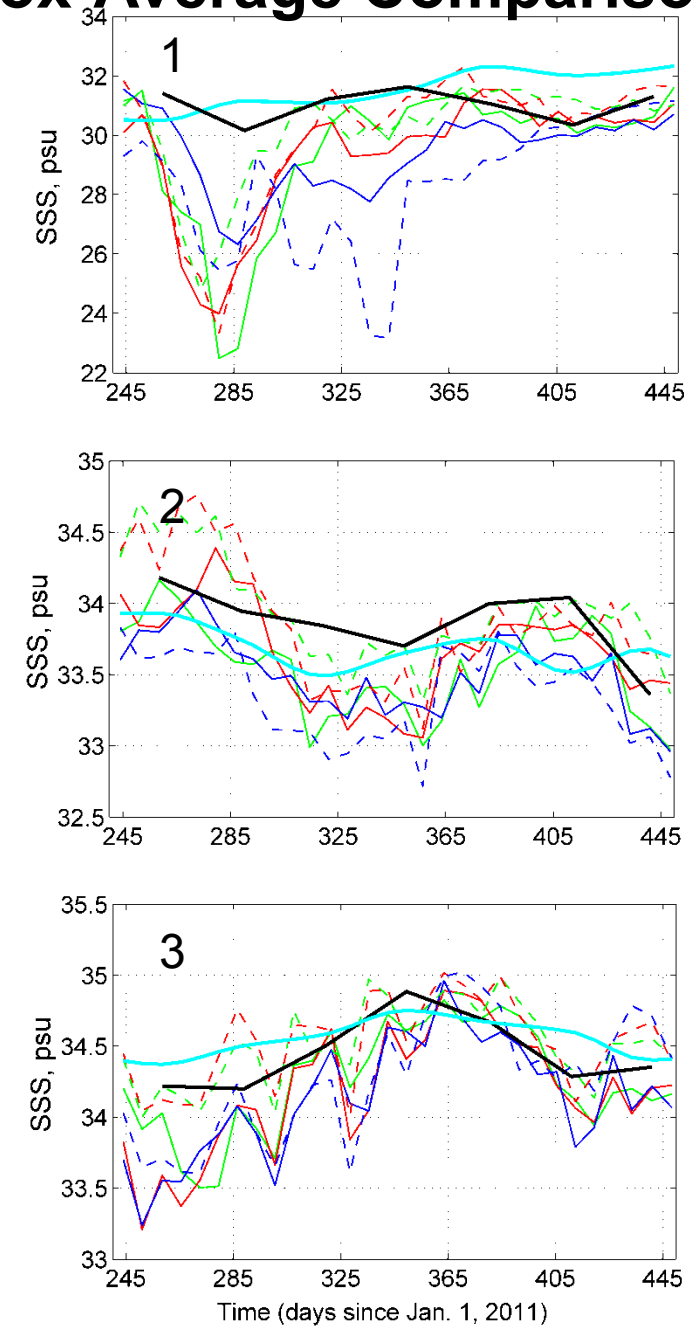

Note-
Expanded salinity scale 26-36 psu;
Half of the annual cycle observed;
Some aliased signals in time and space.

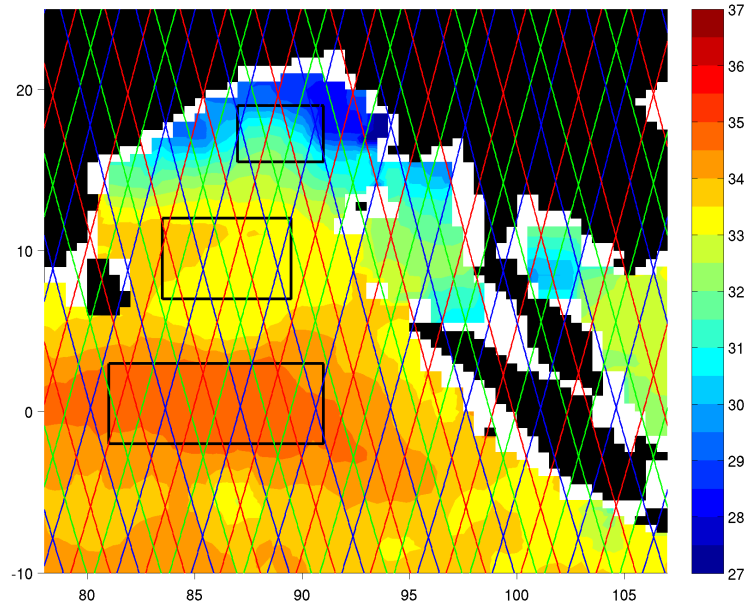
# Box-Average Comparisons: Beams, Argo, WOA09




Note-
Improved spatial coverage of Aquarius sampling compared to Argo.

# Box-Average Comparisons: Beams (Asc,Dsc), Argo, WOA09



Argo
WOA09
Beam #1
Beam #2
Beam #3
Solid-Asc; Dashed -Desc

# Table: Aquarius Inter-Beam Comparisons

Box 1

| Ascending | Mean | R.M.S. | Descending | Mean | R.M.S. |
|---|---|---|---|---|---|
| 2-1 | -0.06 | 1.16 | 2-1 | -0.22 | 1.00 |
| 2-3 | -0.01 | 1.58 | 2-3 | 1.64 | 2.45 |
| 3-1 | -0.06 | 1.70 | 3-1 | -1.83 | 2.16 |
| | | | | | |
| Asc-Desc | -0.45 | 0.65 | | | |

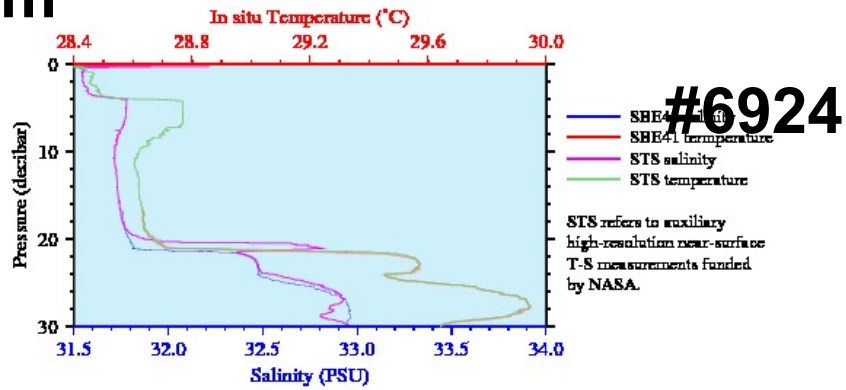
Box 2

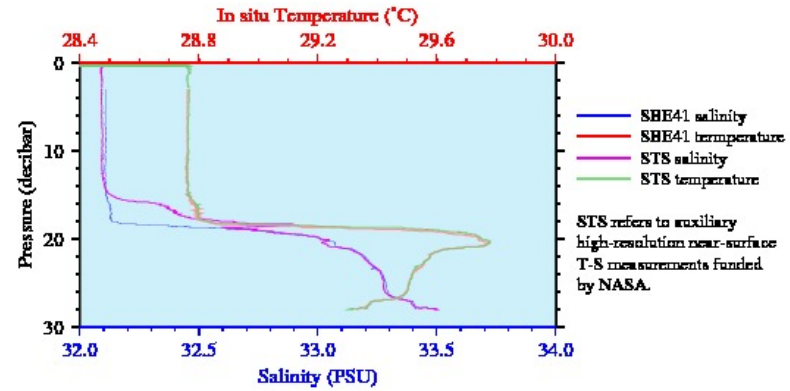
| Ascending | Mean | R.M.S. | Descending | Mean | R.M.S. |
|---|---|---|---|---|---|
| 2-1 | 0.12 | 0.27 | 2-1 | -0.08 | 0.19 |
| 2-3 | 0.15 | 0.23 | 2-3 | 0.52 | 0.30 |
| 3-1 | -0.03 | 0.19 | 3-1 | -0.59 | 0.26 |
| | | | | | |
| Asc-Desc | -0.28 | 0.16 | | | |

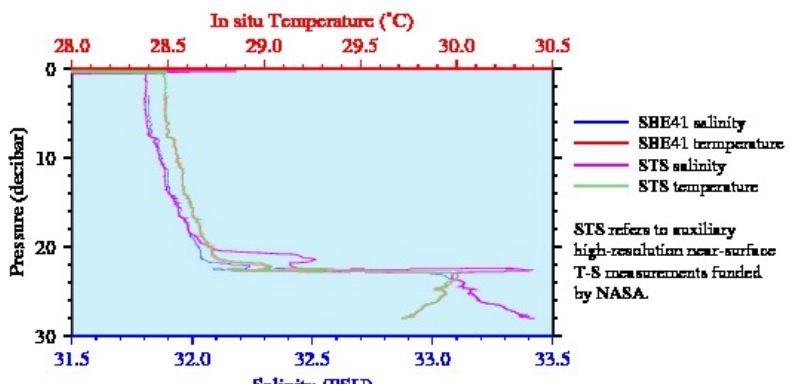
Box 3

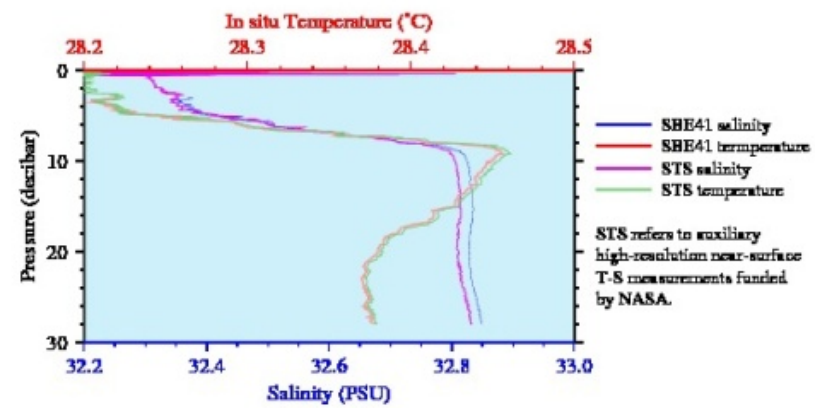
| Ascending | Mean | R.M.S. | Descending | Mean | R.M.S. |
|---|---|---|---|---|---|
| 2-1 | -0.08 | 0.22 | 2-1 | 0.02 | 0.13 |
| 2-3 | 0.04 | 0.15 | 2-3 | 0.26 | 0.26 |
| 3-1 | -0.12 | 0.23 | 3-1 | -0.24 | 0.29 |
| | | | | | |
| Asc-Desc | -0.31 | 0.19 | | | |

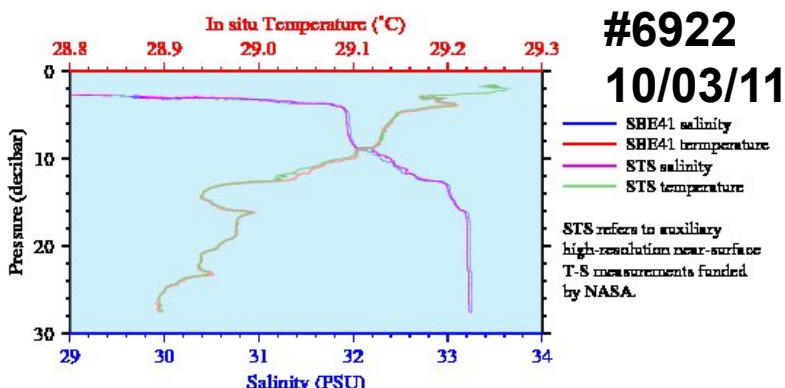
# Riser's Advanced Argo Floats, Nov 11, 13, 15, 25; 0-30 m

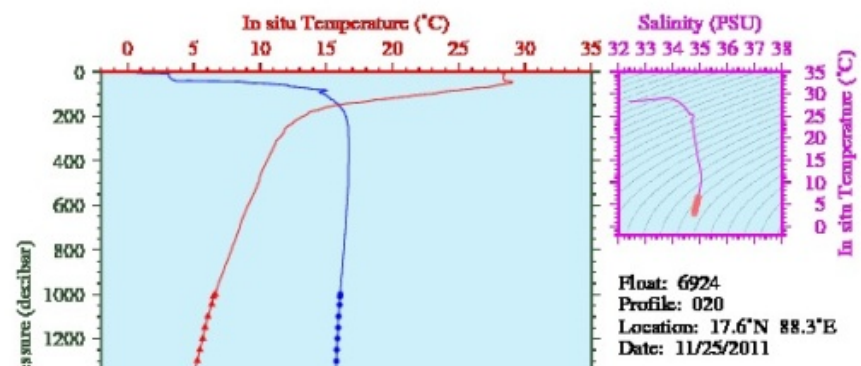


# Preliminary Results and Tentative Plans

Results-
Aquarius SSS provides significant value-added information in the tropical Indian Ocean using L2 v1.2.3 data.

Along-track Aquarius SSS provides improved latitude and time resolution compared to in situ data products.

Regional empirical correction of ascending/descending and inter-beam biases for production of improved L3 products appears feasible.

Plans-
Improve global analysis of ascending/descending trends (perhaps include low frequency variation at each grid point, not just trends).

Improve global analysis of inter-beam biases (quantify space/time variation and develop methodology to harmonize the 3 beams; this should ?? take into account the “official” calibration/reference plan at some point).

Continue to improve space/time analysis methodology for the tripical Indian Ocean, since the region has large intraseasonal to interannual variability.

Thank You!

To the many
who have worked so hard for
years to make
Aquarius SSS data a reality!

EVALUATION OF AQUARIUS SSS SPACE/TIME VARIABILITY AND BIASES IN THE INDIAN OCEAN

Hacker, P., O. Melnichenko, J. Potemra, N. Maximenko

University of Hawaii

The Indian Ocean is characterized by large SSS signals, with higher SSS in the western Arabian Sea sector and fresher water in the eastern Bay of Bengal sector. The basin is subject to strong seasonal and intraseasonal wind forcing, resulting in strong, reversing currents in the near-equatorial region. These currents result in zonal mixing of the salinity field and strong space/time variability of the SSS field.

The goal of this project is to evaluate and optimize the utility of the Aquarius SSS products at short time and space scales in order to characterize the space/time variability of SSS both globally and in the Indian Ocean, specifically. Useful tools for this analysis include: latitude-versus-time plots over the first seven months of the mission to quantify the oceanic SSS variability as well as sources of error; difference maps for the three beams and between ascending and descending passes; and time-series of SSS over selected domains. Particular topics of study include: the fresh water river inflow in the Bay of Bengal and the Sunda Strait inflow from the Java Sea.

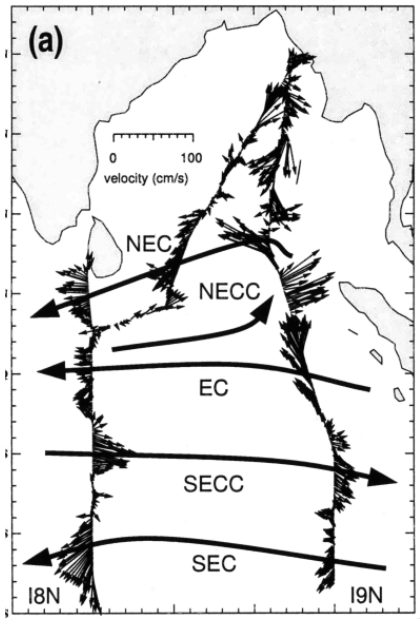
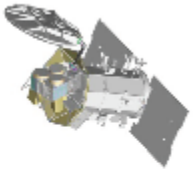



Figure from:
Hacker et al., **GRL, VOL. 25, NO.15, PAGES 2769-2772, AUGUST 1, 1998**

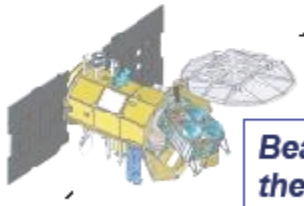
AQUARIUS/SAC-D

# Mission Design and Sampling Strategy



***Sun-synchronous exact repeat orbit***
***6pm ascending node***
***Altitude 657 km***

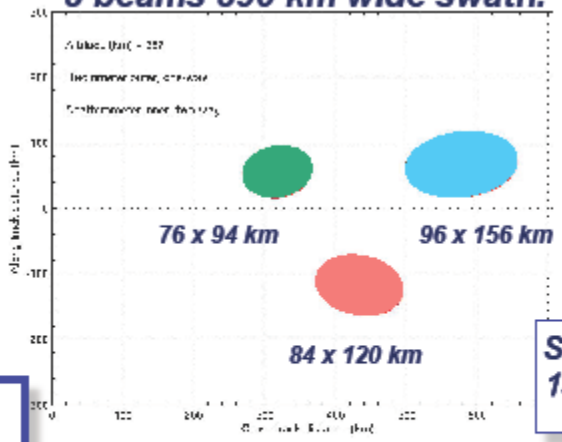
- ***Global Coverage in 7 Days***
- ***4 Repeat Cycles per Month***



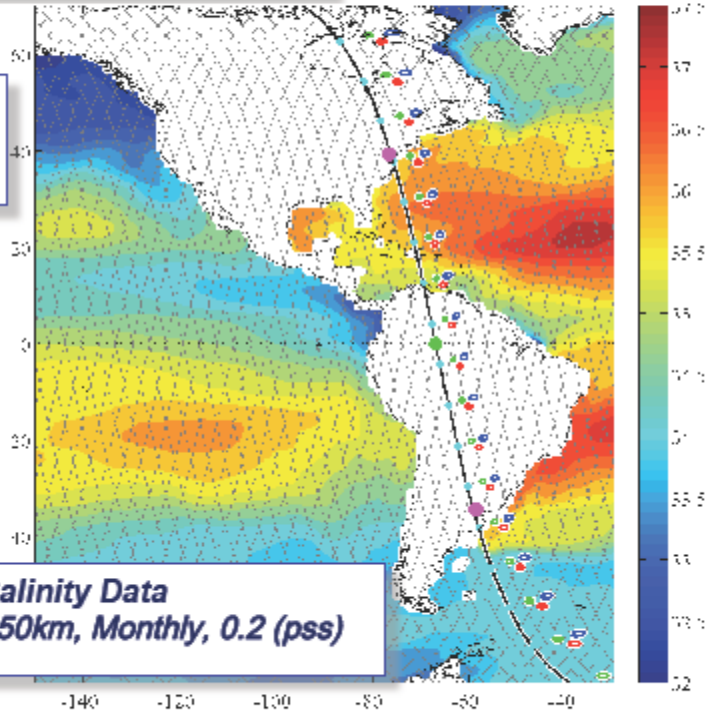
***Beams point toward the night side to avoid sun glint***

In Orbit Checkout

***3 beams 390 km wide swath.***




Launch 2010



***Salinity Data***
***150km, Monthly, 0.2 (pss)***

# Spatial patterns and variability of near-surface vertical gradients of salinity from historical CTD and Argo float data

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Argo Workshop
October 18, 2011
San Diego, CA

## 1. Abstract

Sea surface salinity (SSS) is an important variable that characterizes the intensity of the marine hydrological cycle [US CLIVAR Salinity Working group, 2008]. The Aquarius and SMOS satellite missions are providing, for the first time, global repeat observations of SSS with space resolution and frequency not accessible by other components of the ocean observing system. Among these components, the Argo float array is the most compatible due to its continuous global coverage. Yet, Argo float measurements are limited to layers at and below 5 m depth, thus leaving the most active near-surface ocean layer unobserved. As a step towards a synergy between the satellite and sea-based observations, we analyze near-surface vertical gradients of salinity in historical CTD and Argo float data.

This way, to characterize salinity differences in the uppermost ocean layer and their relation to subsurface stratification, we analyze open ocean data of high-resolution CTD profiles collected in the World Ocean Database 2009. Globally, the mean value and standard deviation of the difference between salinity at 5 m depth and SSS do not exceed 0.03 psu and 0.2 psu, respectively. At the same time, the probability distribution of this difference is strongly skewed towards positive values due to events of anomalously low SSS. Using the statistics, gained from the analysis of historical CTD casts, the Argo float data are then utilized to reconstruct seasonal maps of probability of appearance of a complex vertical structure of salinity in the near-surface layer. The areas of high probability indicate the areas where the Aquarius and SMOS satellite missions are expected to add fundamentally new information for climate and ocean research. Alternatively, the areas of low probability indicate the areas most suitable for calibration and validation of the satellite data. A struggle between precipitation and vertical mixing, which appears to be responsible for the observed evolution of the complexity of the near-surface salinity structure, is also discussed on a seasonal basis.

## 2. Historical CTD data

To characterize salinity differences in the uppermost ocean layer we use high-resolution CTD data collected as part of the World Ocean Circulation Experiment (WOCE). The WOCE CTD data are known to be carefully calibrated by accompanying bottle samples, resulting in unprecedented accuracy of 0.002°C for temperature and 0.002 psu for salinity (Saunders et al., 1991).

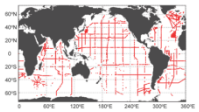

**Figure 1.** Locations of CTD casts with valid surface (0-1m depth) temperature and salinity measurements from WOCE data archive. Stations located within approximately 200 km distance off the nearest coast were excluded from the analysis. The selection of WOCE data is also made according to provided quality flags. Only profiles with good data (quality flag=2) are retained.

For each vertical profile:

$$\Delta S_{z_i - z_{i-1}} = S(z_i) - S(z_{i-1})$$
$$\Delta T_{z_i - z_{i-1}} = T(z_i) - T(z_{i-1})$$
$$\Delta \rho_{z_i - z_{i-1}} = \rho(z_i) - \rho(z_{i-1})$$

$S$ - salinity (psu),
$T$ - temperature (°C )
$\rho$ - density (kg/m$^3$)
$z_i$ - depth: [0,1]m; [4,6]m; [9-11]m.

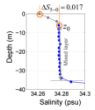


**Table 1.** Statistics of $\Delta S_{5-0}$

| WOCE | profiles | mean (psu) | std (psu) | skew |
|---|---|---|---|---|
| all data (flag=2) | 5635 | 0.021 | 0.145 | 14.8 |
| Tropics 22°S -22°N | 1934 | 0.028 | 0.157 | 12.4 |
| Off tropics | 3701 | 0.016 | 0.126 | 16.3 |

Over the whole dataset, the mean and standard deviation of $\Delta S_{5-0}$ are equal 0.021 and 0.15 psu, respectively. Probability distributions of $\Delta S_{5-0}$ are severely skewed toward positive values due to anomalous low-salinity measurements at the surface (Table 1).

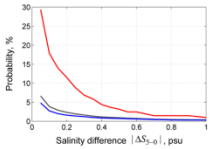


**Table 2.** Statistics of $\Delta S_{5-0}$ for different sub-sets of CTD data

| WOCE | profiles | mean (psu) | std (psu) | skew |
|---|---|---|---|---|
| All data | 5635 | 0.021 | 0.145 | 14.8 |
| $\Delta S_{10-5} < 0.02$ | 5226 | 0.016 | 0.131 | 16.4 |
| $\Delta S_{10-5} \geq 0.02$ | 409 | 0.075 | 0.186 | 4.7 |

**Figure 2.** Probability, P (%), that the difference between salinity at 5 m depth and SSS, $|\Delta S_{5-0}|$, is larger than or equal to a prescribed threshold, calculated for three distinct groups of CTD profiles. Some statistical characteristics of the near-surface salinity differences for each group of profiles are provided in Table 2. Colors of numbers in Table 2 correspond to those of curves in Fig. 2. Over the whole dataset, only about 6% of CTD profiles exhibit near-surface salinity differences larger than or equal to 0.1 psu (black curve). However, CTD profiles, which exhibit relatively large salinity difference between 10 m and 5 m depth, are also more likely to show large values of the near-surface salinity difference (red curve).

## 3. Argo data

Unlike historical CTD data, the Argo float array provides global coverage with high density of observations in both time and space. Although Argo observations are limited to layers at and below 5 m depth, combined with statistics inferred from the analysis of historical CTD data, they appear to be useful for characterizing regions where and when discrepancies between *in situ* salinity measurements and Aquarius SSS retrievals are expected to be significant.

Consider, for example, two groups of Argo profiles, one of which combines all profiles that have a signature of a 'complex' vertical structure of salinity in the near-surface layer, |S(10m)-S(5m)|>0.02 psu, and the other group combines 'simple' profiles, characterized by well mixed salinity in the near-surface layer, |S(10m)-S(5m)|<0.02 psu. Since these two groups of profiles are mutually exclusive (two events cannot occur at the same time), probability of occurrence of a 'complex' salinity structure in the near-surface layer can readily be calculated from the statistics of Argo floats.

$A$: $|\Delta S_{10-5}| < 0.02$ psu, $B$: $|\Delta S_{10-5}| \geq 0.02$ psu, $P_B = N_B/(N_A + N_B)$, $P_A = 1 - P_B$, $N$- number of profiles in a $10^0 \times 10^0$ bin

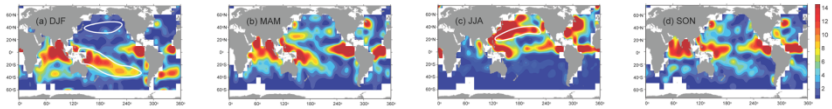


**Figure 3**. Probability, $P_B$ (%), of appearance of a complex vertical structure of salinity in the near-surface ocean layer. The areas of high probability indicate the areas where the Aquarius mission is expected to add fundamentally new information for climate and ocean research. Alternatively, the areas of low probability indicate the areas, which are most suitable for the Aquarius calibration and validation. The maps are smoothed for better visualization. Bins with less than 70 profiles are blanked.

It is also instructive to compare seasonal patterns of probability of occurrence of a complex vertical structure of salinity in the near-surface layer with those of some forcing agents, responsible for the evolution of the upper ocean mixed layer:

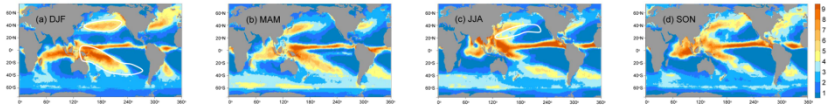


**Figure 4**. Seasonal mean precipitation (mm/day), calculated from GPCP daily data (2001-2009).

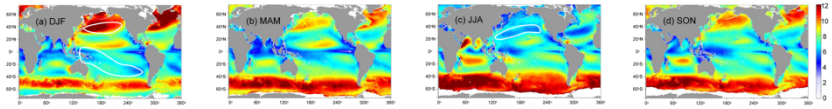


**Figure 5**. Seasonal mean QuikSCAT wind speed (m/sec).

The geographical distribution of probability of occurrence of a complex vertical structure of salinity in the near-surface ocean layer (Fig. 3) is highly heterogeneous, vary seasonally, and reflects a struggle between precipitation and the mixing action of the wind. In boreal winter, for example, the tilted tongue of high probability (Fig. 3a) coincides with a region of high precipitation associated with the South Pacific convergence zone (Fig. 4a). This region is also characterized by relatively low near-surface winds (Fig. 5a). In the North Pacific, however, the vast area of high precipitation is largely compensated by the mixing effect of strong winds, resulting in low probability of appearance of a complex salinity structure in the near-surface ocean layer.

This is further confirmed by comparing Fig. 3 and Fig. 6; the latter is probability of occurrence of a shallow mixed layer ($A$: MLD>15 m, $B$: MLD≤15 m)

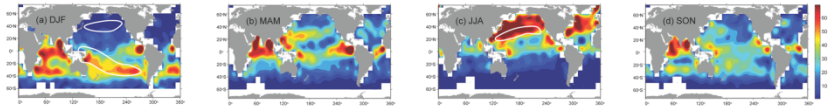


**Figure 6**. Probability that the mixed layer depth, as seen by Argo floats, is shallower than 15 m depth. A search for the mixed layer depth for each Argo profile was conducted using the potential density threshold of 0.02 kg m$^{-3}$.

## 4. Implications for Aquarius

Given the statistics of the difference between salinity at 5 m depth and SSS for each group of CTD profiles in the historical dataset, it is possible to reconstruct spatial distributions of the expected mean values and standard deviations of salinity differences between *in situ* Argo measurements and Aquarius SSS:

By splitting Argo profiles into two mutually exclusive groups, $A$ and $B$, and using the statistics gained from the analysis of historical CTD casts

$A$: $\Delta S_{10-5} < 0.02$ psu, $B$: $\Delta S_{10-5} \geq 0.02$ psu,

$$\mu_{A,B} = (P_A \mu_A + P_B \mu_B)/P_{A,B}$$

$$\sigma_{A,B} = \sqrt{(P_A(\sigma_A^2 + \mu_A^2) + P_B(\sigma_B^2 + \mu_B^2))/P_{A,B} - \mu_{A,B}^2}$$

where $P$- probability, $\mu$ - mean, and $\sigma$ - standard deviation

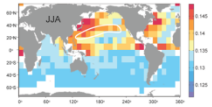


**Figure 7.** Expected standard deviation of salinity difference between *in situ* Argo measurements and Aquarius SSS for boreal summer (JJA). These differences arise solely due to the depth difference and does not include other errors, such as due to temporal or spatial offset between the satellite and in situ samples.

An example is given in Fig. 7. Due to large ambiguities in salinity measurements at the surface or very near the surface made by ship-borne CTD instruments, the exact numbers are not discussed here. However, the geography of the error due to the depth difference between *in situ* Argo measurements and Aquarius SSS will likely look similar to that presented in Fig. 3. Note, that Fig. 3 is based solely on the Argo data.

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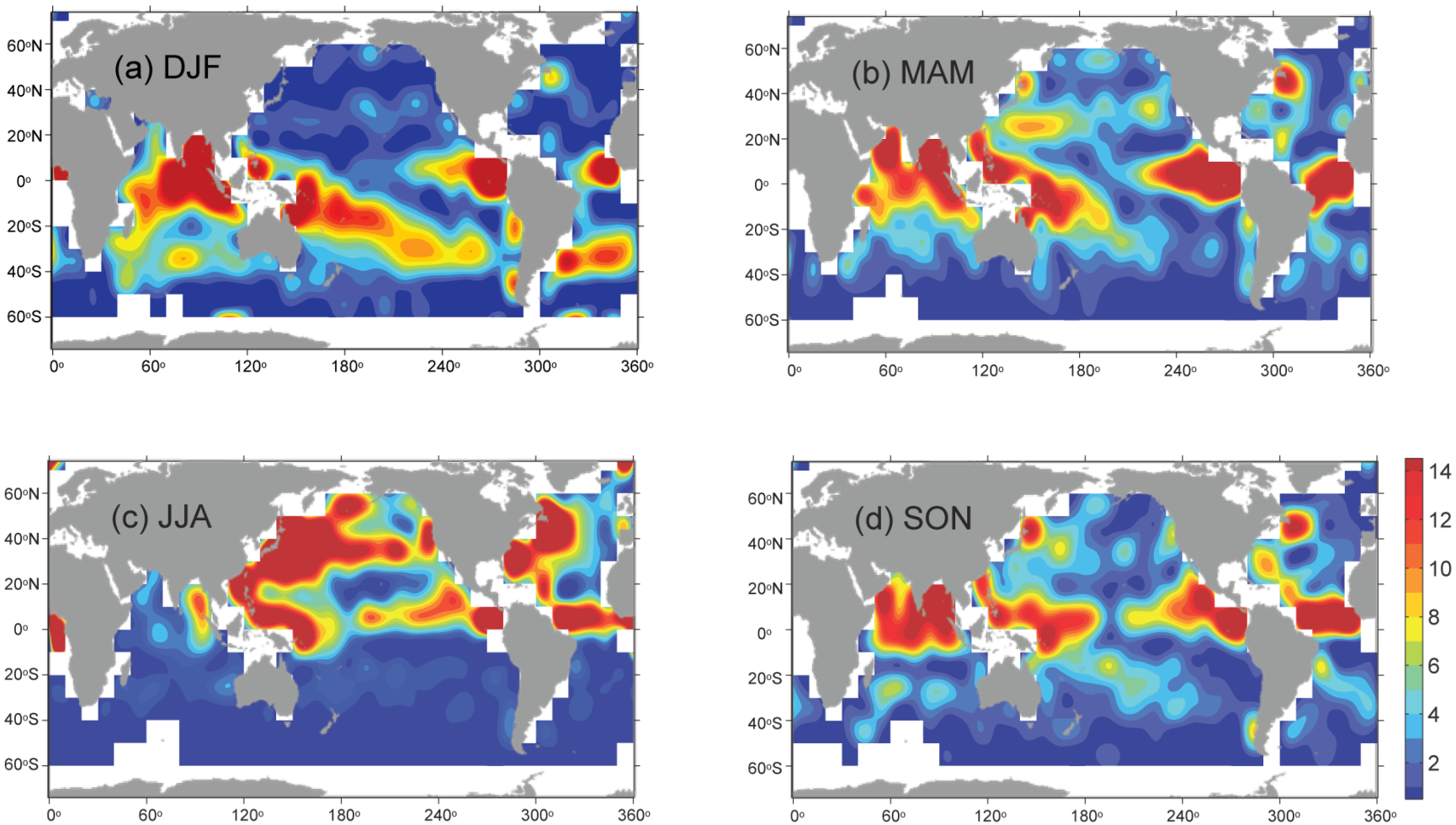


Probability, P (%), of appearance of a complex vertical structure of salinity in the near-surface ocean layer. The areas of high probability indicate the areas where the Aquarius mission is expected to add fundamentally new information for climate and ocean research. Alternatively, the areas of low probability indicate the areas, which are most suitable for the Aquarius calibration and validation. The maps are smoothed for better visualization. Bins with less than 70 profiles are blanked.