Aquarius Ocean Salinity Open Discussion

Yi Chao and Peter Hacker

- Surface Stratification

Advanced Argo floats

Flag in situ data for expected mixed layer (or not)

- Aquarius/SMOS intercalibration (harmonization)

- Merging Aquarius, SMOS, in situ data

- Error Budget and Analysis

- Other (New Working Groups?)

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- Surface Stratification (perhaps 2 groups)

Engineering: How to use in situ data to infer skin to validate Aq data?

Advanced Argo floats;

Flag in situ data for expected mixed layer (or not);

Previous work: Henock? (Fred); Melnichenko;

Establish mixed layer condition, for validation;

Each Argo float surfacing, atmospheric conditions;

New technology is emerging, STS float, drifters, wave gliders;

Key regions: validation mask, calibration sites like Harvest, clustered Argo floats, moorings.

Science: How to use Aquarius data to infer bulk SSS for oceanographic studies?

Skin vs bulk SSS, GHRSST as a possible example.

Diurnal cycles, physics of upper layer, fresh-pool processes.

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- Aquarius/SMOS intercalibration (harmonization)

Identify issues common to both;

Joint workshop;

Aquarius can help SMOS;

SMOS can also help Aquarius;

Compare Aquarius and SMOS; (ascending/descending), together/against in situ data (to eliminate bad data).

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- Merging Aq, SMOS, in situ data

- Merging to create L4 data
- NOAA NESDIS STAR group (through Eric Bayler), will use the GHRSST infrastructure to compare the various L4 data products
- Assimilation, will use L2 data, beam 3 data for example has a bias, how to provide error information for the data assimilation?
- Other data are available (NODC, STAR)
- The community should use all available in situ observations, TSGs for example are not well used, better organize the various observational data sets.

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- Error Budget and Analysis and need to quantify errors.

Measurement system errors;

Geophysical errors;

Mapping errors, L3 and L4 (focus for the future);

PODAAC/GHRSST error considerations and DMAC issues.

- Other (New Working Groups?)

Two now active: sss cal/val, mwr cal/val.

Need new focused working groups (sub-groups) to address:

Ascending vs descending bias, 3 beam biases, intercalibration/harmonization.

Galaxy correction issues.

SPURS, joint US and Europe (is this science and applications focus??).

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Science and Applications:

Thematic areas for special focus-

Coastal: funded collaboration; engineering and science; Coastal/shelf; boundary conditions for modeling; errors.

Ocean as a rain gauge, fresh water budget

Clearly defined scientific problems, trying to focus/work on these topics, Amazon outflow, Bay of Bengal, etc.

- Coastal salinity,
  - There is a funded project on the US side, south China Sea.
  - Argentina, Reul on the Argentina side
  - Important problem, both engineering and science, need a validation data set, better land correction, possibly a working group to be formed to further explore like, similar as the coastal altimetry
  - Two aspects,
    - coastal/shelf study,
    - Use AQ data as boundary conditions to improve coastal understaindg
  - Error budget

Reference Materials and Notes

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

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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).

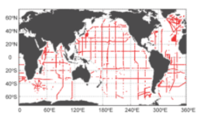

Figure 1. Locations of CTD casts with valid surface (0-1m depth) temperature and salinity measurements from WOCE data archive. Stations located within approximately 200 km distance off the nearest coast were excluded from the analysis. The selection of WOCE data is also made according to provided quality 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)
ρ - density (kg/m³)
z_i - depth: [0,1]m; [4,6]m; [9-11]m.

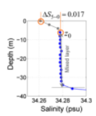

Table 1. Statistics of ΔS_{5-0}

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 ΔS_{5-0} are equal 0.021 and 0.15 psu, respectively. Probability distributions of ΔS_{5-0} are severely skewed toward positive values due to anomalous low-salinity measurements at the surface (Table 1).

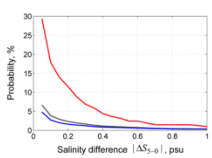

Table 2. Statistics of ΔS_{5-0} for different sub-sets of CTD data

WOCE	profiles	mean (psu)	std (psu)	skew
All data	5635	0.021	0.145	14.8
ΔS_{10-5} <0.02	5226	0.016	0.131	16.4
ΔS_{10-5} ≥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° × 10° bin

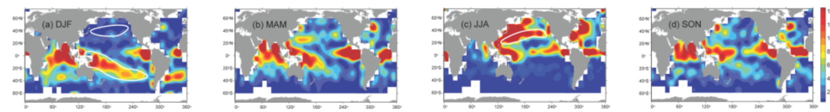

Figure 3. Probability, P_B (%), of appearance of a complex vertical structure of salinity in the near-surface ocean layer. The areas of high probability indicate the areas where the Aquarius mission is expected to add fundamentally new information for climate and ocean research. Alternatively, the areas 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:

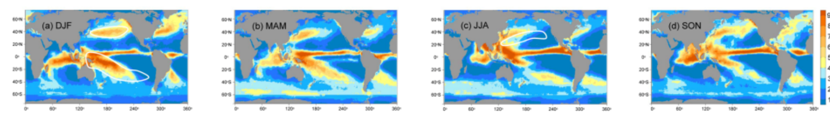

Figure 4. Seasonal mean precipitation (mm/day), calculated from GPCP daily data (2001-2009).

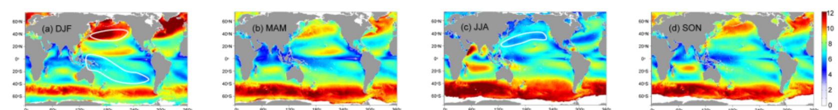

Figure 5. Seasonal mean QuikSCAT wind speed (m/sec).

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)

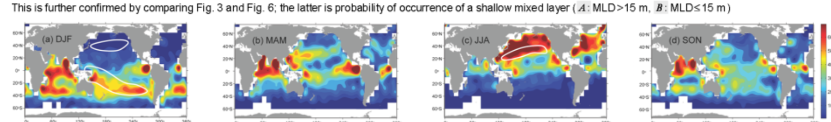

Figure 6. Probability that the mixed layer depth, as seen by Argo floats, is shallower than 15 m depth. A search for the mixed layer depth for each Argo profile was conducted using the potential density threshold of 0.02 kg m⁻³.

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;

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

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

where P - probability, μ - mean, and σ - standard deviation

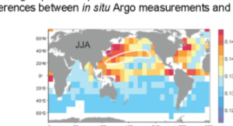

Figure 7. Expected standard deviation of salinity difference between *in situ* Argo measurements and Aquarius *SSS* for boreal summer (JJA). These differences arise solely due to the depth difference and does not include other errors, such as due to temporal or spatial offset between the satellite and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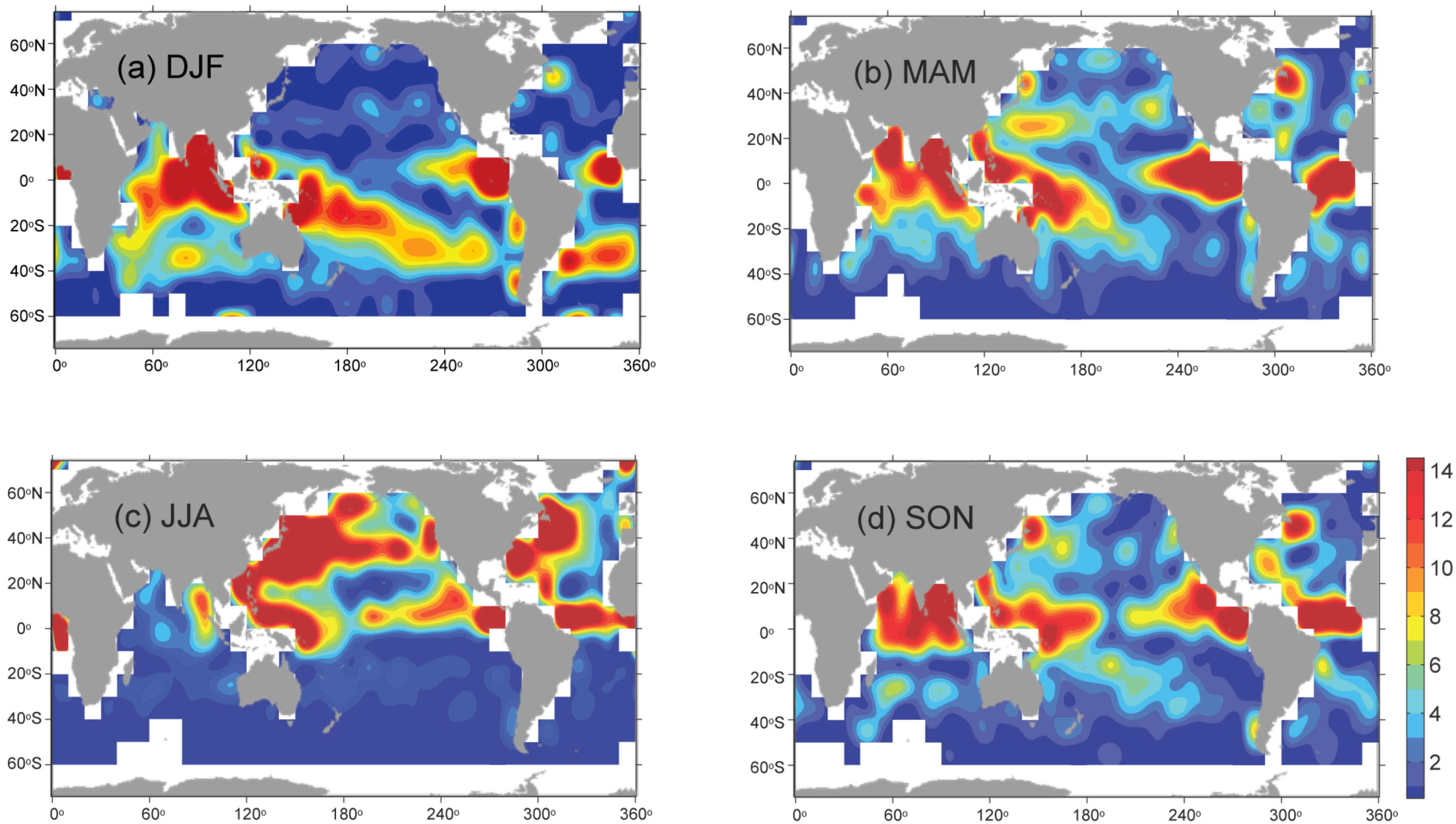

Probability, P (%), of appearance of a complex vertical structure of salinity in the near-surface ocean layer. The areas of high probability indicate the areas where the Aquarius mission is expected to add fundamentally new information for climate and ocean research. Alternatively, the areas of low probability 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.

- Gary:
  - Engineering: How to use in situ data to infer skin to validate Aq data?
  - Science: How to use Aquarius data to infer bulk SSS for oceanographic studies?

- Validation mask idea, identify few key regions, where the validation should take place? Coordination with SMOS, similar as super-site for TOPEX/Poseidon validation, US Harvest platform, France Med site.
- On the ship, very accurate salinity measurements
- Argo floats, heavily clustered area,
- OOI deep ocean moorings, should look into their data
-

- Skin vs bulk SSS, GHRSST as a possible example,
- Henock? (Fred)
- mixed layer condition, for validation
- Each Argo float surfacing, atmospheric conditions
- Ocean as a rain gauge, ocean is important, how Aquarius can help to close the fresh-water budget?
- New technology is emerging, STS float, drifters, wave gliders,

- ESR AVDS, in situ data collection for AQ, more data can and should be considered, possible help from NODC and STAR
- PODAAC, GHRSST, each sensor has errors and bias on each location, with the same format, known as L2P data, enable for merging data from multiple sensors
- Working groups, formed at the 2009 meeting, not much activities, cal/val working group in the only active group, MWR is another group, think about what new working group is needed

- Tall poles not being addressed by the current cal/val working groups, need new working groups to the address the following:
  - Ascending vs descending bias
  - 3 beams intercalibration
- Are these calibration performance issue or geophysical (where does it come from)?

Aquarius/SMOS

- Joint workshop
- Aquarius can help SMOS
- SMOS can also help Aquarius
- Compare Aquarius and SMOS (ascending/descending), together against in situ data (to eliminate bad data)

Working groups

- SPURS, joint US and Europe,
- Surface stratification working group?

Research and Applications

- The community should use all available in situ observations, TSGs for example are not well used, better organize the various observational data sets
- Clearly defined scientific problems, trying to focus/work on these topics, Amazon outflow, bay of Bengal, etc.

Error budget and Analysis

- Systematic error, Geophysical error, (Mapping error at a later stage)
- Currently, the cal/val working group meets every week, providing these error estimates