Simulation of the Argo Observing System

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1. PROJECT SUMMARY

The Argo array currently consists of 3000 instruments that make vertical profiles of temperature and salinity every 10 days over the depth range of 1500 meters. The array has been brought to full strength, and a comprehensive assessment of the limitations of the Argo observing system is urgently needed.

The main goal of our study is to examine how well the Argo observing system determines the state of the global upper ocean. We sample and reconstruct oceanic fields from ocean general circulation models (OGCMs), in gradually more realistic sequence of simulations. By quantifying errors in the reconstructed fields, we estimate accuracy of the Argo observing system, and therefore directly address NOAA's Program Plan for *Building a Sustained Ocean observing System for Climate*.

This project is conducted at the University of Washington, Seattle, Washington.

2. ACCOMPLISHMENTS

In close collaboration with Drs. Wei Cheng and D.E. Harrison, we have been looking at the expected performance of the Argo observing system for the ocean. We have used a global coarse-resolution OGCM and a regional eddy-resolving OGCM to produce fields that we have sub-sampled in ways similar to how the Argo float array samples the ocean. We have then compared the fields reconstructed from this "Argo data set" with the complete model fields.

The activities during the FY 2008 were focused on the analysis of the effects of float movements and of changing the number of floats, as well as on the role mesoscale variability. We carried extensive analysis in the Antarctic Circumpolar Current (ACC) and high-latitude North Atlantic. We have completed preparation of one manuscript describing the results, and are on advanced stages of preparation of the second paper. Our findings, which these two manuscripts describe, are summarized below.

2.1. Coarse-resolution studies

The global ocean model used in this study has 2^o resolution in both latitude and longitude. The atmospheric forcing used to drive the model is derived from observation-based estimates. Daily values for the 2-meter air temperature and humidity, 10-meter wind speed, and zonal and meridional components of the wind stress are taken from years 1979-2001 of the NCEP-NCAR reanalysis. Climatological monthly values are used for all other atmospheric variables and freshwater fluxes. The simulated ocean state is as realistic as can be expected in a coarse-resolution model. However, because of the coarse resolution, the intensity of the boundary currents is underestimated and the mesoscale eddies are not resolved. The effects of the oceanic velocities on the Argo array in reality are expected to be even stronger than in this model.

In these simulations, 3,000 Argo floats are advected with the GCM-simulated velocities at 1500m depth during most of the time. Every 10^{th} day, a simulated float surfaces, while taking the temperature and salinity (T/S) profile; it then spends 8 hours at the surface, where the float is advected by the surface currents. A float becomes "lost" if it enters a shallow region. Resulting data are used to reconstruct temperature and salinity of the ocean, using objective analysis. The simulations are carried for five years.

a) Reconstruction of the oceanic state

We have analyzed the expected accuracy of the Argo system in reconstructing such important oceanographic variables as temperature, salinity, upper ocean heat content (UOHC), calculated over the top 800 m) and mixed layer depth (MLD). For each of the variables, the analysis is carried for:

(i) the annual-mean values;
(ii) the amplitude of the annual cycle: the absolute value of the difference between the August and February values;
(iii) the amplitude of the interannual difference: the absolute value of the difference between the annual means for year 5 and year 1.
(iv)

The first two or these variables characterize the climatology averaged over 5 years of GCM data. The second and third variables quantify the amplitude of the variability on annual and interannual time scales.

We analyze the **reconstruction errors**, the difference between the actual GCM-simulated and reconstructed fields.

Reconstruction errors in the vertical profiles of temperature and salinity decrease with depth, in concert with decreasing spatial gradients and temporal variability in the actual fields (Figure 1). The errors in temperature exhibit a maximum at approximately 100-150m, where the average errors in the annual mean reach 0.6 degrees in ACC and 0.3 degrees elsewhere. Average errors below 1000m are very small, less than 0.1 degrees.

The reconstructed climatology of UOHC is close to the actual GCM-simulated values over most of the ocean (Figure 2). The errors are particularly small for the annual-mean values and the magnitude of the annual cycle. However, the reconstruction errors are more significant in the regions of high gradients and intense currents, particularly in ACC and high-latitude North Atlantic. The largest errors in these regions are found in the magnitude of the interannual difference, which suggests that the detection of interannual trends from the Argo data alone can be problematic.

Similar to UOHC, the reconstruction errors in MLD are significant (Figure 3) in ACC and the high-latitude North Atlantic. MLD is highly sensitive to the near-surface values of temperature and salinity, and even small errors in these variables result in large errors in MLD. Errors in the magnitude of the annual cycle are particularly large.

b) Effects of float movements

Movements of the Argo floats by oceanic currents have complicated effects on the overall accuracy of the Argo system. The resulting redistribution of floats acts to increase the spatial sampling coverage of the Argo system, by providing observations from more points in the domain. The float movements, however, negatively impact the reconstruction of the time variability in sampled fields, by decreasing the time a float spends near any particular location. Significance of both effects increases in the regions of high gradients and strong currents, such as ACC.

The effects of float movements are studies in two sensitivity experiments. In the first experiment ("**parked floats**" case), the advection of the floats is turned off. The reconstruction errors are noticeably decreased in most of the domain (Figure 4a). In particular, the float movements are the main cause of the increased errors in the magnitude of the interannual difference of UOHC in ACC and high-latitude North Atlantic.

In the second experiment ("**random position**" case), the float advection is replaced by random redistribution of floats every time the sampling takes place. The reconstruction errors decrease (Figure 4b), demonstrating potential significance of an increase in spatial sampling coverage, caused by rapid redistribution of floats.

c) Effects of the changed number of floats

Two additional experiments estimate effects of the density of spatial sampling coverage. In the first experiment, the number of floats is doubled, and the average spacing between floats is decreased from 300 to 215 km. The reconstruction errors become smaller. The remaining errors in ACC and high latitudes suggest that even the doubled sampling coverage is not sufficient for accurate reconstruction in those regions.

In the second experiment, the number of floats is halved. The errors increase significantly (30-40 per cent), demonstrating the potential decrease in the reconstruction skill due to the floats gradually reaching the end of their lifetime.

2.2. Eddy-resolving simulations of the North Atlantic

To investigate the effects of mesoscale variability on the accuracy of the Argo system, we carried our analysis in a high-resolution regional model of the North Atlantic. High horizontal resolution ($1/8^o$ resolution in latitude/longitude) permits simulation of mesoscale eddies. The model has 30 levels in the vertical. The topography is estimated from the Scripps 1^ox1^o dataset; the total depth of the ocean is 3,000 meters. Initially, 250 Argo floats are evenly distributed in the model domain; the floats are then advected by

GCM-simulated currents. For the analysis, we used 9 years of high-resolution data from the model.

In our **control** simulation, the Argo floats are advected by the full velocities. In agreement with our previous coarse-resolution experiments, the regions of the fast advection correspond to the largest systematic biases in the reconstructed fields. In particular, in the vicinity of the North Atlantic Current, the reconstructed MLD is shallower than in the original GCM data. The reconstruction errors in UOHC are also substantial in most of the subpolar gyre (Figure 5a).

Next, we analyze the effects of mesoscale variability on the expected accuracy of the Argo system. In our second experiment ("**time-mean**" case), the mesoscale variability is removed from both the velocities and temperature/salinity fields. As Figure 5b demonstrates, the mesoscale variability explains a substantial part of the reconstruction errors in the control experiment, particularly in the subpolar gyre.

If the mesoscale variability is removed from the velocities and not from the temperature and salinity ("**mean-advection**" case), the errors are very similar to those in the time-mean case. We conclude that the high-frequency variability in velocities (and float movements) is the main cause of the increase in reconstruction errors due to eddies. The mesoscale variability in temperature and salinity has secondary importance.

To further quantify effects of advection, we conduct the fourth experiment, in which the magnitude of mesoscale variability is amplified by a factor of 2.5. This amplification factor was chosen to bring the variance in the simulated sea-surface height closer to the observed one. As a result of the amplification, the biases in the simulated fields increase everywhere in the domain, with the largest change within the Labrador Current, and near the Cape Hatteras.

2.3. Significance of results

Our study helps to identify the regions, in which the reconstruction of oceanic variables from the Argo data set can be less reliable than in the rest of the World Ocean. The results also demonstrate several important effects of oceanic advection on the accuracy of the reconstruction. As shown by our coarse-resolution global simulations, float movements represent a major source of reconstruction errors in ACC and the high-latitude North Atlantic, particularly in the year-to-year variability. Our eddy-resolving simulations further suggest that the mesoscale variability in velocities and float movements act to increase reconstruction errors in the North Atlantic.

The results emphasize the need for additional, dense spatial sampling in ACC and the high-latitude North Atlantic, as well as in the regions characterized by intense mesoscale variability. Combining Argo data with other in situ measurements less affected by oceanic currents, such as XBTs and mooring data, will also help to improve accuracy of the reconstruction of oceanic variables.

3. PUBLICATIONS

Kamenkovich, I., W. Cheng, E.S. Sarachik, and D.E. Harrison, “Simulation of the ARGO observing system in a global ocean model”. *J. Geophys. Res.*, submitted.

Kamenkovich, I., W. Cheng, E.S. Sarachik, and D.E. Harrison, “Effects of mesoscale variability on the accuracy of the ARGO observing system”, to be submitted.

4. FIGURES

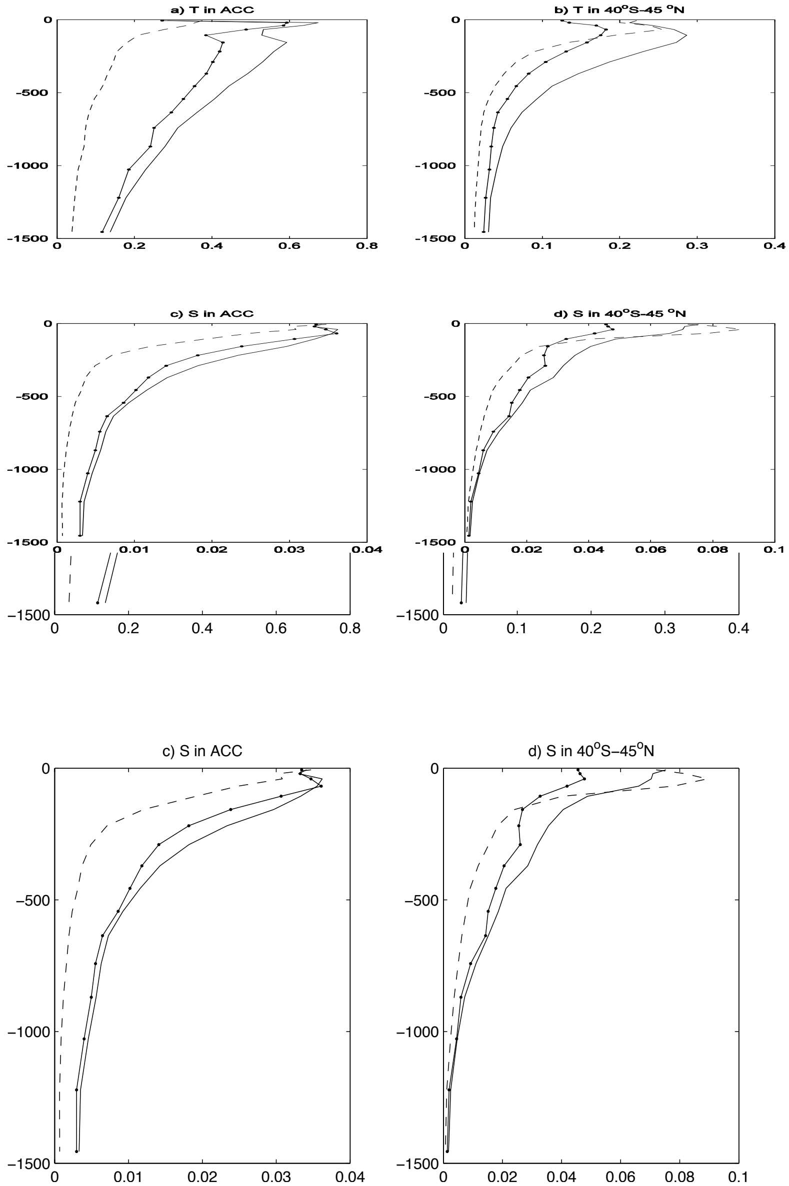

Figure 1. Area averaged magnitude (absolute value) of reconstruction errors in temperature (top row) and salinity (bottom row) as functions of depth. The values in the left column (panels a,c) are computed within ACC (south of 40°S); in the right column (panels b,d) – in the mid- and low latitudes (between 40°S and 45°N). The solid lines show errors in the annual means, dashed – in the magnitude of the annual cycle; dots –in the magnitude of the interannual difference.

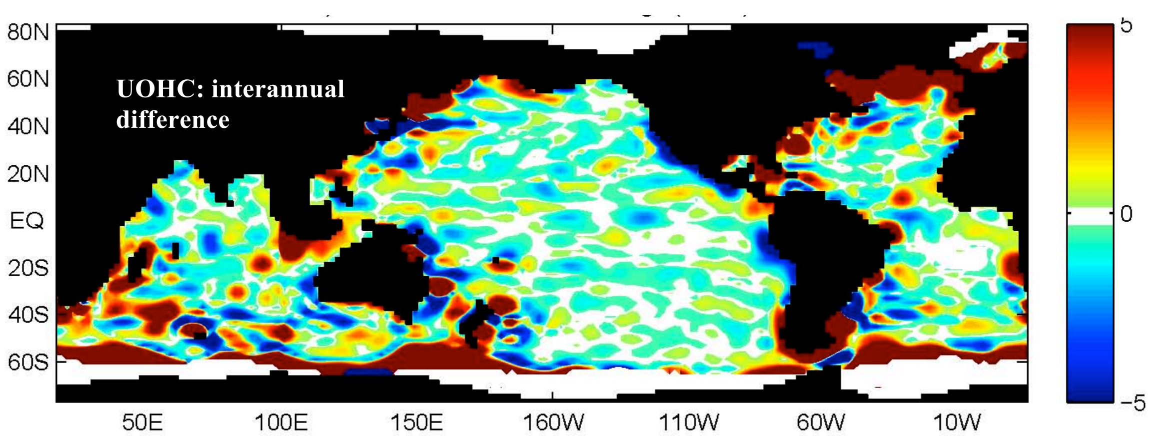

Figure 2. Accuracy of the reconstruction of UOHC in the standard 5-year simulation. Reconstruction errors are shown for the amplitude of the interannual difference (in flux units, contour interval is $0.25 Wm^{-2}$). Values under ice are not shown.

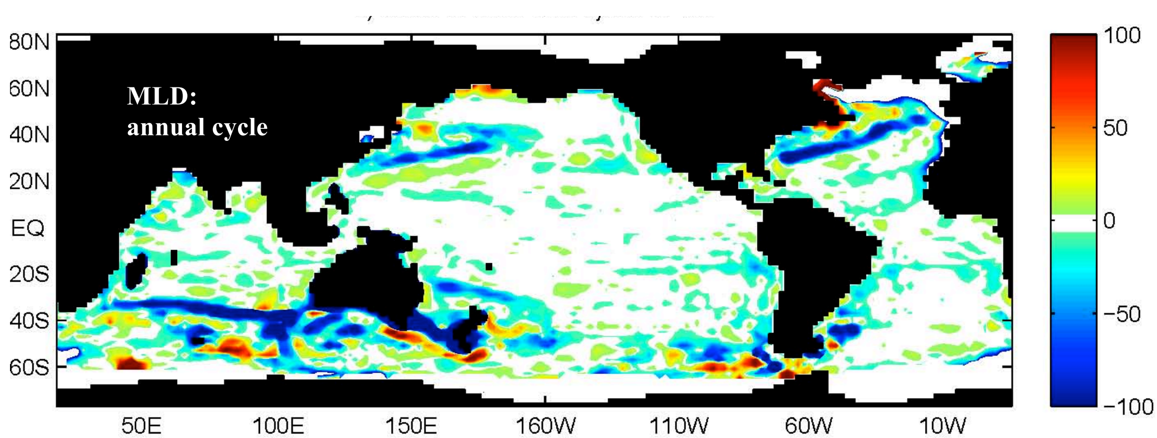

Figure 3. Accuracy of the reconstruction of the mixed layer depth in the standard 5-year simulation. Reconstruction errors are shown for the amplitude of the annual cycle. Contour interval is 5m. Values under ice are not shown.

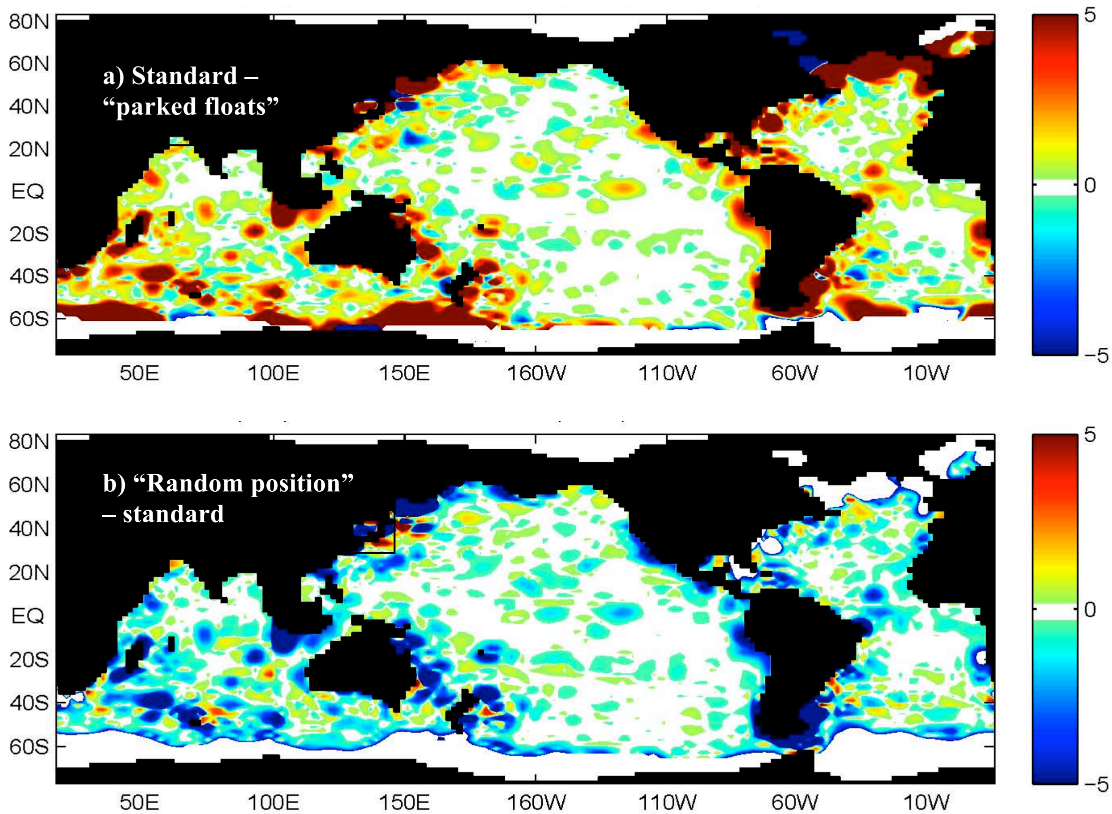

Figure 4. Effects of float movements on the reconstruction of the magnitude of interannual difference. Shown are the differences in the magnitude of reconstruction errors between the standard and “parked floats” cases (top panel) and the “random position” and standard cases (bottom panel). The contour interval is 0.25Wm^{-2}. Values under ice are not shown.

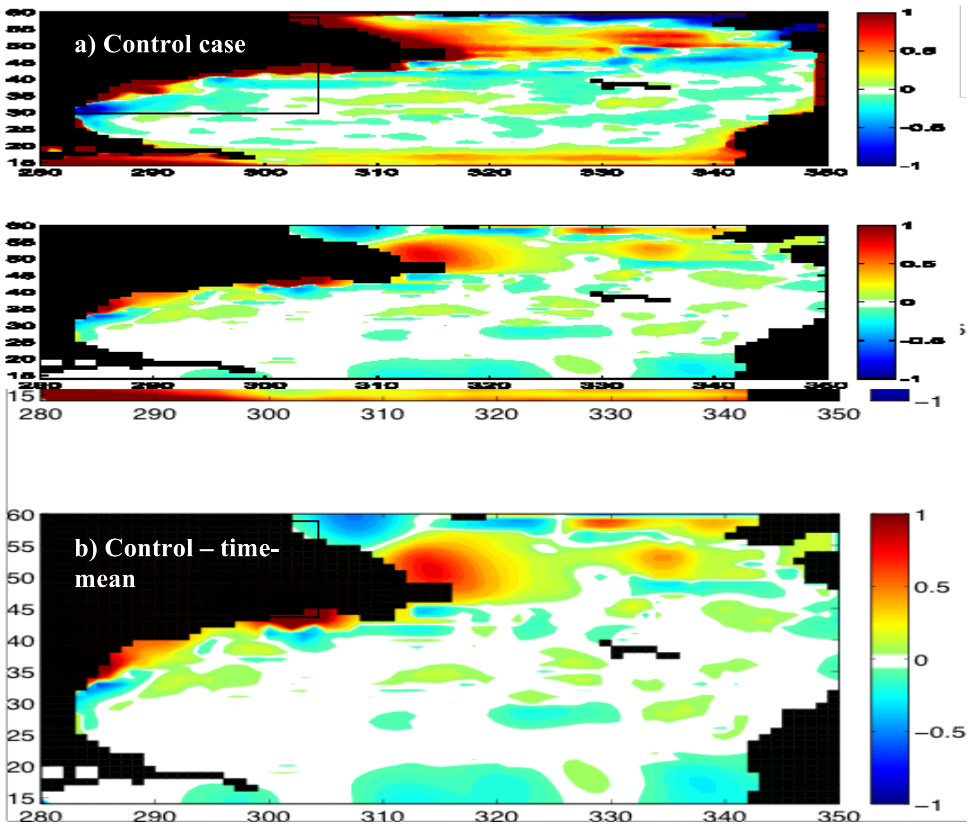

Figure 5. Reconstruction errors and importance of mesoscale eddies for reconstruction of UOHC in the eddy-resolving North Atlantic simulations. Top panel: reconstruction errors in the control case. Bottom panel: the difference in the error magnitudes between the control case and the experiment with the time-mean fields. Units are degrees C (heat content per unit area is divided by $3.4 \times 10^9 Jm^{-2}deg^{-1}$).