Evaluating the Ocean Observing System: Performance Measurement for Heat Storage

Claudia Schmid and Gustavo Goni
NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami FL

1. PROJECT SUMMARY

The main objective of this project is to provide quarterly reports that evaluate the accuracy of estimates of the global upper ocean heat storage and its time derivative. This product will show (a) locations where upper ocean temperatures were collected in each quarter, (b) how well the observations satisfy the GOOS/GCOS temperature requirements, (c) the locations where future observations are needed to improve the observing system, and (d) how successfully the system reduces the potential bias error. This product will display the performance in terms of these goals since January 1997 and will be used to detect anomalies of the heat storage. The evaluation will incorporate profiles of temperature and salinity from XBTs, CTDs and Argo floats. In addition these estimates will be compared with heat storage estimates from altimetry. The heat storage estimates from altimetry will also be used to extend the heat storage fields into regions where the coverage with in-situ data is poor. An example of a quarterly product is given in Figure 1.

Profiles from XBT, CTD and profiling floats, and data from profiling floats are part of the Global Ocean Observing system. The increasing number of profiles makes an improved estimation of the upper ocean heat storage possible. This parameter is critical for the understanding of the climate system and it has been shown to have a significant impact on the weather over adjacent landmasses and on the strength and frequency of tropical cyclones. Therefore, improving the accuracy of estimates of the upper ocean heat storage and budget is key for climate research.

In this work we estimate the heat storage of the upper ocean on a quarterly basis on a regular grid, both for the mixed layer and for layers of constant depths. To accomplish this, upper ocean temperatures from various sources and instruments (WOD 2001, GTSPP, Argo, XBTs, including high-density lines; thermistor chains; profiling floats; CTDs) are being combined.

All profiles undergo a series of quality control tests to ensure that only profiles of good quality are used in the analysis. For Argo floats these tests are described in a document available on the Internet (http://www.ifremer.fr/coriolis/cdc/argo_rfc.htm - link to ``Argo Real-time Quality Control Tests Procedures"). Similar tests are applied to all non-float profiles. Additionally, quality control tests are performed to detect profiles that deviate significantly (by 10 standard deviations or more) from the NCEP reanalysis and the World Ocean Atlas 2001 or from other profiles collected in the same region and time period. Preparatory work was performed in the Atlantic to ensure that XBT and float profiles can be combined without introduction of artificial climate signals.

The error (potential bias) of the heat storage from in situ observations is derived as based on the statistics and data distribution. The methodology accounts for the error introduced into the estimates by non-uniform spatial and temporal sampling. Firstly, the statistical degrees of freedom of the non-independent observations (e.g. TAO moorings) are homogenized to that of the ARGO array. Weighting factors are computed with the resulting independent observations to quantify their bias with respect to an ideal uniform sampling. The sample standard deviation of the heat storage is computed. Both quantities are derived for a global 5^o by 1.5^o grid. The error of heat storage is computed by weighting the sample standard deviation with the bias factors accounting for non-uniform temporal and spatial sampling.

The currently available upper ocean data set covers the period 1968 to present. The data will be analyzed on a year-by-year basis. For the purpose of this proposal, the quarterly heat storage is being derived for 1992 to present. Once the system is operational an extension into earlier years will also be attempted.

Additionally, comparisons between altimetry- and hydrographic-derived estimates of upper ocean heat storage are conducted. They allow us to investigate the extent in depth of the sea height signal in different regions of all ocean basins. The local changes in upper ocean heat storage are estimated from altimetry-derived sea height anomaly fields, using regressions based on historical in-situ observations. For example, similar estimates of altimetry-derived heat storage are currently used to identify long periodic climate signals, such as the variability of the warm pool in the western Pacific Ocean associated with El Niño.

Of key interest are the dynamical effects that have been shown to be dominant over steric effects in some regions, where a very weak sea surface signal is observed as a compensation of these two components. Altimetry observations will also allow us to complete our estimates in regions where hydrographic data are not available or severely under-sampled in space and time.

2. ACCOMPLISHMENTS

We continued creating the Quarterly Status Report for the heat storage of the mixed layer from in situ observations on a quarterly basis (example in Figure 1). We developed a method to derive the error of this heat storage and extended the time series back to 1992. This product will be used as guidance for the future collection of hydrographic data. It will also achieve the objective required by OCO to identify the locations where anomalies occurred. We created a quarterly report of the heat storage in the upper 750 m using satellite altimetry in conjunction with in situ observations (example in Figure 2). The methodology is described below. The quality of the heat storage estimates from satellite altimetry is quite good in mid and low latitudes. The method can not be used in high latitudes, partly because the coverage with satellite and in situ data is insufficient. Eventually, the estimates based on satellite altimetry may help to optimize the in-situ observation system by increasing the number of collected profiles in regions where the satellite-derived estimates are less reliable. The trend in the top right panel of Figure 2 is due to increases in the satellite-derived sea surface height anomaly. This trend could be, for example, due to ocean warming, haline effects or changes in the geoid.

A web site that reports on various key variables describing the state of the ocean (AOML/SOTO) is available. This site gives an outline of the methodology, links to OCOs web site, and links to a web site that shows monthly estimates of the heat storage rate of the mixed layer in the tropical Atlantic together with the mixed layer properties. Please refer to this site: www.aoml.noaa/gov/phod/soto/.

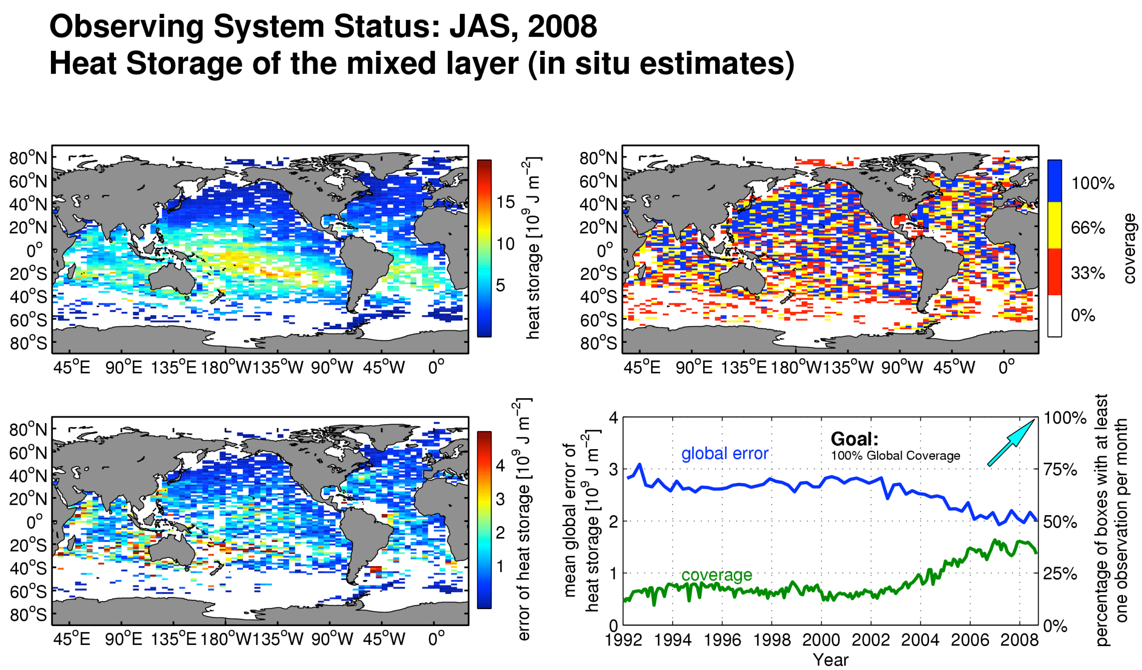

Figure 1. Most recent estimate of Quarterly System Status Report for heat storage of the mixed layer, covering the time period July through September 2008.

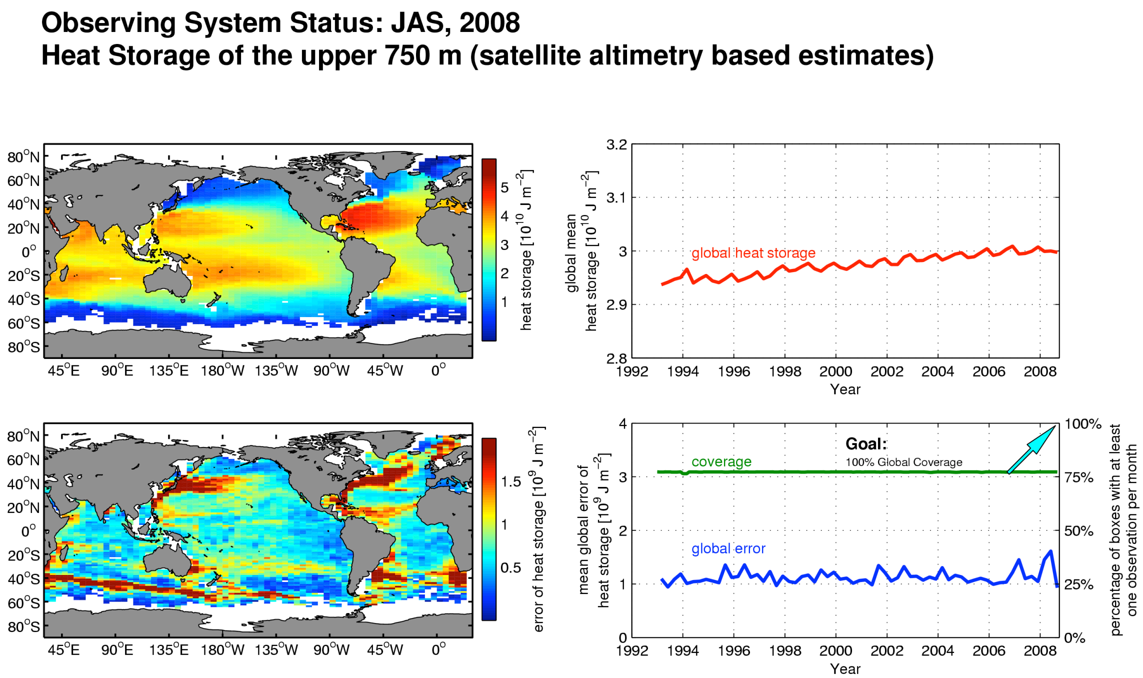

Figure 2. Example of Quarterly System Status Report for heat storage of the upper 750 m, covering the time period July through September 2008. The goal is to generate these quarterly reports regularly.

The correlation coefficient between the sea height anomaly and the oceanic heat storage derived from the hydrographic profiles is computed for different layers (an example is given in Figure 3). The layers are: mixed layer (the mixed layer depth is defined as the depth where the vertical temperature gradient is larger than 0.05ºC/m) and from the surface to selected depths (50m to 1000m, with 50m intervals). In areas where the correlation between sea height anomaly and the oceanic heat storage is good, the altimeter-derived sea height anomalies can be used as a proxy to estimate the upper ocean heat storage. Our results indicate that global correlation coefficients are low (0.5) for the mixed layer and 50m, but that they exceed 0.6 for layer depths of 100m or more.

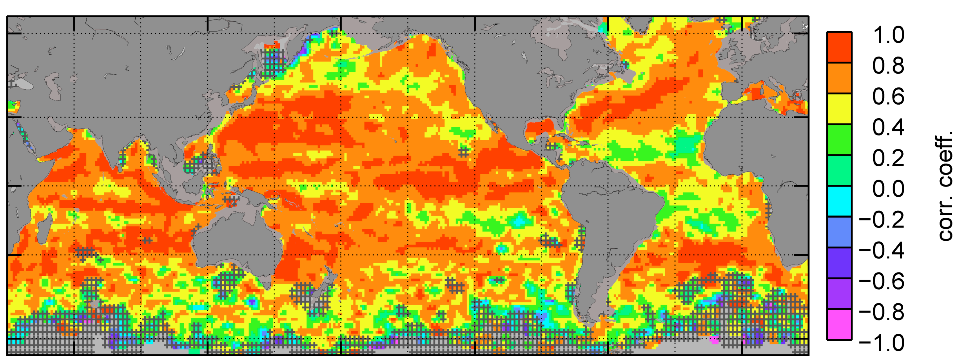

Figure 3. Correlations coefficients between the sea height anomaly and the observed upper ocean heat storage for the upper 750m.

The trend of the heat storage for each layer is derived from the heat storage fields for the 15-year long record (an example is given in Figure 4). In some regions, these trends are related to shifts of currents (e.g. Kuroshio, Gulf Stream). In other regions the changes may be due to heat storage or haline effects.

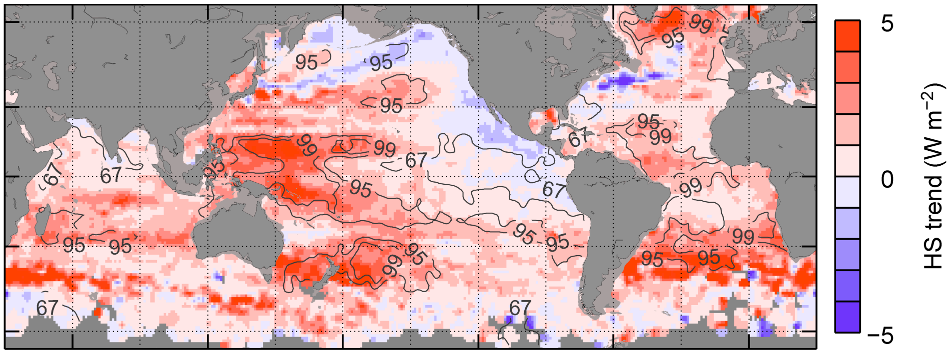

Figure 4. Trend of heat storage for the upper 750m (bottom).

It has to be cautioned, that the magnitudeof the heat storage derived from these observations may be biased due to the fall rate problems of XBTs. Figure 5 shows estimates of the depth dependent biases between Argo floats and XBTs. Figure 6 shows the impact of these biases on the heat storage. Work is currently underway to resolve this issue.

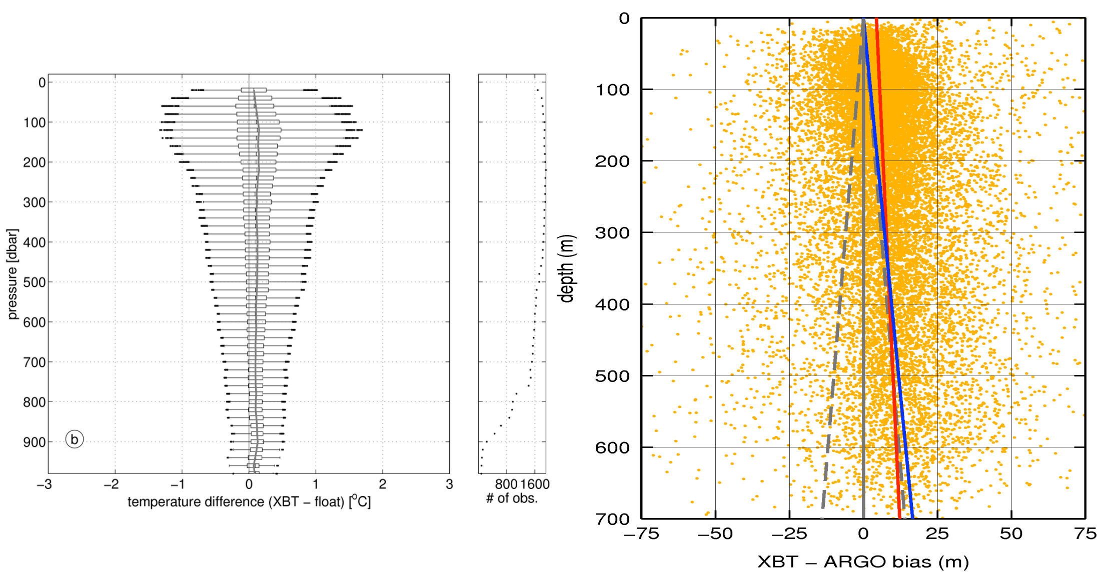

Figure 5. Bias betweeen XBT and Argo profiles. Left: from comparison of nearby profiles. Right: using correlations between satellite altimetry and profiles. Dashed lines are 2% error bounds of the depth specified by the XBT manufacturer. The blue (red) line is a least squares fit of the bias without (with) a 5 m offset at the surface. The blue line is outside of the depth error.

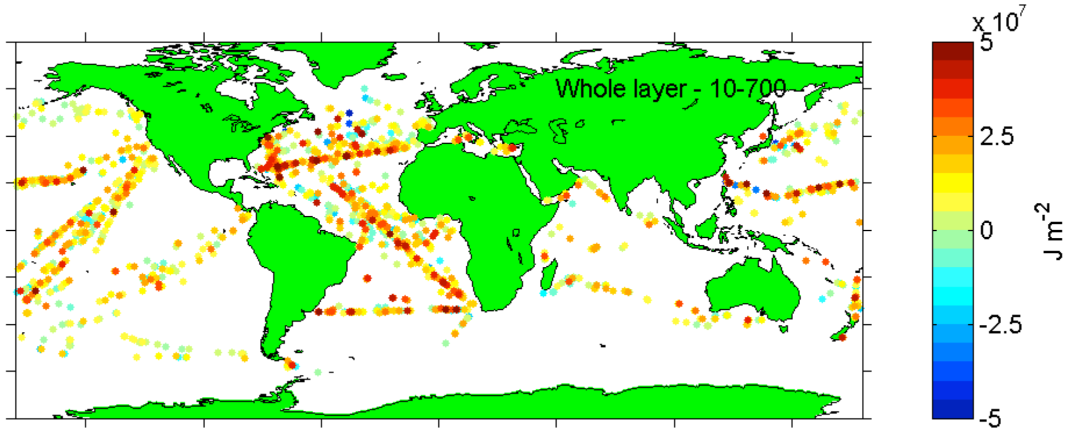

Figure 6. Difference of the heat storage of the upper ocean estimated from floats (including floats with known pressure bin assignment problems in the Atlantic Ocean) and XBTs. Positive values indicate that XBTs overestimate the heat storage. It is obvious that the XBTs yield predominantly larger heat storage estimates than the floats.

Research Highlights.

- Produce status reports of the heat storage of the mixed layer from in situ observations (Figure 1).
- Prepared the first quarterly report of the heat storage in the upper 750 m of the ocean from the combined data set (Figure 2).
- Improved identification of regions where altimetric sea height anomalies are correlated to in-situ observations of heat storage (Figure 3).
- Improved quantification of the error of the altimetry-derived heat storage.
- Develop software to derive trends of the heat storage in the upper 750 m (Figure 4) from the weekly fields derived with the combined data set (altimetry and in situ).

3. PUBLICATIONS

Schmid, C., 2008: Variability of the mixed layer heat budget in tropical Atlantic, in preparation.

Schmid, C., 2008: Comparative analysis of surface heat flux data sets in the Atlantic Ocean. *J. Climate*, submitted.

DiNezio P., G. Goni, C. Schmid, 2008: Identifying and estimating biases between XBT and Argo observations using satellite altimetry, in preparation.

Lentini, C, G. Goni and D. Olson, 2006: Investigation of Brazil Current rings in the Confluence Region. *J. Geophys. Res.,* 111, C06, doi=10.1029/2005JC002988.

Schmid, C., R. L. Molinari, R. Sabina, Y.-H. Daneshzadeh, X. Xia, E. Forteza and H. Yang, 2007: The Real-Time Data Management System for Argo Profiling Float Observations. *J. Atmos. Ocean. Technol*., 24(9), 1608-1628, doi=10.1175/JTECH2070.1.

Schmid, C., 2005: The impact of combining temperature profiles from different instruments on an analysis of mixed layer properties. *J. Atmos. Ocean Technol*., 22(10), 1571-1587, doi=10.1175/JTECH1785.1.

4. MEETINGS

Schmid:
GTSPP Workshop in Hobart, November 12, 2007.
Argo Regional Center Workshop in Hobart, November 13, 2007.
Argo Data Management Meeting in Hobart in November 14 - 16, 2007 (including executive committee on November 12, 2007).
Meeting of the US Argo Panel in Silver Spring, MD, December 12-14, 2007.
XBT fall rate workshop in Miami, March 10-12, 2008.
Office of Climate Observations Review Workshop, Silver Spring, MD, September 3-5, 2008.

Goni:
XBT fall rate workshop in Miami, March 10-12, 2008.
Office of Climate Observations Review Workshop, Silver Spring, MD, September 3-5, 2008.

5. COMMUNITY SERVICE

C. Schmid:
Argo Data Management Team, Executive Committee.
Member of US Argo Panel

G. Goni:
Ocean Surface Topography Science Working Team
WMO/IOC Ship Of Opportunity Program Implementation Panel, Chairman