Determination of the information content in long-occupied Voluntary Observing Ship (VOS) Expendable Bathythermograph (XBT) transects.

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Project Summary:

Smith et al. (1999) developed a strategy for evolving the Upper Ocean Thermal (UOT) network that considered the Ten Climate Monitoring Principles. This strategy included the discontinuation of the XBT deployments in Low Density (LD) mode from ships of the Ship of Opportunity Program (SOOP) as the Argo program coupled with satellite imagery were viewed as suitable replacements. However, the development and the application of the principles were accomplished in a qualitative manner with no quantitative assessment of the impact of ending the SOOP LD network, particularly with respect to the following three monitoring principles:

- ***Principle 1***: The impact of new systems or changes to existing systems should be assessed prior to implementation.
- ***Principle 2:*** A suitable period of overlap for new and old observing systems is required.
- ***Principle 6:*** Operation of historically uninterrupted stations and observing systems should be maintained.

This add-on is directed at the quantitative assessment needed to ensure that the Monitoring Principles are followed in the evolution of the UOT system. Specifically, the information content in LD lines with respect to decadal and other time-scale signals of variability will be quantified. Particular attention will be directed at decadal signals as historical observational and modeling studies have shown that oceanic variability at these time-scales could be coupled to atmospheric climate and several low-density lines have sufficient length to resolve such variability. Decisions on the value of specific lines and the desirability of continuing a portion of the LD XBT network will then be based on the monitoring principles given above. In the following the evolution of the UOT network is described (i.e., this evolution formed part of the information used by Smith et al. (1999) to design a new network). The information content that has been obtained on decadal signals from analysis of several lines is then briefly described to demonstrate the importance of these lines to climate studies.

The history of low-density sample begins with mechanical bathythermographs (MBT), which were available from World War II to the mid-1960s and provided profiles to 200-250 m. XBT were first introduced to oceanography in the mid-1960s and sampled temperature profiles to 450m. In the early 1970, XBTs that measure to 750m were introduced. MBT coverage immediately after WW II and early XBT coverage was concentrated in the vicinity of the intense boundary currents of the northern western subtropics (see Molinari, 2004). Few repeat transects were regularly occupied in the 1960s and 1970s. New sampling strategies that employed SOOP, primarily commercial vessels, were developed in recognition of the need for repeat sections in climate studies. Both the Tropical Ocean Global Atmosphere (TOGA) and World Ocean

Circulation Experiment (WOCE) were responsible for the institution of regularly occupied SOOP transects. The resulting transition from research cruise coverage in the 1960s and 1970s to repeat transect coverage in the 1990s is illustrated in Molinari (2004).

The data coverage from the early MBT and XBT research cruises often overlap the TOGA/WOCE transects permitting generation of upper layer (i.e., typically above 200 m) temperature time series that would include several phases of existing decadal signals. For instance, A-10 and A-7 in the Atlantic cross the Gulf Stream at about 73ºW and subtropical gyre at about 30ºN-35ºN, respectively. By combining MBT and XBT data it is possible to generate time series from 1950 through 2005 to study decadal signals (i.e., among the longest in situ time-series available to oceanographers). Molinari (2004) generated time-series of Gulf Stream transport and position from data collected along A-10 that clearly show decadal signals as found in the NAO record and other representations of these two Gulf Stream characteristics. Watanabe et al. (1999) used XBT data collected along A-7 to demonstrate that model explanations for decadal signals in the Atlantic are not correctly simulating these features. Similar analyses are possible using data from lines in the Pacific and Indian Oceans.

The two-year project proposed here has two-components. During the first year, data collected along lines that have been occupied for more than 30-years in all ocean basins will be analyzed statistically to identify significant interannual to decadal signals. For the lines that include MBT data, records can be generated back to the late 1940s for the upper 200m of the water column. Various variables will be analyzed (e.g., temperature on various depth surfaces, depth averaged temperature to various depths as a measure of heat content changes, etc.) to evaluate the 3-dimensional (depth, horizontal distance along the line and time) structure of the variability.

Analysis of the selected variables will allow characterization of the surface and subsurface properties of the interannual and interdecadal climatic signals. A simple averaging analysis was used to generate the time-series in Molinari (2004). The decadal signals have large enough amplitude that even this simple technique demonstrates their presence. More sophisticated analyses will be applied to provide additional quantification of the existing signals. For example, the space-time signature of this variability will be explored and described using multivariate statistical analyses (e.g. EOFs). The climatic signatures extracted with the multivariate techniques will be compared with the known modes of climatic variability (e.g. Pacific and Atlantic El Nino, North Atlantic Oscillation, Pacific Decadal Oscillation) using conventional correlation analysis. Our analyses will characterize the subsurface structure of the known climatic modes. Confidence limits on these signals as well as their association with the climatic indices (i.e., nowcasts of the phase of a particular interannual or decadal signal) will also be estimated.

During the second year, the ability of other observing systems to continue the important records initiated by MBTs and XBTs will be determined. For example, many of the lines in LD mode are now occupied in high-density (HD) mode. Observing System Experiments will be conducted with data and model results to determine if the seasonal sampling provided by HD sampling can resolve the important signals previously identified by monthly LD sampling. Sea height anomaly fields derived from a constellation of available altimetry missions since 1992 will be used to determine correlations between these data along XBT transects and the upper layer heat content changes from XBT data. These correlations will be used to determine (1) the ability of the satellite data to replicate decadal signals (the 12 years of data include important phases of decadal signals, Molinari, 2004), (2) the ability of the altimetric data to fill spatial and temporal gaps in the in situ observations, where needed, and (3) regions where in situ can provide the only measure of decadal signals (e.g., regions where steric effects mask thermocline effects on sea surface height anomalies).

Accomplishments:

This annual report provides accomplishments since receipt of project funding from the Office of Climate Observations in June, 2006 (i.e., a full year of effort has not been performed). In addition, accomplishments have been slowed by the departure of Dr. Alberto Mestas Nunez, co-Principle Investigator, from AOML in July 2006. In spite of these factors, we have made progress in developing the generic software that can be used to perform analyses on all the selected lines.

Specific software included:

(1) Software to generate time-series of temperature as a function of depth, typically 25m increments, and location along the line, at various spatial resolutions depending on coverage and features observed. The time series from various depths were then band-passed filtered to generate time-distance plots that high lighted the energy in specific period bands (typically surrounding decadal periods). The zonal time-distance plots will also be reviewed to determine if there is signal propagation along the line (e.g., planetary wave propagation should appear at thermocline depths with phase speeds dependent on the latitude of the section).

(2) Software to generate geostrophic velocity sections using climatological temperature-salinity relations to estimate density and thus dynamic height has been developed. Geostrophic transports for particular segments of a section are then calculated and time-series plotted to search for periodicity in the transport record. Transport variability existing in boundary currents such as the Gulf Stream and Kuroshio and Gulf Stream and equatorial currents in the Atlantic and Pacific such as the Equatorial Countercurrents can be estimated from this software.

(3) Programs that for a particular grid point compute spectra and estimate the terms in a simplified vorticity relation were developed for earlier research have been retrieved and will be modified for application in this project.

Deliverables:

One year from receipt of funding, 31 May 2007:

(1) Characterization of the global upper layer temperature structure and variability from those lines with sufficient data to generate time-series.

(2) Nowcasts of the state of the ocean along these lines with respect to known decadal climate signals (i.e., the phase of the PDO, NAO, TAV, etc.) will be generated.

(3) Identification of low-density lines with sufficient information content to justify continuation.

References

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