High Resolution XBT Transects

Dean Roemmich, Bruce Cornuelle, Janet Sprintall and Glenn Pezzoli
Scripps Institution of Oceanography
University of California San Diego, La Jolla CA

Project Summary

The High Resolution Expendable Bathythermograph (HR-XBT) network was initiated in 1986 along a commercial shipping route between New Zealand, Fiji, and Hawaii. It was subsequently expanded during the 1990's to include basin-spanning temperature transects in all of the oceans. Major partners in the HR-XBT network include Scripps (Pacific and Indian Ocean), NOAA/AOML (Atlantic), and CSIRO (SW Pacific, Indian). Typically, each transect is repeated on a quarterly basis to resolve variability in temperature, geostrophic circulation and transport on annual and longer periods. A technician is on board in order to carry out sampling, with XBT probe spacing at 50 km or less in the ocean interior and as fine as 10-15 km in boundary currents. The ship rider also provides technical support for ancillary programs including improved marine meteorological sensors (VOS-IMET), Argo float and surface drifter deployments, underway thermosalinograph, and water sampling. Fig 1 shows the present transects sampled by the Scripps HR-XBT program and its partners in the Indian and Pacific Oceans. A typical temperature section is shown in Fig 2.

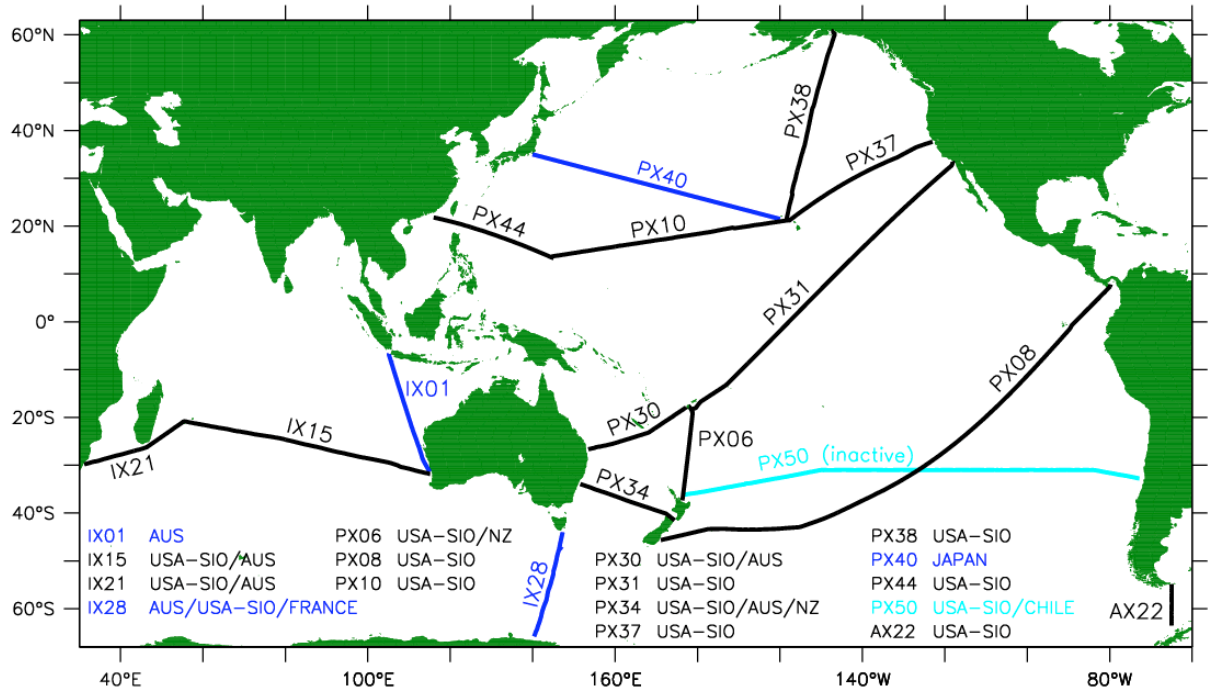

Fig 1: The HRX Network in the Pacific and Indian Ocean. International partnerships are indicated in the notes on the bottom of the figure.

Scientific Objectives-

A primary scientific goal of the HR-XBT network is to determine whether interannual variability in the transport of heat by ocean currents is a major contributor to the heat budget of the ocean

and hence to air-sea interactions and feedbacks in the climate system. Specific scientific objectives of the HR-XBT program are to:

- Measure the seasonal and interannual fluctuations in the transport of mass, heat, and freshwater across transects which define large enclosed ocean areas.
- Determine the long-term mean, annual cycle and interannual fluctuations of temperature, geostrophic velocity and large-scale ocean circulation in the top 800 m of the ocean.
- Obtain long time-series of temperature profiles at precisely repeating locations in order to unambiguously separate temporal from spatial variability.
- Determine the space-time statistics of variability of the temperature and geostrophic shear fields.
- Provide appropriate *in situ* data (together with Argo profiling floats, tropical moorings, air-sea flux measurements, sea level etc.) for testing ocean and ocean-atmosphere models.
- Determine the synergy between HR-XBT transects, satellite altimetry, Argo, and models of the general circulation. What are the minimal sampling requirements for *in situ* data?
- Identify permanent boundary currents and fronts, describe their persistence and recurrence and their relation to large-scale transports.
- Estimate the significance of baroclinic eddy heat fluxes.

In the context of NOAA's *Program Plan for Building a Sustained Ocean Observing System for Climate,* the HR-XBT Network is a part of the Ship-of-Opportunity Networks. It directly addresses objective 3 of the Plan: *Document the ocean's storage and global transport of heat and fresh water.*

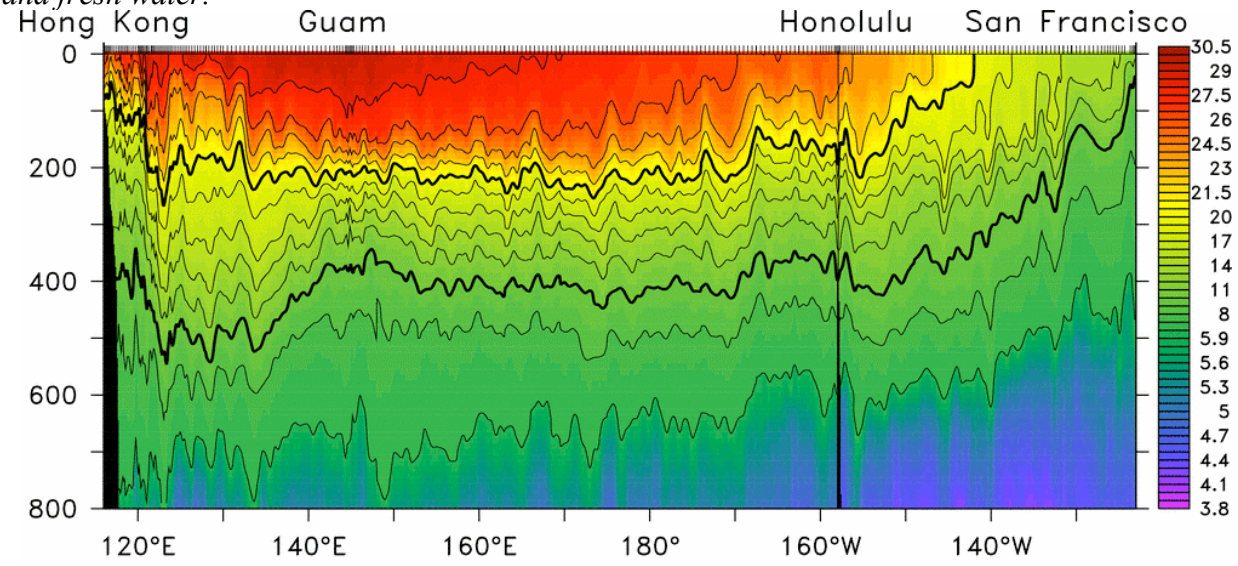

Fig 2. Example of a single temperature transect using 321 XBT profiles along PX37/10/44.

The configuration of the HR-XBT Network is in accordance with the recommendations of the Upper Ocean Thermal Review (Melbourne, 1999, see http://www.brest.ird.fr/soopip/).The Scripps HR-XBT network is managed for compatibility with the NOAA/SEAS system, and all XBT casts are transmitted (Global Telecommunications System) in near real-time for operational users as well as sent to NODC for archiving. The HRX Network is managed in accordance with the Global Climate Observing System (GCOS) Ten Climate Monitoring Principles.

FY2007 Accomplishments: October 2006 – September 2007.

Observations -

HRX transects were collected by ship riders along the routes illustrated in Fig 1, and as described in the previous section, in the following months, including yearly sums for total XBT drops and good XBT drops:

PX37/10/44 (North Pacific - San Francisco to Hawaii to Guam to Hong Kong)
4 transects: Nov 2006, Feb 2007, May 2007, July 2007 (1223 good/1253 total drops)

PX38 (North Pacific – Hawaii to Alaska)
2 transects: Dec 2006, July 2007 (211 good/224 total drops)

PX08 (South Pacific – New Zealand to Panama)
4 transects: Dec 2006, March 2007, May 2007, July 2007 (997 good/1018 total drops)

PX06/31 (Central Pacific – New Zealand to Fiji to Los Angeles)
3 transects – Feb 2007, June 2007, Sep 2007 (760 good/806 total drops)

PX30 (South Pacific – Brisbane to Fiji, collaborative with Australia)
3 transects – January 2007, April 2007, July 2007 (338 good/360 total drops)

IX21 (South Indian – Durban to Mauritius)
3 transects – Feb 2007, April 2007, July 2007 (249 good/261 total drops)
+ 2 IX06 Mauritius to Strait of Malacca, April 2007, July 2007 (131 good/133 total drops)

IX15 (South Indian – Mauritius to Fremantle or Bass Strait)
3 transects – Oct 2006, Jan 2007, July 2007 (599 good/615 total drops)

Data return rate is close to the planned four occupations per year for all lines, except for the short PX38 line due to lack of shipping. The number of transects in any 12-month period may vary from 3 to 5 depending on ship schedules. Sampling issues and our strategy for dealing with them are explained in the logistics section below.

In addition, logistical assistance and/or some XBT probes are provided collaboratively (480 probes per year are as part of our collaboration with CSIRO) for:

PX34 (South Pacific – Wellington to Sydney)
IX28 (Southern Ocean – Hobart to Antarctica)
AX22 (Southern Ocean - Drake Passage, occasionally providing a ship rider)

Logistics -

The commercial shipping industry has undergone enormous change since the beginnings of the HR-XBT network 20 years ago. With respect to HR-XBT sampling, there are two main changes. First, consolidation in the industry has resulted in the elimination of many shipping routes and an increasing reliance on feeder vessels. Second, ships remain on a given line for a much shorter period of time, necessitating frequent recruitment/changeover to new vessels. Specific impacts on HRX sampling include:

1. Elimination of the preferred South Pacific route (PX50) in 2003. The best alternate is PX08, with occasional PX50 transits by research vessels.
2. Occasional disappearance of IX15/21. We re-initiated sampling in September 2005 using two vessels (including a feeder vessel on IX21), and enlisted collaborative support from the University of Capetown. This line appears stable for the time, though is going to Bass Strait rather than Fremantle. It is logistically very difficult due to its remote location.
3. Serious reduction in tanker traffic along PX38.

All of these logistical issues result in increasing demands on the HR-XBT program's operations manager and the staff of trained ship riders, for recruitment and setup of new vessels. The transient nature of remote commercial shipping routes will continue. Our strategy is to continue sampling at our full capacity, but to shift to alternate routes with high scientific value in case shipping is unavailable along primary routes.

Development and technical issues –

The most substantial XBT technical issue of the past year has been the identification of a (warm) temperature bias due to variations over time of XBT fall-rate. Work is ongoing to estimate the time history of fall-rate corrections and to apply this correction to historical data:
Wijffels, S. and 7 co-authors: Changing eXpendable Bathythermograph Fall-rates and their Impact on Estimates of Thermosteric Sea Level Rise, In preparation.
Our role in this work is through providing datasets, suggestions, and ancillary calculations.

The SIO Automatic XBT launcher system and its software are now fully integrated with the NOAA/SEAS XBT data acquisition system. This allows HRX data to be transmitted in near real-time, and permits SIO HRX hardware to be used for broadscale XBT sampling.

Analysis and research highlights -

HR-XBT data are being incorporated in regional, basin-wide, and global analyses.

- There is now a 20-year time-series of HRX measurements along PX06 (Auckland-Suva). The PX06 long time-series has revealed permanent small-scale features of the circulation, shown interannual and decadal variability in transport, closed mass and heat budgets of the "Tasman Box" region, and provided a valuable dataset for ocean data assimilation modeling.
- E. M. Douglass is completing her PhD thesis in which HRX data are analyzed in combination with other datasets and results from the ECCO Ocean Data Assimilation model (Douglass, 2007, Douglass et. al., 2007). North Pacific HRX transects are a key dataset in this work, providing strong tests of the ODA model to correctly represent geostrophic velocity and ocean heat transport.
- In other work on Ocean Data Assimilation modeling, I. Hoteit and B. Cornuelle are using a regional eddy-permitting ($1/3^o$) model of the tropical Pacific (Hoteit *et al.*, 2006), to explore the capabilities and sensitivities of the ECCO model in the tropical domain. Again, HRX transects are a key dataset for challenging the capability of ODA models.
- J. Gilson is pursuing accuracy and consistency issues for both HRX and Argo datasets (e.g. Willis et al., 2007). Objectives are to identify and remove systematic errors in both

of these global datasets to enable the XBT and Argo records to be combined with one another as well as with other historical and ongoing data collections.

Refereed publications –

Hoteit, I., B.D. Cornuelle, A. Köhl and D. Stammer, 2006. "Treating strong adjoint sensitivities in tropical eddy-permitting variational data assimilation," *Quarterly Journal of the Royal Meteorological Society*, **131**, 3659-3682, doi:10.1256/qj.05.97.

Uehara, H., S. Kizu, K. Hanawa, Y. Yoshikawa, and D. Roemmich, 2007. Estimation of heat and freshwater transports in the North Pacific using the high resolution XBT data. Accepted by *J. Geophys. Res.*

Ueno, H., E. Oka, T. Suga, H. Onishi and D. Roemmich, 2007. Formation and variation of temperature inversions in the eastern subarctic North Pacific. *Geophys. Res Lett., 34,* L05603, doi:10.1029/2006GL028715.

Willis, J., J. Lyman, G. Johnson, and J. Gilson, 2007. In situ data biases and recent ocean heat content variability. Submitted to *Geophys. Res. Lett.*

Douglass, E. M., D. Roemmich, and D. Stammer, 2007. North Pacific variability from a data-assimilating model. In preparation.

Douglass, E.M., 2007. *Interannual Variability in North Pacific Ocean Circulation and Heat Transport: Results from Data Analysis and Ocean Data Assimilation Modeling.* PhD Thesis, Scripps Institution of Oceanography, University of California San Diego. (In preparation for December 2007)

Community service –

D. Roemmich is active in design, coordination, and implementation of global ocean observations. He serves as co-chairman of international CLIVAR's Global Synthesis and Observations Panel, and as co-chairman of the Argo Science/Steering Team. He is also a member of the Steering Team for Pacific Islands - Global Ocean Observing System (PI-GOOS) and for the SEREAD education initiative, which develops teaching units and educational materials relevant to climate and ocean observations for primary and secondary curricula in South Pacific island nations.