SIO High Resolution XBT Transects

Dean Roemmich, Janet Sprintall, and Bruce Cornuelle
Scripps Institution of Oceanography, La Jolla CA 92093-0230

Table of Contents

1. Project Summary

As an element of the global ocean observing system for climate, the unique role of the High Resolution Expendable Bathythermograph (HR-XBT) Program is in providing boundary-to-boundary repeating transects that resolve both the oceanic boundary currents and the corresponding interior circulations of the global oceans. Boundary current mass and heat transport are critical elements in the global circulation and heat budget, playing as large a role as the entire interior ocean circulation. The Scripps HR-XBT Network includes ocean-spanning lines in the Pacific and Indian Oceans, and is implemented in collaboration with U.S. and international partners making complementary measurements in all oceans.

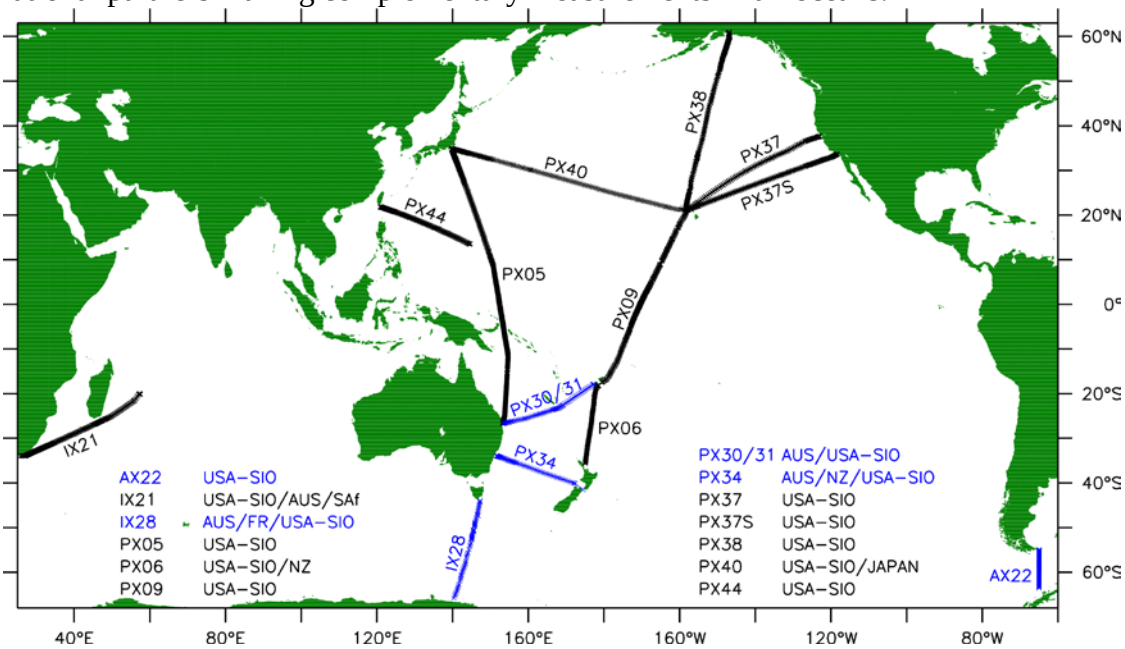

Figure 1: The HR-XBT Network in the Pacific and Indian Ocean. International partnerships are indicated in the notes at the bottom of the figure, the first-listed having primary responsibility.

The HR-XBT Program was initiated in 1986 along a commercial shipping route between New Zealand and Fiji (PX06, Figs 1,2). 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), CSIRO (SW Pacific, Indian), and Tohoku University (NW Pacific). The goal of the program is to document gyre-scale variations in ocean circulation and transport on seasonal and longer timescales. Each transect is repeated nominally on a quarterly basis. 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 km in boundary currents. The ship rider also provides technical support for ancillary programs including Argo float and surface drifter deployments. 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. In recent years, some reorganization of the network has been to focus on boundary current observations while maintaining a few trans-ocean routes.

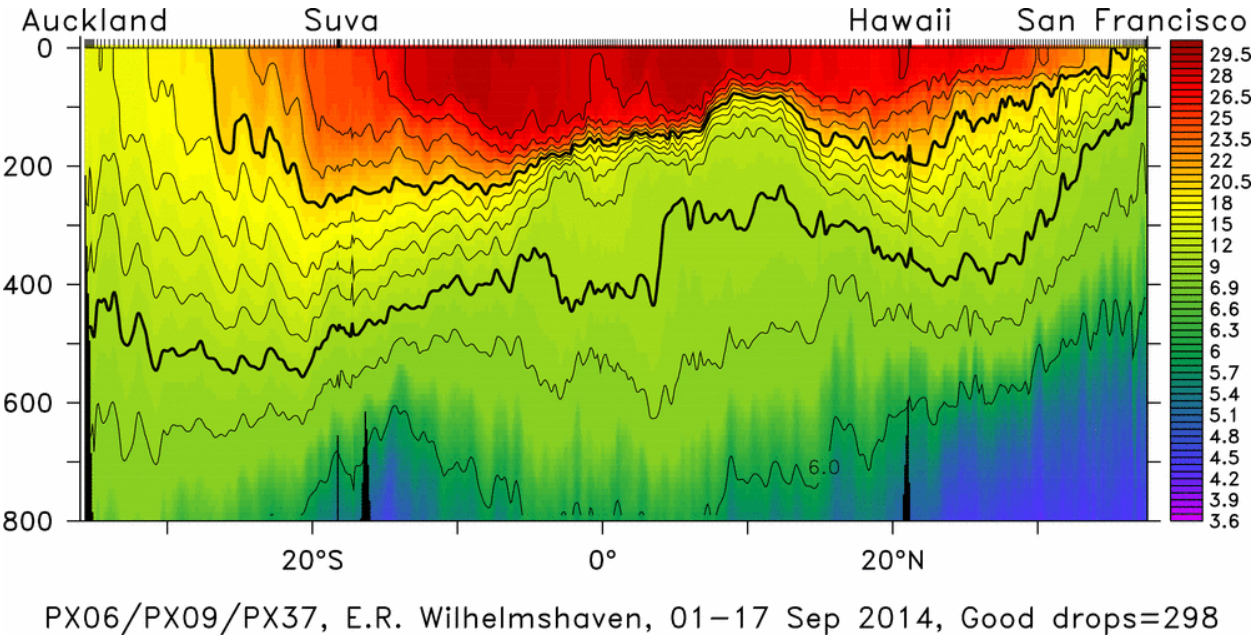

Figure 2. Example of a recent temperature transect (°C) with 298 XBT profiles along PX06/09/37. Tick marks at the top are profile locations.

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 (Fig 1).
- 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.
- Determine the spatial and temporal statistics of variability of the temperature and geostrophic velocity 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.
- 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.

Multi-decadal HR-XBT datasets are used for basic research in the ocean/climate system to understand the role of upper ocean circulation and variability in the mean and time-varying mass and heat balances and in air-sea interaction. The knowledge gained through basic research is applied in global and regional models for understanding and prediction of the economic and human impacts related to variability in the physical state of the oceans. Interactions in the ocean-atmosphere system are responsible for extreme weather events and for extended periods of drought or flooding. The warming and expansion of the oceans is a large component in regional and global sea level rise, and therefore important in assessing risks to coastlines and coastal infrastructure. Ocean temperature and circulation are also primary factors influencing marine ecosystems, and their systematic observation is essential for ecosystem management. Important elements of ocean circulation and air-sea interaction occur on spatial scales of order 100 km, including boundary currents, fronts, and mesoscale eddies. The HR-XBT network is the only element of the global ocean observing system to provide systematically repeating observations that resolve these important circulation features.

2. Scientific and Observing System Accomplishments

The HR-XBT Program, through its global collection of temperature and salinity profile data and ocean circulation observations, contributes importantly to several NOAA/Climate Observation Division Program Deliverables:

• ***Sea Surface Temperature and Surface Currents.*** HR-XBT data provide the near-surface temperature structure and the geostrophic surface current flowing across the sampled routes, with spatial resolution of 10-15 km in boundary current regions.

• ***Ocean Heat Content and Transport.*** HR-XBT observations of temperature and geostrophic velocity are used to estimate seasonal to decadal variability in the meridional transport of heat across ocean-spanning transects, including the large contributions of boundary currents to the ocean-wide heat transport. Historically, XBT profile data has been a primary source for global estimation of 0–800 m ocean heat content, including for national and international climate assessments, and it remains important in that role to the present.

• ***Sea Level.*** Sea level variability and change is caused by both mass and density (mostly from temperature) components. Redistribution of temperature by strong and variable boundary currents is an important element in regional sea level variability over periods of years to decades.

2.1 HR-XBT transects

The deliverables of the HR-XBT Program consist of (approximately) quarterly XBT transects along the nominal routes shown in Fig 1 and described below. Actual locations of all XBT profiles obtained during FY14 are shown in Fig 3.

Here we provide a summary of the transects collected on each route, including problems encountered and measures to overcome them, followed by a description of how near real-time and delayed-mode data are made available. Further details on ships and routing, and temperature sections similar to Fig 2 are available at http://www-hrx.ucsd.edu .

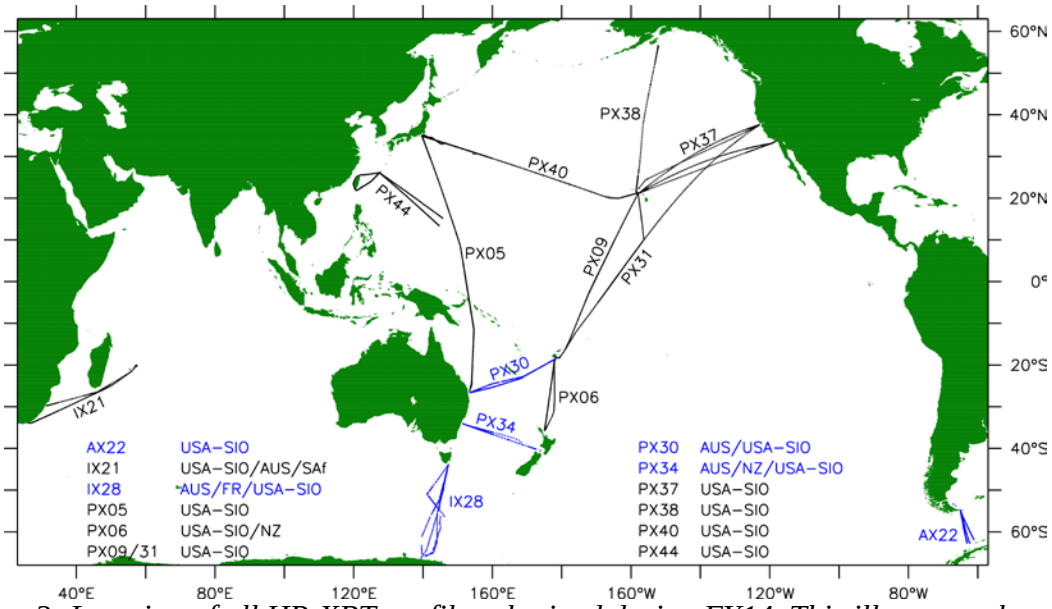

Figure 3: Location of all HR-XBT profiles obtained during FY14. This illustrates that some routes follow a repeating track exactly, e.g. the 3 transects along PX05, while others follow variable itineraries, while still connecting land or island endpoints.

The primary challenge for the HR-XBT Program is the increasingly transient nature of ships and routing in the commercial shipping industry, and the increase in size of container ships leading to a reduction in ocean-crossing routes. Our priority is to sustain long time-series transects, particularly including boundary currents.

1. **The zonal crossing of the North Pacific Ocean** (PX40, PX37). PX40 (Honolulu to Yokohama) was carried out 5 times using JRS Canis, in December 2013 and February, May, June, and August 2014. PX40 samples the Kuroshio and interior subtropical gyre. PX37S (Los Angeles – Honolulu, Horizon Spirit), sampling the California Current System, was carried out 5 times, in December 2013, and in January, March, May, and August 2014. PX37 (San Francisco to Honolulu, Horizon Enterprise) also sampling the California Current System, was carried out 4 times, in January, March, May, and August 2014.
2. **The zonal crossing of the South Pacific Ocean** (PX50, New Zealand – South America) is inactive due to lack of shipping.
3. **The western boundary region of the South Indian Ocean** (IX21 Durban – Mauritius) sampling the Agulhas and western boundary region near Madagascar, was carried out twice, in March and August 2014 using the Maersk Senang.
4. **The western boundary region of the North Pacific** (PX44, Taiwan – Naha – Guam) sampling the upstream Kuroshio and western boundary region near Taiwan, was carried out 3 times using the Mell Springwood in May, July, and September 2014.
5. **The meridional crossing of the Central Pacific Ocean** (PX06/09/31, New Zealand – Fiji – Honolulu or California) sampling the East Auckland Current and the zonal tropical Pacific current system, was carried out 5 times, in October and November 2013 and in March, May

and September 2014. An additional transect of PX06 (New Zealand – Fiji) was in July 2014. All transects used the E.R. Wilhelmshaven.

6. **The meridional crossing of the Western Pacific Ocean** (PX05, Brisbane – Solomon Sea – Yokohama), crossing the East Australian Current, Solomon Sea, and Kuroshio, was carried out 3 times, in October 2013, and in May and September July 2014, onboard the Safmarine Meru.
7. **The Hawaii – Alaska** (PX38) transect was carried out once, in January 2013 onboard USCG Spar. There is at present no regular commercial shipping along this route but there are occasional U.S. Coast Guard and research vessel transits.
8. **Other short transects and collaborative support for partners.** Routes PX30, PX34, and IX28 in the southwestern Pacific are carried out collaboratively with CSIRO, who typically sample 3 to 5 transects per year on PX30 and PX34 and 6 to 8 transects per year on IX28. CSIRO has primary responsibility for these transects, providing logistics, coordination and most of the XBT probes. Scripps provides occasional ship-riders on PX30 and 480 XBTs per year (half the number required for PX30 and PX34). Route AX22 in the Drake Passage is carried out primarily with support from NSF (J. Sprintall, P.I.). The HR-XBT Program provides technical and logistical assistance as needed.

Transects collected and XBTs deployed	Transects	Total XBTs	Good profiles
1. Zonal crossing of the North Pacific	5 PX40, 5 PX37S, 4 PX37	1786	1760
2. Zonal crossing of the South Pacific	Inactive	-	-
3. Western boundary of the South Indian	2 IX21	211	211
4. Western boundary of the North Pacific	3 PX44	422	417
5. Meridional crossing of the Central Pacific	6 PX06, 3 PX31, 2 PX09	1368	1355
6. Meridional crossing of the Western Pacific	3 PX05	759	747
7. Hawaii to Alaska	2 PX38	211	209
8. Other short transects/collaborations	See text	480	456 (est)
Totals		5237	5155

Table 1: Summary of FY14 transects, total XBTs dropped, and good temperature profiles. The high proportion of good-to-total XBTs (> 98%) is due to mounting of an automatic XBT launcher on the stern of the ships, rather than conventional hand-launching from the ship's bridge.

2.2 Scientific Highlight – XBT and Argo for boundary current transport estimation

A long-term project is the synthesis of HR-XBT, Argo, and altimetric sea surface height data for accurate estimation of boundary current transport and variability. In a case study carried out in the East Australian Current (EAC) near Brisbane, Argo trajectory data show a significantly weaker EAC and weaker recirculation transport than a 2000 m reference level calculation (Fig. 4). The HR-XBT data provides a much greater density of profiles than Argo across the boundary

current, including many profiles in depths less than 1000 m where Argo floats are typically not found due to grounding problems.

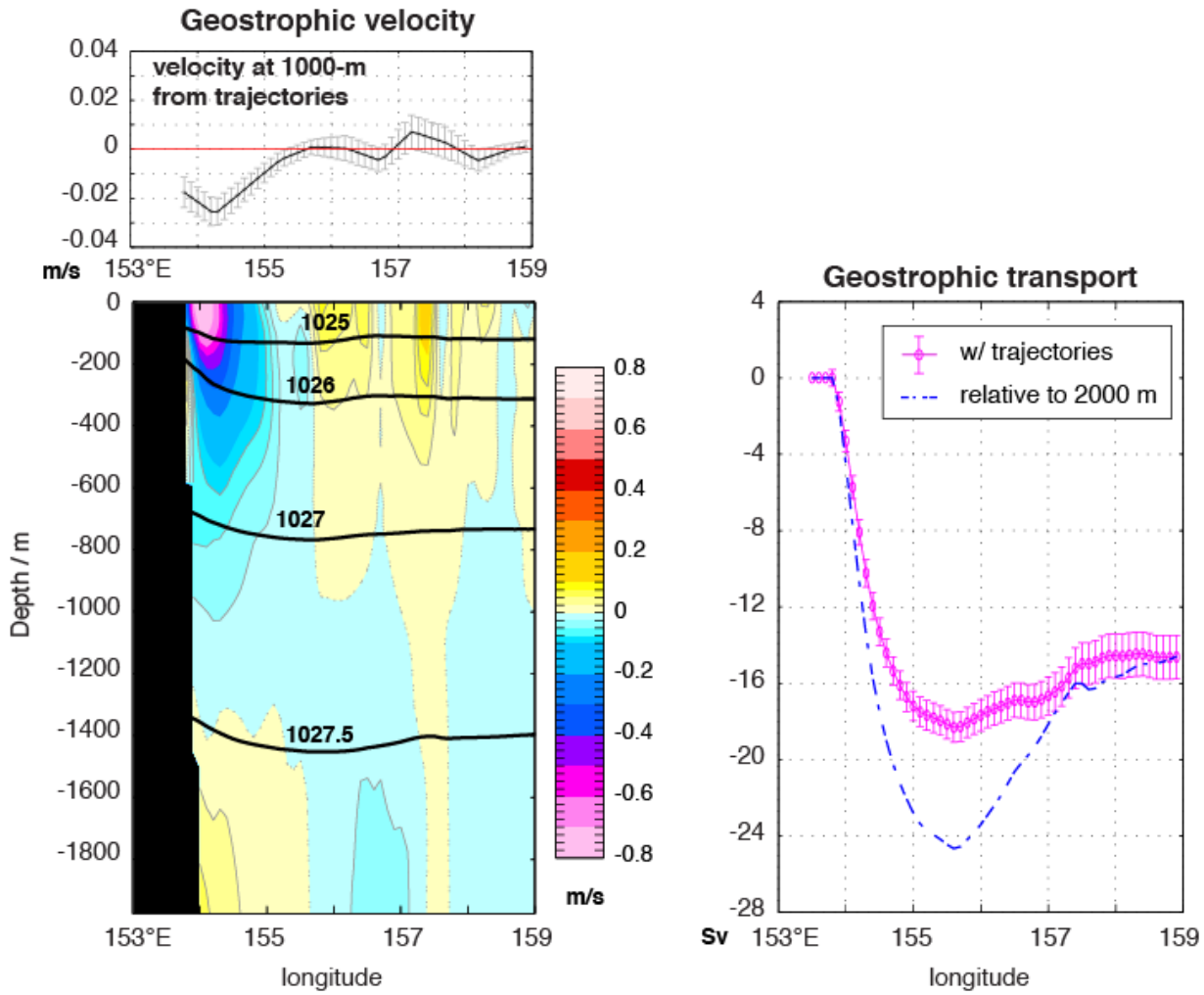

Figure 4: Mean absolute velocity (left) and transport integral (right), 0 – 2000 m for the EAC, 2004 – 2012. Shear from XBT and Argo profiles is combined with Argo trajectory data providing reference velocities at 1000 m.

This project (Zilberman et al, in preparation) also uses altimetric height projected onto subsurface density both to correct temporal aliasing of mean fields and for improved temporal resolution of the EAC system transport.The boundary current region is combined with the ocean interior for basin-wide estimation of mean and time-varying volume and heat transport and meridional overturning circulations. Both the line-mode (HR-XBT) and the area-mode (Argo) of sampling are essential for the integrated ocean observing system.

2.3 Data availability

All HR-XBT data are available without restriction in near real-time and delayed-mode versions.

a) Near real-time data are transmitted from the ship by the Scripps ship-rider using the NOAA/SEAS System, following quick visual inspection, and distributed via the Global Telecommunications System.

b) The real-time data are freely available via the internet from the Global Temperature-Salinity Profile Program (GTSPP) http://www.nodc.noaa.gov/GTSPP/ .

c) The delayed mode dataset, produced by expert examination of all profiles and statistical comparison to adjacent profiles and to previous profiles along the same track, is made available in transect form at http://www-hrx.ucsd.edu . This publicly available dataset includes transects collected as recently as September 2014. Most transects are made available within a week or two of collection.

d) The HR-XBT dataset is archived and distributed by the National Oceanographic Data Center. We transmit delayed-mode data to NODC on an annual basis.

e) The web site where the HR-XBT data can be accessed is: http://www-hrx.ucsd.edu . In addition to the transect data delivered via the program web site, our data manager also responds to requests (e.g. for high vertical resolution data, or for specific collections of transects).

f) We have successfully retrieved HR-XBT data recently from the program web site.

A data flow chart for the HR-XBT program can be found at http://www-hrx.ucsd.edu/data_management.html and data quality control procedures are consistent with those described in NODC's GTSPP Data Quality Control manuals: http://www.nodc.noaa.gov/GTSPP/document/qcmans/index.html

3. Outreach and Education

The Scripps HR-XBT Program has made strong contributions to education by serving as a source of data for PhD and Master's theses and for research by post-doctoral investigators. To date, ten completed PhD theses at three different institutions have used Scripps HR-XBT data as a primary dataset in studies of time-varying ocean circulation, global ocean heat content, water mass formation, and ocean heat transport:

Michele Y. Morris (PhD, Scripps Institution of Oceanography, UCSD, 1996)
Mary C. McCarthy (PhD, Scripps Institution of Oceanography, UCSD, 2000)
Joshua K. Willis (PhD, Scripps Institution of Oceanography, UCSD, 2004)
Takamasa Tsubouchi (PhD Tohoku University, 2006)
Elizabeth M. Douglass (PhD, Scripps Institution of Oceanography, UCSD, 2007)
Andrew Thompson (PhD, Scripps Institution of Oceanography, UCSD, 2007)
Yueng-Djern Lenn (PhD, Scripps Institution of Oceanography, UCSD, 2007)
Katherine L. Hill (PhD, University of Tasmania, 2009)
Gordon Stephenson (PhD, Scripps Institution of Oceanography, UCSD, 2012)
Yvonne Firing (PhD, Scripps Institution of Oceanography, UCSD, 2012)

The increasing use of the HR-XBT dataset in recent student research is indicative of the increasing value of ocean observations that are sustained over a long period of time.

The Scripps HR-XBT Operations Manager and the ship-riders perform key outreach functions in relation to the shipping industry. They inform shipping company managers and ships' crews, while at sea, of the objectives and results of the HR-XBT program in order to promote the ongoing partnership of the research community with the commercial shipping industry. Through these outreach efforts as well as articles published in shipping industry trade magazines, we inform management and crews of the need for their assistance in climate change research and the value of their contributions.

4. Publications and Reports

4.1. Publications by Principal Investigators

Published:

Jiang, C., S. T. Gille, J. Sprintall, and C. Sweeney, 2014: Drake Passage Oceanic pCO2: Evaluating CMIP5 coupled carbon/climate models using in-situ observations, *J. Clim., 27*, 76100. doi: 10.1175/JCLI-D-12-00571.1

Zilberman, N. V., D. H. Roemmich, and S. T. Gille, 2014: Meridional volume transport in the South Pacific: Mean and SAM-related variability, *J. Geophys. Res. Oceans, 119*, 2658–2678, DOI: 10.1002/2013JC009688.

In press:

Proceedings (peer-reviewed):

Roemmich, D., S. Cravatte, T. Delcroix, F. Gasparin, D. Hu, G. Johnson, W. Kessler, R. Lumpkin, G. Reverdin, J. Sprintall, and S. Wijffels, 2014: In situ temperature, salinity, and velocity observations. White Paper #10: Tropical Pacific Observing System – TPOS 2020 Workshop. January 2014, La Jolla California.

Book chapter:

Goni, G., J. Sprintall, D. Roemmich, A. Gronell Thresher, R. Cowley and M. Baringer, 2014: The Global Network of XBT Temperature Sections in Support of Oceanographic and Climate Studies. in Oceans and Society: Blue Planet, S. Djavidnia, V. Cheung, M. Ott and S. Seeyave (eds). Cambridge Scholars Publishing, Newcastle upon Tyne, UK, pp 37-45.

Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang, 2013: Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

4.2. Other Relevant Publications

A bibliography of publications using XBT data is maintained by AOML on the XBT Science Page, http://www.aoml.noaa.gov/phod/goos/xbtscience/bibliography.php . The bibliography contained 81 research papers in 2013 alone.

5. Slides

Please attach up to three slides highlighting your project's progress (including relevant notes and credits).
Attached slide: Roemmich_FY14_Annual_Report_HRX.pptx