The Panularis Hydrographic Stations: Year 60-64

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The objective of this program is to observe the water column structure and time-series variability of North Atlantic Ocean waters near Bermuda at the nominal Hydrostation 'S' site (32° 10'N, 64° 30'W). This sustained ocean observation program has a frequency of 24 shipboard occupations of the Hydrostation 'S' per year. As of March 2014, we have 61 years of hydrographic data in hand from the time-series. Hydrostation 'S' data contributes to understanding of: (i) upper ocean physics, subtropical mode water, and climate connections in the North Atlantic subtropical gyre; (ii) deep water processes and Atlantic Meridional Overturning Circulation (AMOC); (iii) physical processes arising from measurements of gases and tracers; and (iv) biological processes and new production in the North Atlantic subtropical gyre. Funding for Hydrostation 'S' has been renewed until 2017.

Sampling program

The sampling program consists of two CTD hydrocasts per cruise (Sea-Bird SBE-09 CTD with an internal Digiquartz pressure sensor, a Sea-Bird SBE-03f temperature sensor, a Sea-Bird SBE-04 conductivity cell, and a Sea-Bird SBE-05 pump; Sea-Bird SBE-43 dissolved oxygen sensors, a *Wetlabs* deep transmissometer, a deep (6000m) *Chelsea Instruments* fluorometer and a *Biospherical* PAR sensor). The Sea-Bird CTD is mounted with a 24-position Sea-Bird model 32 rosette, which is equipped with 12L Ocean Test Equipment bottles, and wet salinity and Winkler dissolved oxygen measurements are also collected. Many other gas, tracer, and ocean biogeochemical measurements have and are being collected at Hydrostation S.

Recent results

For this current award, a total of 33 additional hydrographic stations have been performed at the nominal Hydrostation 'S' site increasing the total number of stations to 1255 as of October 1, 2014. All cruises during this current period were conducted on the R/V *Atlantic Explorer* with a station frequency ranging between 7 to 21 days and most stations consisted of two CTD casts. Hydrostation 'S' data have played a central role in understanding the seasonal and longer-term variations of hydrography and biogeochemistry in the Sargasso Sea as outlined in the four themes above (Schroeder et al. 1959; Menzel and Ryther 1960; Schroeder and Stommel 1969; Pocklington 1972; Talley and Raymer 1982; Jenkins 1982; Jenkins and Goldman 1985; Jickells et al. 1989; Joyce and Robbins 1996; Joyce and Talley 1996; Hazeleger and Drijfhout 1998, Curry et al. 1998; Joyce et al. 2000; Curry and McCartney 2001; Bates et al. 2002; Johnson 2003; Rossby et al 2005; Phillips and Joyce, 2006; Goodkin et al. 2008; Molinari 2011. Bates et al. 2012; 2014; IPCC, 2014). Several hundred papers have cited Hydrostation S data, and these papers have been cited more than 40,000 times.

Online data

The bottle salinity and dissolved oxygen data have been available at FTP site (ftp://batsftp.bios.edu/Hydrostation_S/). At this site users can access either the bottle data (one single file from 1955 to December 2011) or the individual CTD profiles from October 1988 to July 2012. Users can download both BATS and Hydrostation 'S' data from the interactive Matlab based web site http://www.bios.edu.

Bibliography

Bates, N. R. 2012*:* Multi-decadal uptake of carbon dioxide into subtropical mode waters of the North Atlantic Ocean. *Biogeosci.,* bg-2011-478, 8, 12451-12476.

Bates, N. R., C. Pequignet, R. J. Johnson, and N Gruber, 2002: A short-term sink for atmospheric CO2 in subtropical mode water of the North Atlantic Ocean. *Nature*, **420**, 489-493.

Bates, N. R., Y. M. Astor, M. J. Church, K. Currie, J. E. Dore, M. Gonzalez-Davila, L. Lorenzoni, F. E. Muller Karger, J. Olafsson, and J. M. Santana-Casiano, 2014: Changing ocean chemistry: A time-series view of ocean uptake of anthropogenic CO2 and ocean acidification. *Oceanogr.*, http://dx.doi.org/10.5670/oceanog.2014.03.

Curry, R. G., M. S. McCartney, and T. M. Joyce, 1998: Ocean transport of subpolar climate signals to mid-depth subtropical waters. *Nature,* **391**, 575-577.

Curry, R. G. and M. S. McCartney, 2001: Ocean gyre circulation changes associated with the North Atlantic Oscillation. *J. Phys. Oceanogr.*, **31**, 3374-3400.

Goodkin, N. F., K. A. Hughen, W. B. Curry, S. C. Doney, and D. R. Ostermann, 2008: Sea surface temperature and salinity variability at Bermuda during the end of the Little Ice Age. *Paleoceanogr.*, **23**, PA3203.

Hazeleger, W. and S. S. Drijfhout, 1998: Mode water variability in a model of the subtropical gyre: response to anomalous forcing. *J. Phys. Oceanogr.*, **28**, 266-288.

Jenkins, W. R. 1982: On the climate of a subtropical ocean gyre: decade timescale variations in water mass renewal in the Sargasso Sea. *J. Mar. Res. Supp.,* **40,** 265-290.

Jenkins, W. R. and J. C. Goldman, 1985:. Seasonal oxygen cycling and primary production in the Sargasso Sea. *J. Mar. Res.*, **43**, 465-491.

Jickells, T. D., A. H. Knap, R. Sherriff-Dow, and J. N. Galloway, 1989: No ecosystem shift. *Nature* **347**, 25-26.

Johnson, R. J., 2003: Climatic and mesoscale modulation of the upper ocean at the Bermuda time-series sites. Ph.D thesis, University of Southampton, U.K.

Joyce, T. M. and P. Robbins, 1996: The long-term hydrographic record at Bermuda. *J. Climate*., **9**, 3121-3131.

Joyce, T. M. and L. Talley, 1996: The Bermuda Hydrostation 'S' – A long-running oceanographic show. *Oceanus,* **39**, 14-15.

Joyce, T. M., C. Deser, and M. A. Spall, 2000: The relation between decadal variability of subtropical mode water and the North Atlantic Oscillation. *J. Climate*, **13**, 2550-2569.

Menzel, D. W. and J. H. Ryther, 1960: The annual cycle of primary production in the Sargasso Sea off Bermuda. *Deep Sea Res.,* **6**, 351-367.

Molinari, R.L., 2011: Information from low-density expendable bathythermograph transects: North Atlantic mean temperature structure and quasi-decadal variability. *Prog. Oceanogr.*, **88**, 131-149.

Phillips, H. E. and T. M. Joyce, 2006: Bermuda's tale of two time series: Hydrostation 'S' and BATS. *J. Phys. Oceanogr.,* **37**:554-571.

Pocklington, R. 1972. Secular changes in ocean off Bermuda. *J. Geophys. Res*., **77**, 6604-6637.

Robbins, P.E., J. F. Price, W. B. Owens, and W. J. Jenkins, 2000: The importance of lateral diffusion for the ventilation of the lower thermocline in the subtropical North Atlantic. *J. Phys. Oceanogr.,* **30**, 67-89.

Rossby, T., C. N. Flagg and K. Donohue, 2005: Interannual variations in upper-ocean transport by the Gulf Stream and adjacent waters between New Jersey and Bermuda. *J.Mar. Res.* **63,** 203-226.

Schroeder, E., H. Stommel, D. W. Menzel, and W. Sutcliffe Jr., 1959: Climatic stability of the eighteen degree water at Bermuda. *J. Geophys. Res.,* **64**, 363-366.

Schroeder, E. and H. Stommel,1969: How representative is the series of PANULIRUS stations of monthly mean conditions off Bermuda? *Progr. Oceanogr.,* **5**, 31-40.

Talley, L. D. and M. E. Raymer, 1982: Eighteen degree water variability. *J. Mar. Res.,* **40**, 757-775.

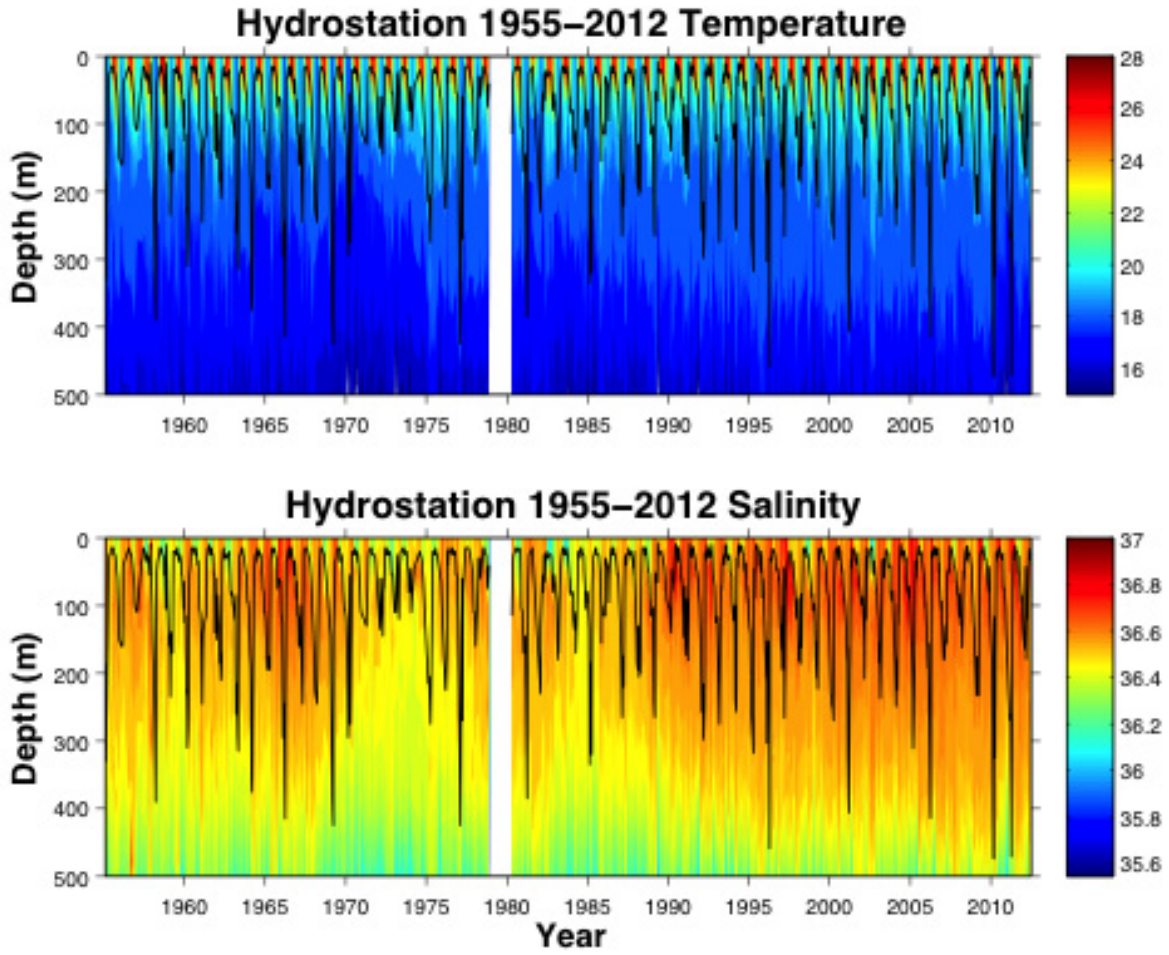

Figure 1. Contour plots of (top) temperature and (bottom) salinity for Hydrostation 'S' from January 1955 through July 2012. Mixed layer depth overlaid as the black line and is computed using the variable sigma__ method (Sprintall & Tomczak, 1992). The data gap from January 1979 through April 1980 represents the period where the hydrowire with all Nansen bottles and reversing thermometers was lost at sea and resources were not available for immediate replacement (Figure courtesy R. Johnson).