HadGOA — Hadley Centre global subsurface ocean analysis of temperature and salinity

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Abstract: HadGOA is a project to develop an ocean subsurface analysis and climatology product designed for model validation and evaluation of historical ocean variability. The project is currently in the preliminary stages, so our focus has been on the scientific strategy and clarifying user requirements. The product is based on quality-controlled observational data from ENACT (Enhanced Ocean Data Assimilation and Climate Prediction) and is planned to incorporate near real-time updates by its completion. The HadGOA analyses will be made freely available for use by the climate research community.

One of the motivations for this project is the community's need for an alternative to the NODC (National Oceanographic Data Center, USA) analyses. Some of the key advantages of our analyses will be: (i) averaging of properties on isotherms and/or isopycnals; (ii) a rigorous quality control procedure; and (iii) error estimates of derived quantities. The gridding and interpolation algorithms used by HadGOA will be clear and open-source. This will enable observation-model comparisons to be performed in the most meaningful way. The potential difficulties of model comparisons with the NODC products have been documented in Gregory et al. [2004].

The first stage of the project will concentrate on evaluation of the historical ocean heat content. To do this, the depth of each isotherm will be mapped in order to use all available temperature data. This approach has the advantage over a more traditional z-level analysis of removing some influence of ocean dynamics on variations in heat content in any particular ocean depth range.

1. Strategy: The ideal choice of vertical coordinate for ocean analyses is potential/neutral density (ρ/γ) [e.g. Lozier et al., 1995, Gouretski and Koltermann 2004]. However, if this approach is pursued in estimating ocean heat content (OHC) one must sacrifice the large number of temperature-only (T-only) observations in the historical database. On the other hand, if one employs depth (z) as the vertical coordinate [e.g. Ishii et al., 2003, Levitus et al., 2005] all the available T data can be used, but the ocean can be poorly represented in areas of sloping isopycnals (especially where data are sparse). For HadGOA we have chosen isotherms or z(T) as the vertical coordinate. T is the dominant influence on ρ over much of the upper ocean (where most data exist, **Fig. 1**) and isotherms form a natural framework for estimating heat content. Thus we are able to use all of the T data and remove some of the influence of ocean dynamics (via adjustment of isopycnals) on heat content estimates. By using a different coordinate system to previous authors we are also better placed to aid understanding of structural uncertainty in estimates of OHC.

The estimates of OHC will be calculated for the water bounded by a certain isotherm, similarly to Toole et al. [2004]. The choice of bounding isotherm is limited by the depth to which XBT observations reach in the subtropical gyres (**Figs. 1 and 4**). To maintain adequate sampling over the subtropical gyres the lower limit in T-space is approximately 10-12C. Using z(T) is problematic in areas where S has a substantial influence on ρ (e.g. high latitudes, Mediterranean outflow) because T inversions can occur. The 10-12C isotherms outcrop in the mid-latitudes, so we naturally avoid high latitudes. In other regions where S causes T inversions we take the deepest occurrence of the given isotherm as our estimate of z(T).

2. Method: We have produced preliminary estimates of z(T) for isotherms in the range 10-30C at 1C intervals. The data are assigned to a 2°×2° horizontal grid with no distance weighting or horizontal interpolation (note data gaps, **Fig. 3**). We compute monthly climatologies and standard deviations using data over the period 1956–2004 (**Fig. 3a, b**). Each climatology incorporates data from the adjacent months in a ratio of 1:2:1, to assist data coverage. The same method is applied to the periods 1965–1984 and 1985–2004 to produce anomaly maps of isotherm depth (**Figs. 3c, d**). A 3-point binomial filter is used to remove some of the noise from the isotherm depth anomaly maps.

Using the monthly climatologies we produce anomaly fields of isotherm depth for each month and average these to produce a mean anomaly field for each year. We compute the area-averaged anomalous isotherm depth and produce a time series for each of the major ocean basins (**Fig. 4**). There is no interpolation or infilling of data and many ocean basins have poor coverage, particularly before the 1970s. Results here are for the 12C isotherm.

3. Data: HadGOA uses *in situ* ocean temperature (T) and salinity (S) profiles from ENACT/ENSEMBLES (EN2). The data are quality controlled using a set of objective checks developed at the Hadley Centre [Ingleby and Huddleston, 2005]. The raw data come primarily from the World Ocean Database 2001 (often referred to as 'Levitus') but are supplemented other data sources*.

The bulk of the data are XBT observations (T-only), which have generally increased in number and depth over time (**Fig. 1**). XBT data largely determine the depth range over which analyses can be carried out. Spatial coverage of the observations in the historical database is better for later years than near the start of the record.

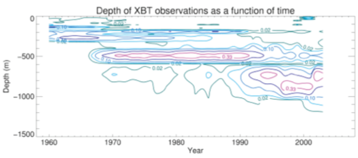


Figure 1: *A contour plot of the fraction of XBT observations that occur at different depths for each year of ENACT data*

*World Ocean Circulation Experiment (WOCE); the Bureau of Meteorology Research Centre (BMRC, Australia); the Commonwealth Scientific and Industrial Research Organisation (CSIRO, Australia); the Pacific Marine Environmental Laboratory (PMEL, USA); and the Global Temperature-Salinity Profile Program (GTSPP, Australia, Canada, France, Germany, Japan, Russia).

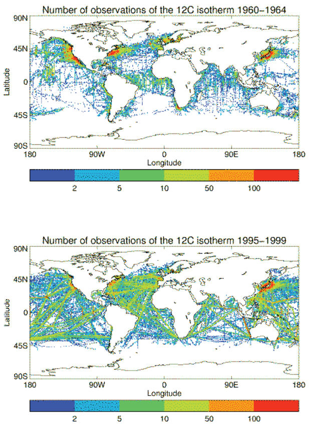


Figure 2: *The total number of observations of the 12C isotherm in each 1°×1° grid box for two periods of the ENACT data. There are few observations poleward of 45N and 45S because the isotherm outcrops near these latitudes*

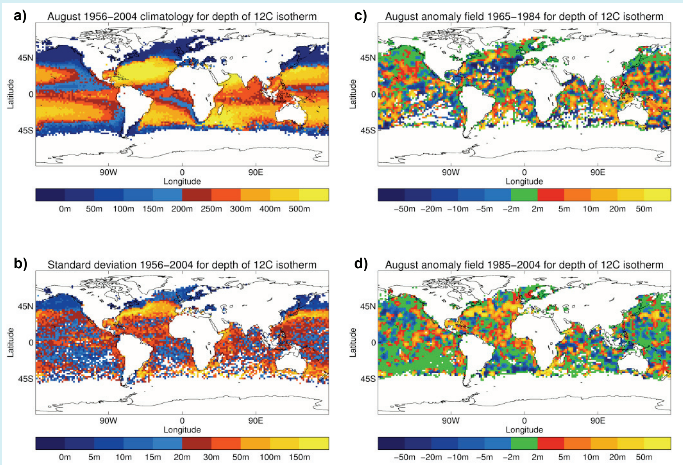
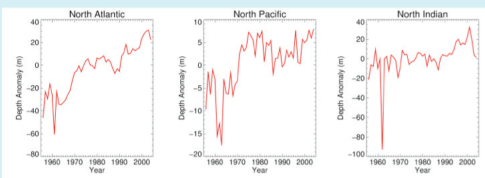


Figure 3a): *Median 12C isotherm depth for August;* **3b):** *Standard deviation of 12C isotherm depth for all Augusts;* **3c):** *The 12C depth anomaly field for August 1965–1984;* **3d):** *12C depth anomaly field for August 1985–2004. All data are on a 2°×2° grid*



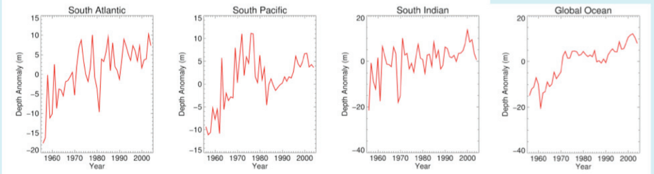


Figure 4: *Time series of the annual mean isotherm depth anomaly (in metres) for the major ocean basins and global ocean, computed on a 2°×2° grid. Note the different scales on the y-axis*

4. Results: The climatology of the 12C isotherm for August (**Fig. 3a**) highlights the locations of the ocean gyres, where the thermocline is deepest. Other features are the regions of equatorial upwelling and the Agulhas leakage around the south African coast. The standard deviation (**Fig. 3b**) shows peak values in the energetic western boundary current regions, off the east coast of Africa and near the Indian and Pacific sectors of the Southern Ocean. The maps of depth anomaly for August in two 20-year periods (**Figs. 3c, d**) show changes in isotherm depth that appear to be coherent over large scales. For example, the 12C isotherm has deepened over most of the N. Atlantic over the last 40 years (e.g. Gulf of Mexico). In contrast, much of the Pacific and Indian Oceans show a shoaling of the isotherm over the same period.

The times series of annual depth anomaly averaged by basin (**Fig. 4**) show a net deepening of the 12C isotherm in all ocean basins over the last 40 years. This implies more water with a temperature above 12C, but not necessarily increased OHC as this depends on similar diagnostics for the other isotherm depths. The signal is largest in the N. Atlantic, where the mean depth has increased by about 60m. The N. Atlantic, N. Pacific and S. Pacific oceans show the 12C isotherm to be relatively deep during the late 70s and early 80s. Levitus et al. [2005] find a similar feature in their analysis of historical OHC for these basins. The time series for the global ocean appears to be dominated by the N. Atlantic, which is the most well-observed basin.

5. Future work: The next step is to develop a time series of historical OHC from the z(T) analyses. This work is currently under way and will be finished in the next few months. Longer-term objectives include:

- Development of isotherm interpolation and infilling schemes. This is being done in collaboration with Ruth Curry and will eventually form part of the HydroBase toolbox (http://www.whoi.edu/science/PO/hydrobase/)
- Use of HadISST [Rayner et al., 2003] sea-surface temperature data for the OHC surface boundary condition and outcrop areas to assist in data interpolation
- Development of error statistics to identify which features of the time series are robust
- Comparisons with Levitus and evaluation of the influence of gridding method on the historical OHC estimates (structural uncertainty)
- Eventually we would like to introduce S data by mapping it onto the isotherm geometry. It has been shown that S(T) has larger correlation length scales than S(z) [Haines et al., 2005] which would be an advantage for interpolation/infilling of S data

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