A New Analysis of Hydrographic Data in the Atlantic and its Application to an Inverse Modelling Study

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In the late 70's climatologies of ocean properties have been produced by several authors (Levitus and Oort, 1977; Reid, 1978; and Levitus, 1982) from analyses of temperature and salinity measurements collected since the beginning of this century. The climatology of Levitus (1982) is traditionally used by the modelling community. Although this climatology has been and still is of great help to the scientific community it also has been criticised because important frontal structures have been smoothed out: nearly no North Atlantic Current (NAC), no Deep Western Boundary Current (DWBC). The absence of these structures restricted the use of this climatology in diagnostic studies. Recently, Lozier et al. (1995) carried out an analysis along isopycnal surfaces over the North Atlantic domain which was found to improve significantly the water mass distribution because their analysis scheme preserves density fronts. However, their *along isopycnal* binning procedure does not directly provide values at depth level and requires a subsequent vertical interpolation procedure for modelling applications.

The climatology presented here for the Atlantic Ocean is based on a simple isobaric averaging scheme similar to that used by Levitus but with a higher vertical resolution and a smaller horizontal radii of correlation. This analysis is seen as an improvement because important observed frontal structures are well represented on the gridded fields.

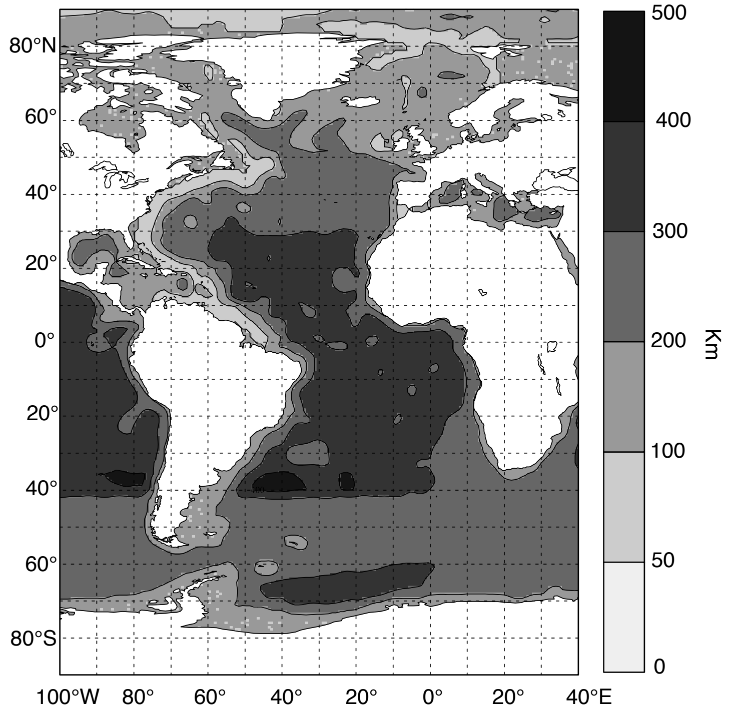

Figure 1. Radius of influence (km).

Table 1. Data set composition before and after the quality control procedure.

Origin	Initial	Final
NODC Bottle	519,016	384,304
NODC CTD (C022)	37,698	26,548
NODC CTD (F022)	38,948	21,054
CTD Brest (WOCE+other)	1,632	1,614
CTD Bremerhaven	1,421	1,294
CTD Scripps	2,763	2,328
CTD US Navy	312	162
CTD WOCE	1,465 +295	1,096 +237
Bottle MEDS	37,416	7,522
CTD Reid	958	910
Bottle WOCE	111	111
Total	642,035	447,180

Data set composition

The data set used in this analysis contains nearly 640,000 hydrographic stations coming mostly from the NODC archive. Some problems were found while processing the NODC data: truncated CTD profiles, double stations, incomplete sections, etc. Consequently, it was found necessary to complete the NODC data set by all available hydrographic stations including the following recent WOCE sections:

Atlantic One-time sections:

A1E, I6, A5, A6-A7-A13-A14-A17, Romanche1 and 3, A9, A10, A11, A12, A15, A21 and S4.

Atlantic WOCE Repeated sections:

AR7E(90-92), AR7W(90-92-93), AR15(90-91-92), AR15(95-96, ETAMBOT 1-2), AR18(92), SR01(92), SR02(90) and SR4(89-90-92).

The description of the composite data set is summarised in Table 1.

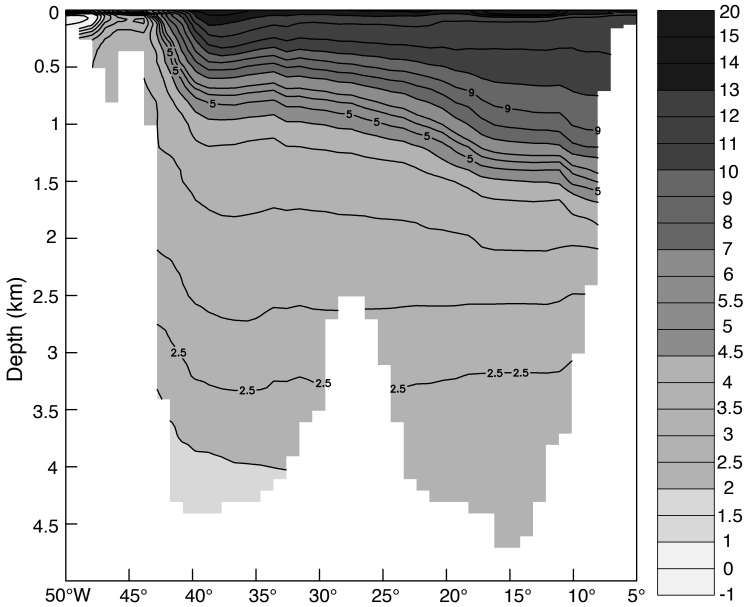

Figure 3. Potential temperature (°C) along section 48°N.

Data process

This composite data set cannot be used directly and must be first quality checked because it contains double stations and suspicious values. The first step of the quality control procedure is to interpolate all the profiles, *temperature, salinity and oxygen*, onto 72 defined standard levels. Notice that the maximum vertical spacing used in this study is 100 m. The interpolation scheme used for bottle and low resolution NODC CTD data is such that the interpolation is proceeded onto the closest standard levels to observation depth to avoid the creation of spurious values. The second step of the quality control procedure consists of eliminating double stations and in detecting/correcting anomalies in profiles. This procedure requires to *range check* all the values and to detect spikes and density inversions. It should be noticed that Russian salinities have been carefully treated.

The detailed composition of the final data set is described in Table 1. It was found that nearly 17% of the original data set is made of double-stations. This figure which occurs mainly in coastal regions is likely over-estimated because of the limit of the programme to distinguish between 2 closed stations taken the same day.

The gridding procedure

At this point of the analysis a relatively reliable validated data set has been obtained, the next step will be to analyse it for producing climatological mean fields for temperature, salinity and oxygen. The above quality checked procedure was not fully able to remove all gross errors. Furthermore, the final validated data set contains dedicated experiment profiles like those for the study of *meddies* in the North Atlantic. Such data are not representative of a climatological mean situation and thus are filtered out in the analysis.

The horizontal domain of this study extended from 100°W–40°E and from 90°S–90°N. The horizontal resolution used is 1° in latitude by 1° in longitude. The vertical resolution is given by the 72 standard levels chosen. The gridded fields are obtained by simply averaging for each grid points all observations located within a prescribed distance. This distance will be referred to as the *radius of influence*, following Levitus (1982).

In contrast with Levitus (1982) and Levitus et al. (1994), this radius is not constant; it is determined as a function of both the bottom topography and data distribution. Its ranges from 50–100 km near coastal regions, to 200–450 km in offshore regions (Fig. 1). The validation of the produced gridded fields is an iterative procedure which consists in finding spurious structures. The responsible hydrographic stations must be identified, problematic values flagged and the procedure restarted. The validation of the oxygen fields is yet not done.

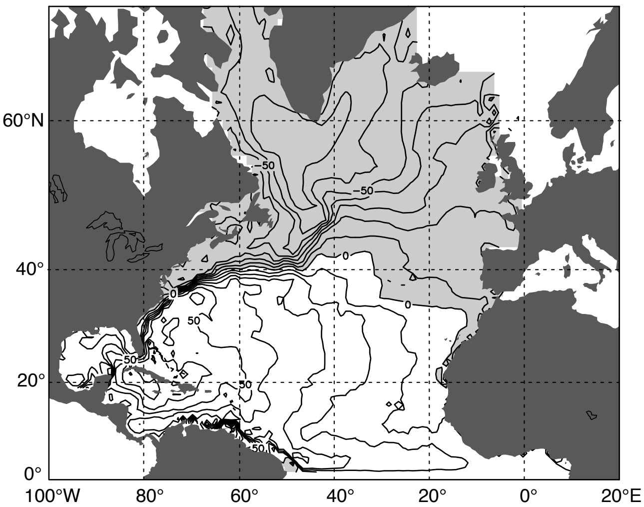

Figure 4. Dynamic topography (cm) from the inverse model. Notice that the basin averaged mean is removed.

In contrast with Levitus (1982) and Levitus et al. (1994) regions with insufficient observations are left flagged. The last step of this gridding procedure is to fill-up these regions. A vertical interpolation is first proceeded when surroundings neighbours are available, a cubic spline is used for that purpose. An objective analysis scheme (De Mey and Menard, 1989) is then applied with correlation radius of 50 to 500 km.

A first look at the annual mean fields

A general statement about this new climatology is that all frontal structures such as the NAC, the Benguela Current or the Antarctic Circumpolar Current, are intensified compared to Levitus et al. (1994). The eastward shift of the NAC near 50°N is also well defined (Fig. 2, page 24) as well as the cyclonic circulation around the Labrador Sea associated with the West Greenland Current and the Labrador Current.

Another important feature is the DWBC which is observed from the Labrador Sea/Irminger Sea to 30°N along the North American coast (Fig. 3). In offshore regions our climatology is similar to Levitus because respective radii of influence are getting closer. An analysis of the water masses found in this study shows a general agreement with literature. A comparison with Lozier et al. (1995) shows many similarities between their work for the North Atlantic and our gridded fields and indicates that the present procedure is performing despite its simplicity.

An inverse modelling comparison

The geostrophic circulation associated with the present climatology is estimated using the finite-difference inverse model of the Laboratoire de Physique des Océans over the North Atlantic domain. The inverse calculation produces an estimate of the absolute geostrophic velocity over a one-degree grid that is consistent with the climatology density field, large-scale mass and heat conservation, Ekman transports calculated using the ERS wind field products, and the thermal wind balance. The mean dynamic topography estimated by the inverse model (Fig. 4) captures the major fronts associated with the Gulf Stream system, the Azores Current, and the Loop Current in the Gulf of Mexico. A comparison of estimates of the circulation at 250 m depth based on the present climatology (Fig. 5a) and the Levitus climatology (Fig. 5b) shows that the present climatology better resolves the main currents and illustrates the benefit of using a mapping procedure that does not overly smooth property fields. This work is still under progress because problems in the continuity of the DWBC have been encountered south of 30°N.

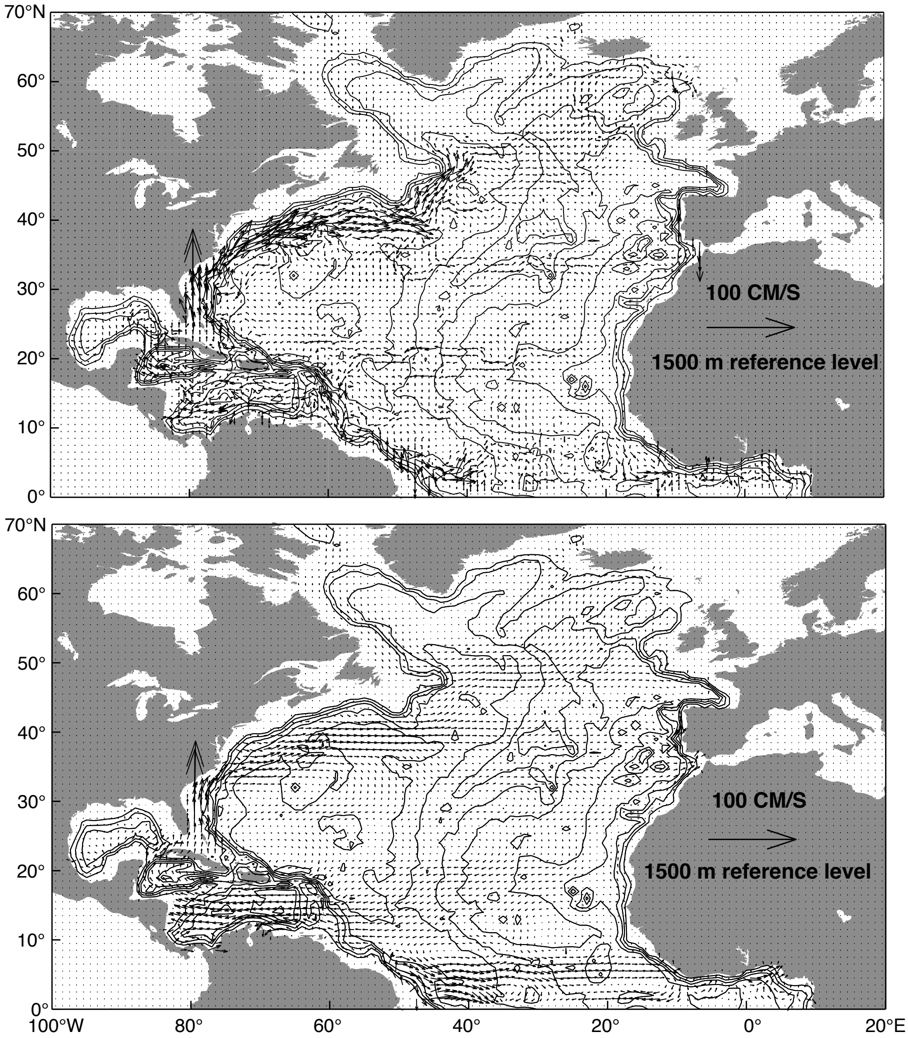

Figure 5. Current at 250 m from the inverse model. Contours indicate bathymetry at 1000 km intervals. Upper: New Climatology. Lower: Levitus et al., 1994.

Conclusion

This climatology has been produced for the needs of the French Clipper modelling experiment. A seasonal analysis has also been proceeded but large holes are found because of the seasonal data distribution which is very poor in some regions (e.g. July–September in the South Atlantic). The winter climatology (January–February–March) was chosen as the most reliable season for initialising the Clipper Experiment. The inverse calculation over the North-Atlantic domain is nearly completed.

Acknowledgements

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