A Comparison between the World Ocean Atlas and Hydrobase Climatology

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(Geophysical Research Letters, submitted July 10, 1999, revised January 31, 2000)

Abstract. The newly developed 1/4° World Ocean Atlas (WOA, Boyer and Levitus, 1998) is compared with the 1° WOA (Levitus et al., 1994) over the North Atlantic Ocean. The temperature and salinity fields from both the 1/4° and 1° WOA are projected on two isopycnal surfaces and compared with the Hydrobase climatology (Lozier et al., 1995). Geostrophic current maps diagnosed from hydrographic temperature and salinity are also presented. Results show that the 1/4° WOA, with a smaller smoothing radius, greatly improves the 1° WOA, particularly in describing the frontal features associated with the western boundary current and the mid-depth recirculation gyre. However, "anomalous anomalies" in the property fields created by the isobaric averaging are still evident in the 1/4° WOA.

1. Introduction

The World Ocean Atlas (WOA) compiled by Levitus (1982) provides a climatological description of the temperature and salinity fields over the global ocean. The later version of WOA (Levitus et al., 1994) included more data during recent years. Both WOA'82 and WOA'94 were computed on a $1^\circ \times 1^\circ$ horizontal grid at 33 isobaric surfaces, and used a 2-dimensional objective analysis method for the horizontal interpolation and smoothing along isobaric surfaces with an influence radius of 557 km. The gridded 1° WOA has been widely used in the ocean modeling community as initial and boundary conditions as well as a verification data set for model simulations.

In parallel to the development of WOA at isobaric surfaces, Lozier et al. (1995) recently compiled a hydrographic database (i.e., Hydrobase) over the North Atlantic Ocean at constant potential density (or isopycnal) surfaces. The advantage of averaging property fields on isopycnal surfaces is to preserve the temperature-salinity structures associated with a particular water mass. Hydrobase was computed on a 1°x1° horizontal grid and used an influence radius of 100 km, much smaller than the 557 km used by WOA'82 and WOA'94. A comparison between Hydrobase and the 1° WOA showed striking differences in the vicinity of the Gulf Stream (GS) and the North Atlantic Current: the fields in the 1° WOA appeared extremely smooth and many frontal features were broadened (Lozier et al., 1994). Furthermore, the isobaric averaging used in WOA created "anomalous anomalies" in temperature and salinity fields on certain isopycnal surfaces because the averaging process mixed surrounding waters with apparently different temperature-salinity characteristics (Lozier et al., 1994). However, the Levitus Atlas, with its global coverage, has the obvious advantage for model initializations and verifications, while the Hydrobase climatology is only available over the North Atlantic Ocean.

Recently, the WOA'94 was gridded with a finer resolution of $1/4^\circ$ and a smaller influence radius of 134 km (Boyer and Levitus, 1998). Both the 1° and $1/4^\circ$ WOA used the same data source (Levitus et al., 1994). The increased horizontal resolution and reduced spatial smoothing in the 1/4° WOA should result in improvements over the 1° WOA and reduce discrepancies with Hydrobase climatology. The objective of this letter is to provide a quantitative evaluation of the 1° and 1/4° WOA against Hydrobase. In what aspect is the 1/4° WOA significantly better than the 1° WOA? To what extent can the 1/4° WOA describe the sharp frontal features associated with the western boundary current and the mid-depth recirculation gyre? What are the remaining problems associated with the 1/4° WOA? In order to address these questions, we project the temperature and salinity fields onto two selected isopycnal surfaces. A three-way comparison is made among the 1° and 1/4° WOA and Hydrobase. Finally, the geostrophic current at 100 m as diagnosed from the 1° and 1/4° WOA temperature and salinity fields are presented.

2. Property Fields on Isopycnal Surfaces ($\sigma_0 = 26.50$ and $\sigma_2 = 36.95$)

The methodology used in the isopycnal analysis follows closely to that of Lozier et al. (1995): the property fields of temperature and salinity are projected onto constant potential density (σ) surfaces. Comparisons are made at two isopycnal surfaces among the 1° and 1/4° WOA and Hydrobase. Isopycnal surfaces of $\sigma_0 = 26.50$ and $\sigma_2 = 36.95$ are selected because they represent the near-surface and mid-depth circulation, respectively. The subscript for σ is the reference level, in db/1000.

Figure 1 shows the pressure and potential temperature on the $\sigma_0 = 26.50$ surface. The salinity fields tend to display similar spatial pattern as the temperature fields, henceforth are not shown here. The most prominent feature on this surface as seen in Hydrobase (Fig.1e, f) is the sharp gradients that extend eastward from Cape Hatteras and curve northward around the Tail of the Grand Banks. These gradients define the GS as well as the western and the northern boundaries of the subtropical gyre. Part of the subtropical gyre water circulates clockwise from north to south and returns westward to supply the Florida Current. Due to the coarse resolution and the heavy spatial smoothing in the 1° WOA (Fig.1a, b), the curvature of the GS is absent and the isobars intersect the coast near Cape Hatteras rather than skirt around it. The 1/4° WOA (Fig.1c, d) shows a substantial improvement over the 1° WOA and is in reasonably good agreement with Hydrobase (Fig.1e, f) in depicting frontal features associated with the Florida Current, the GS and the North Atlantic Current. However, the effect of isobaric averaging is still recognizable in the 1/4° WOA with a broader GS on the pressure map (Fig. 1c) when compared with Hydrobase (Fig. 1e).

In contrast to these sharp gradients associated with fronts, a large pool of homogeneous water can be found on this surface. This Eighteen Degree Water (Worthington, 1959) with uniform temperature (17.4-17.6°C) and salinity (36.4-36.5) is located west of the Mid-Atlantic Ridge. Another pool of homogeneous, called the Madeira Mode Water (Siedler et al., 1987), with 18°C and 36.5, is also found near 25°N and 25°W. These two water masses are identifiable in all three hydrographic data sets. The temperature map of the 1/4° WOA shows several discontinuous pools of the Madeira Mode Water. Given the fact that the 1/4° WOA used the 1° WOA as the initial guess in the objective analysis, we suspect that the limited data coverage and the reduced spatial smoothing are responsible for the noise in the 1/4° WOA.

Figure 2 shows the pressure fields on the potential density $\sigma_2 = 36.95$ surface, which is a representative surface to describe the mid-depth circulation. On this surface (see Fig. 2c) the GS turns toward northeast around the Tail of the Grand Banks becoming the North Atlantic Current. The subtropical waters carried by the GS and the North Atlantic Current are circulated back into the subtropical gyre, forming an anticyclonic recirculation gyre (as defined by the 2200 db contour). Imbedded within this large recirculation gyre are four distinct local recirculation cells separated by low pressure ridges that coincide with topographic features (Fig. 2c). The New England Seamount chain separates two local recirculations near 60°W. A second break in the large recirculation occurs at the southeast Newfoundland Rise, where there is a prominent saddle point in the pressure contours. The third separation occurs at 30°W along the axis of the Mid-Atlantic Ridge, where the local Newfoundland basin cell connects with the anticyclonic circulation east of the ridge. These individual cells link together forming the large recirculation gyre.

Although the large-scale mid-depth recirculation gyre is recognizable in the 1° WOA, its spatial extent is much too broad and the associated pressure gradient is significantly weaker than that in Hydrobase. Small-scale features such as those four local recirculation cells are smoothed out in the 1° WOA (Fig. 2a). The 1/4° WOA (Fig. 2b) resolves most features associated with the mid-depth recirculation as seen in Fig. 2c and described in Lozier (1997). In particular, the four local recirculation cells, which are missing in the 1° WOA, are now resolved in the 1/4° WOA. The northward retroflection of the Labrador Sea Water is also realistically described. However, at mid-depth around 2000 m, the analyzed fields in the 1/4° WOA appear more noisy and wrinkled than those in Hydrobase, presumably resulting from a combination of isobaric averaging, poor data coverage and the initial guess fields from the 1° WOA.

3. Absolute Geostrophic Current Maps

In order to contrast the difference in the flow fields associated with the 1° and 1/4° WOA, we diagnosed the absolute geostrophic current from the temperature and salinity. The method is based on the β-spiral method (Stommel and Schott, 1977) with modifications as described in Chu et al. (1998). The physical base of this method is the conservation of potential density and potential vorticity and there is no need to specify the reference level of no-motion (see Chu et al., 1998 for a detailed description of this method). Figure 3 shows the diagnosed current vector maps at 100 m for the 1° (a) and 1/4° (b) WOA, respectively. Clearly, those undesirable features in the 1° WOA associated with the isobaric averaging and a large influence radius are evident in the diagnosed current map (Fig. 3a). For example, there is a southward current north of the GS separation point. In contrast, the 1/4° WOA shows a very tight and continuous western boundary current (Fig. 3b). The Caribbean Current and the Loop Current in the Gulf of

Mexico which are absent in the 1° WOA are now evident in the 1/4° WOA. The GS core speed derived from the 1/4° WOA is 57 cm s^{-1}, which is much larger than that of 17 cm s^{-1} derived from the 1° WOA. It should be pointed out that the GS core speed derived from the 1/4° WOA is still significantly weaker than the observed speed, which is on the order of 100 cm s^{-1}.

Based on the absolute current fields, we computed the downstream volume transport associated with the GS. The GS path is defined by the 12°C isotherm intersecting 400 m isobath. The zonal and meridional velocities are projected onto the downstream and cross-stream velocities, which are then used for the volume transport calculation. Our computation shows that the GS transport derived from the 1/4° WOA is significantly larger, by almost 50%, than that from the 1° WOA.

4. Summary and Discussion

Our results show that one can significantly improve the 1° WOA by increasing the grid resolution and reducing the influence radius for spatial smoothing. The 1/4° WOA is significantly better than the 1° WOA in describing sharp frontal features associated with the western boundary current. It also provides a more accurate description of the mid-depth recirculation gyre. The four local recirculation cells, which are missing in the 1° WOA, are identifiable in the 1/4° WOA. The diagnosed current field from the 1/4° WOA shows a much more stronger and continuous western boundary current. The GS transport computed from the 1/4° WOA is almost 50% larger than that from the 1° WOA.

Despite the improvement of the 1/4° WOA over the 1° WOA, the "anomalous anomalies" as described in Lozier et al. (1994) and introduced by the isobaric averaging that mixes different water masses still exist in the 1/4° WOA. Another problem associated with the 1/4° WOA is the noise, which becomes more apparent in the deeper layers. This noise problem in the 1/4° WOA can be attributed to a combination of isobaric averaging, finer analysis grid, and the poor data coverage.

During the course of our study, another hydrographic climatology over the global ocean has been released (Gouretski and Jancke, 1998). The horizontal resolution of this database is 1°x1° and an influence radius of 500 km is used for the objective analysis. The property fields are first analyzed on neutral surfaces and then gridded onto 43 pressure levels similar as WOA. The accuracy of this new data set in comparison with $1/4^{\circ}$ WOA and Hydrobase remains to be determined. However, the results from the present study suggest that a 500 km spatial smoothing might broaden the sharp frontal features associated with the western boundary current and the mid-depth recirculation gyre, and further eliminate the mid-depth local recirculation cells.

Recently, the World Ocean Database (WOD, Levitus et al., 1998) has been released and contains significantly more data than WOA'94. Ideally, one should produce a gridded product along isopycnal surfaces as Hydrobase (Lozier et al., 1995). Progress has been made to produce a Hydrobase climatology over the North Pacific Ocean (A. MacDonald, 2000, personal communication). The production of a global Hydrobase is also being planned (R. Curry, 2000, personal communication). However, before the global Hydrobase climatology becomes available, the $1/4^{\circ}$ WOA should continue to provide the needed information for model initializations and verifications. The potential of using the diagnosed current fields (as shown in Fig. 3b) to initialize ocean models should also be explored in the future.

Acknowledgments. The research described here was carried out, in part, by the Jet Propulsion Laboratory, California Institute of Technology, under contract with National Aeronautics and Space Administration (NASA). Support from the NASA High Performance Computing and Communication (HPCC) program is also acknowledged. The authors wish to thank T. Boyer and S. Levitus for providing the $1/4^{\circ}$ WOA data, M. S. Lozier for providing the Hydrobase and software for the isopycnal analysis, and P. C. Chu for providing the modified β-spiral program to diagnose the geostrophic current. Discussions with J. C. McWilliams, and P. Niiler are also acknowledged.

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Figure Captions

Figure 1. Pressure and potential temperature on the σ_0 = ***26.50*** surface over the North Atlantic as derived from the 1° WOA (a, b), the 1/4° WOA (c, d), and Hydrobase (e, f). Contour intervals are 50 m and 1°C for pressure and potential temperature, respectively.

Figure 2. Pressure on the σ_2 = ***36.95*** surface over the North Atlantic as derived from the 1° WOA (a), the 1/4° WOA (b), and Hydrobase (c). The contour interval is 100 m, except 50 m between 2200 m and 2350 m.

Figure 3. Absolute geostrophic current maps at 100 m over the North Atlantic Ocean as derived from the 1° WOA (a) and 1/4° WOA'98 (b) temperature and salinity fields. The unit-length vectors of 17 cm s^{-1} and 57 cm s^{-1} are displayed for the 1° and 1/4° WOA, respectively.

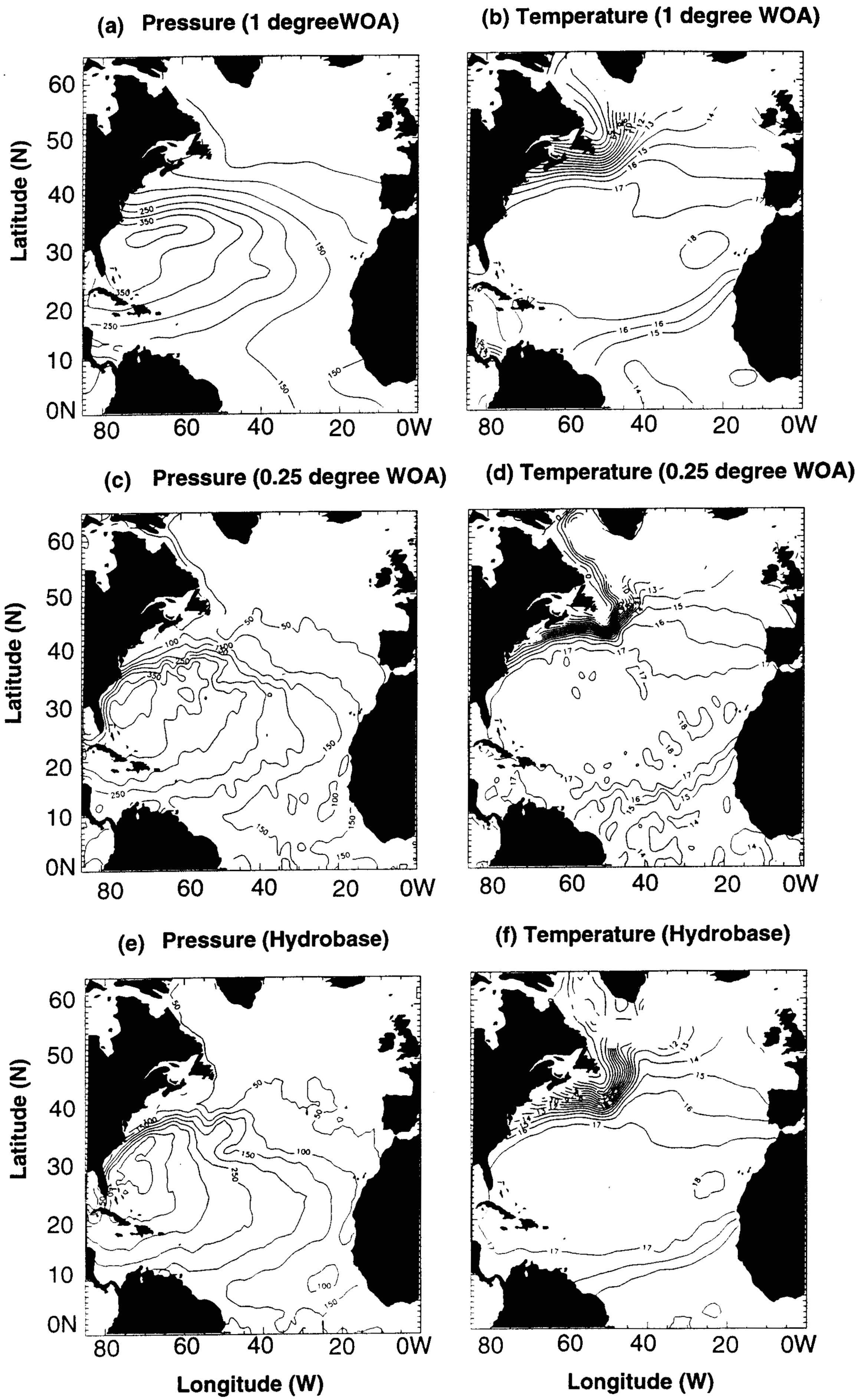

(a) Pressure (1 degreeWOA)
(b) Temperature (1 degree WOA)
(c) Pressure (0.25 degree WOA)
(d) Temperature (0.25 degree WOA)
(e) Pressure (Hydrobase)
(f) Temperature (Hydrobase)
Latitude (N)
60
50
40
30
20
10
0N
80
60
40
20
0W
Longitude (W)

Fig. 1

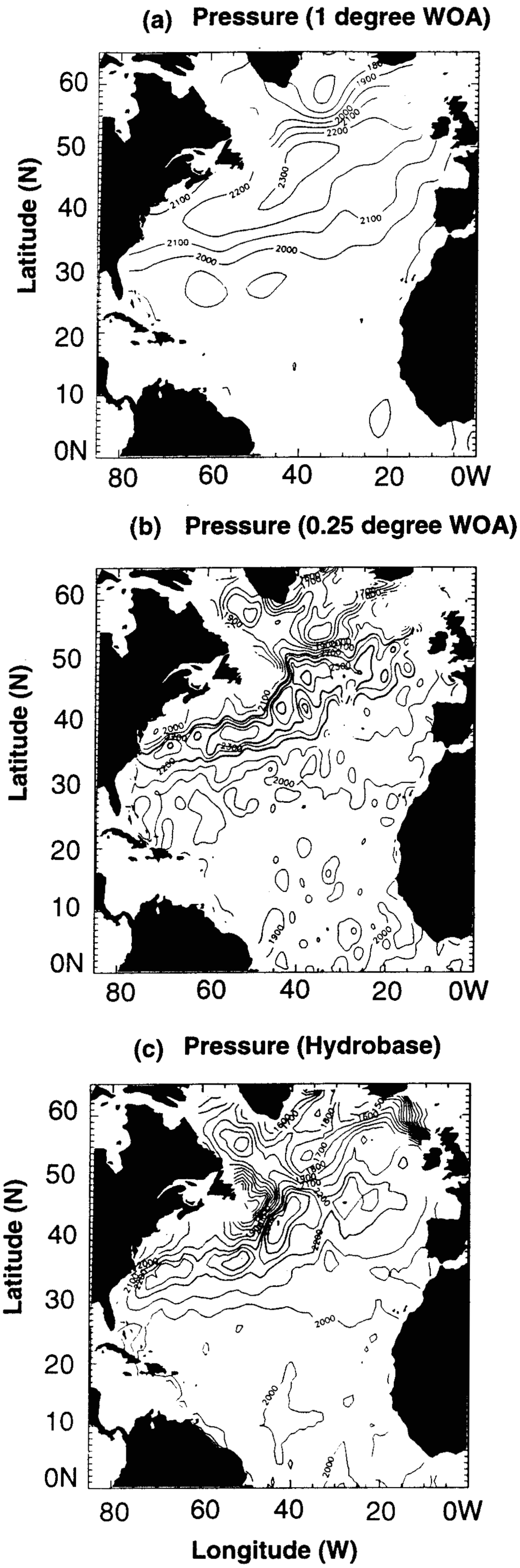
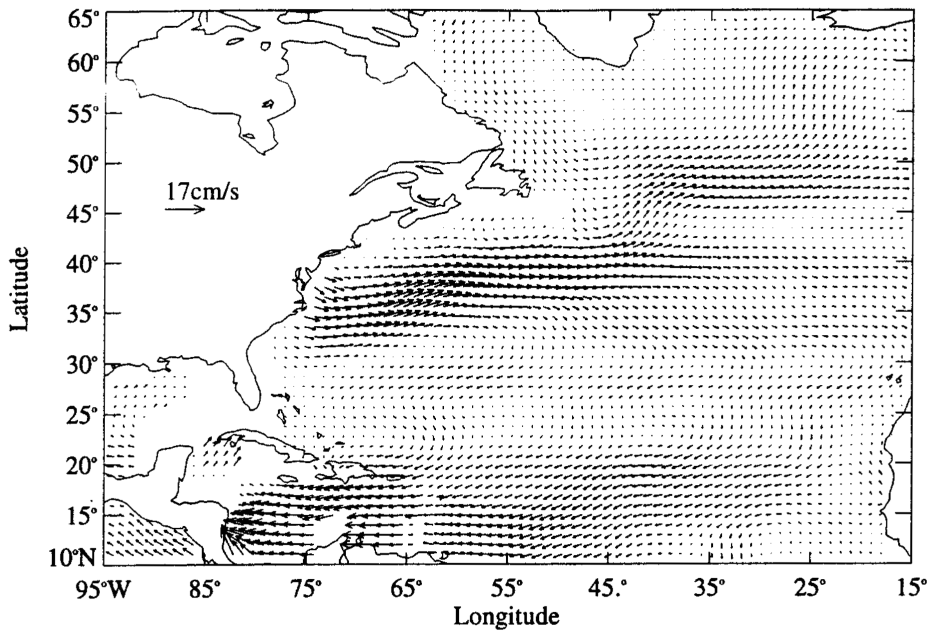

(a) Pressure (1 degree WOA)
(b) Pressure (0.25 degree WOA)
(c) Pressure (Hydrobase)
Latitude (N)
Longitude (W)
60
50
40
30
20
10
0N
80
60
40
20
0W
2300
2200
2100
2000
1900

Fig. 2

(a) Current at 100 meter (1 degree WOA).



(b) Current at 100 meter (0.25 degree WOA).

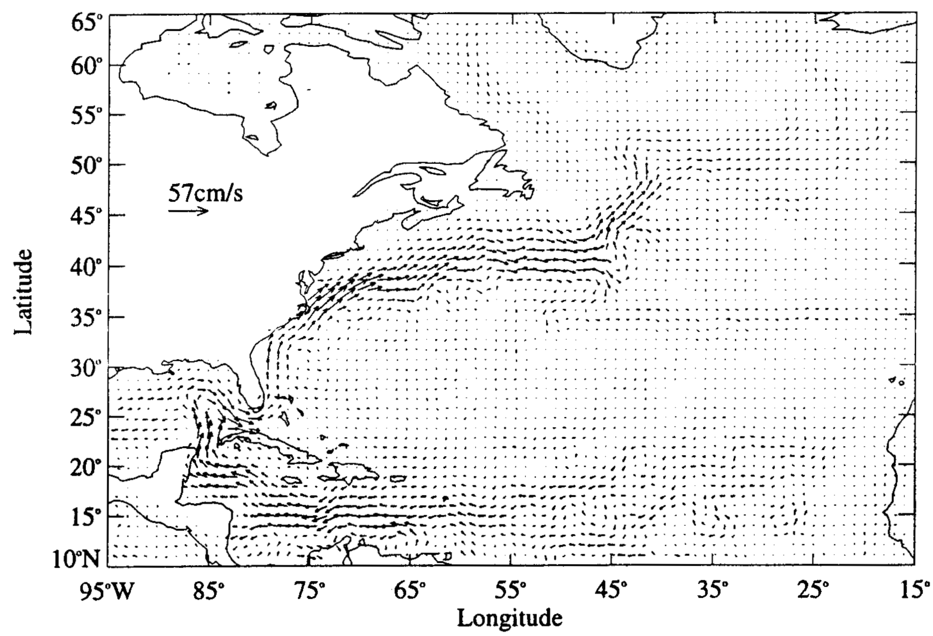


Fig. 3