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Theme Session O

Changes in the North Atlantic Overturning Circulation

by

Jens Meincke
Institut für Meereskunde, Troplowitzstr. 7, D-22529 Hamburg

Abstract

The Northern North Atlantic is the site of extreme interaction between the ocean and the atmosphere. Changes in atmospheric forcing pattern are rapidly transferred by convection into the ocean's interior and affect components of the North Atlantic Overturning Circulation. We present two examples of recent extremes in hydrographic conditions, which vary at decadal time scales: The cessation of convective deep water renewal in the Greenland Sea and the rapid spreading of new Labrador Sea Water, which has extremely low temperatures due to strong convection that started in 1988. The lesson from these observations are straightforward: Any longer term project in the Northern North Atlantic needs to be accompanied by a monitoring scheme which enables a continuous re-definition of its basic hydrographic state.

Introduction

The Northern North Atlantic is the site of extreme interaction between the ocean and the atmosphere. Northward transport of subtropical waters into the high Arctic allows a suite of processes to convert warm surface waters into different species of cold and saline waters and into ice. Whereas the latter eventually melts and flows southward as cold and fresh Surface Waters, the cold and saline species sink and spread southward as intermediate and deep waters (Fig. 1). This thermohaline driven circulation - The North Atlantic Overturning Circulation NAOC - is central to the oceans role in the climate system. For the hydrographic conditions in the North Atlantic this implies a rapid response of stratification and circulation to changes in surface forcing. This has been demonstrated for the outflow of Polar Surface Water in a paper by Dickson et al (1988) on the Great Salinity Anomaly. In the following we will demonstrate

the amplitudes and time-scales of such changes in the interior of the Northern North Atlantic on the example of two recent events:
The cessation of deep reaching convection in the Greenland Sea and the cooling of intermediate waters in the North Atlantic originating from enhanced convection in the Labrador Sea.

Cessation of deep convection in the Greenland Sea

The Greenland Sea is a component of the Nordic Seas / Arctic Ocean thermohaline system, where open ocean convection can reach down into deep and bottom layers, providing the cold and relatively fresh Greenland Sea Deep Water (GSDW, T $\simeq$ 1.25°C, S ~ 34.892).
Through Fram Strait the deep Greenland Sea is connected to the deep Arctic Ocean, where the warm and relatively saline Arctic Ocean Deep Water (AODW, T $\simeq$ 0.82, S ~ 34.93) is formed by slope convection (Rudels and Quadfasel, 1991). According to Meincke et al (1992), Meincke et al (subm.) and Dickson et al (subm.) the conditions for intense convection in the Greenland Sea have become increasingly unfavourable since 1980. Therefore in the deep Greenland Sea the balance between convective renewals of GSDW and advection of AODW has changed in favour of AODW, increasing temperature and salinity for the deep layers and certainly changing the water mass composition. Fig. 2 quantifies the variations in water mass properties and volumes for the period 1958 to 1993. The large signals are found at depths below 1500 m. The time varying balance between the convectively generated GSDW and the warm and saline deep waters (WSDW) advected from the Arctic Ocean are clearly seen from the anti-phase in their volumes. The changes in the deep water of the Greenland Sea radiate out into the Norwegian Sea, which Dickson et al (subm.) have examplified on coupled deep water temperature changes demonstrated in Fig. 3. The convective renewal of the layers above 1500 m, i.e. the formaton of cold and fresh Arctic Intermediate Water (CFAIW) provides the source waters for the overflow across the Greenland-Scotland ridge. The volume increase (Fig. 2) still indicates a healthy renewal. However, it should not be surprising if this changes, because of the changes in the deep thermohaline circulation internal to the Nordic Seas / Arctic Ocean may well affect the conditions for shallow and intermediate convection adversely..

Recent changes of water mass properties in the North Atlantic

With the framework of the World Ocean Circulation Experiment the two transatlantic sections shown in Fig. 4 were repeatedly run by German groups, the section across the Labrador Sea is a Canadian standard section. According to Fig. 1 the sections cut across all the relevant deep

NAOC-paths, including the open ocean convective system of the Labrador Sea. The low salinity Labrador Sea Water (LSW) is spreading along the paths shown in Fig. 4. Dickson et al (subm.) have identified a change in the convective state of the Labrador Sea in winter 1988, when it turned from low to high and has stayed high since then. Luckily enough, the northernmost section shown in Fig.4 meets the LSW branches several times. It has been taken up in 1991 and was since then repeated 5 times (the last coverage was in August 1996). Fig. 5 shows the distribution of salinity, with the major water masses relevant to the NAOC indicated. Changes of this distribution are given in Figs. 6-8, based on differences observed betwen 1991 and 1995. This period was chosen, because it took until 1995 that the by far strongest signal on the section - the changes in LSW which had started 1988 in the Labrador Sea - has reached the European continental slope.

Sy et al (subm.) and Rhein et al (subm.) have analysed the LSW-spreading in detail and conclude: (i) The LSW-spreading across the North Atlantic was 2-3 times faster in the 90's than previous estimates by Read and Gould (1992) for an earlier event in the 70's (7 years compared to 18 years). (ii) The dominant changes in the LSW were cooling and deepening, as evident from Figs. 7 and 8. (iii) The LSW-changes are a demonstration of how rapid a change of the regional windstress curl over the Labrador Sea, which Dickson et al (subm.) have found to initiate the 1988 convection event, alters the water mass structure in the interior North Atlantic.

There are further significant changes seen from the repeat section, which relate to the NAOC: Figs. 7 and 8 show the upper layers of Subpolar Mode Water to be less saline in 1995 than in 1991. This is also true for the Denmark Strait Overflow and for the Iceland Scotland Overflow. Unlike the changes of the LSW we have no information on the causes for the observed changes in the upper layers and the overflows. For the upper layers we cannot distinguish between changes due to advection or air-sea interaction, for the overflows we have no further information on the relative significance of changes in source water properties versus entrainment along the spreading paths.

Summary and Conclusions

With respect to the NAOC we can summarize the foregoing examples as follows:
In our present decade the Nordic Seas experience a period of weakening convection, which has ceased to renew the deep waters, but which is still active enough to ventilate the upper and

intermediate layers for the supply of the overflows across the Greenland-Scotland sill. In contrast to the Nordic Seas the Labrador Sea experiences a period of enhanced convection, supplying colder and denser water to intermediate levels and thus changing the water mass structure in the North Atlantic. The time scale of these changes is the order of 10 years or less.

Dickson et al (subm.) have discussed the timing of these changes in more detail and could relate it to regional atmospheric forcing, which was found to be coupled to the North Atlantic oscillation index (the difference in atmospheric pressure between the Azores and Iceland). This discussion is not repeated here, but its results are used for the conclusions relevant to the topic of the theme session:

- The atmospheric forcing over the North Atlantic differs in space and time such, that - via the rapid convective downward transfer into the ocean's interior - different components of the NAOC are at different stages of activity in a particular period.

- As a consequence, field work related to process studies in the Northern North Atlantic has to be completed within a period much shorter than a decade to ensure a quasi-stationary physical environment.

- From the experience of projects like WOCE in the North Atlantic any longer term studies like GLOBEC need to be supported by a monitoring scheme. Ongoing planning for CLIVAR-GOOS should be drawn into the preparations and analysis of GLOBEC.

References

Bersch, M. (1995): On the circulation of the northeastern North Atlantic. Deep-Sea Res., 42, 9, 1583-1607

Dickson, R.R., J. Lazier, J. Meincke, P. Rhines, J.H. Swift: Long-term coordinated changes in the convective activity of the North Atlantic. Sub. to Progr. Oceanogr.

Dickson, R.R., J. Meincke, S.-A. Malmberg, A.J. Lee (1988): The "Great Salinity Anomaly" in the northern North Atlantic 1968-1982. Progr. Oceanogr., 20, 103-151

Fahrbach, E., J. Meincke : The global ocean circulation. In: Landolt-Börnstein, New Ser., V36, Springer 1986

Meincke, J., S. Jónsson, J.H. Swift (1992): Variability of convective conditions in the Greenland Seas, ICES mar. Sci. Symp., 195, 32-29

Meincke, J., B. Rudels, H. Friedrich: The Arctic Ocean - Nordic Seas Thermohaline System. Subm. to ICES Journ. of Mar. Systems

Østerhus, S., T. Gammelsrød and R. Hogstad: Ocean Weather Ship Staion M (pers. com.)

Read, J.F., W.J. Gould (1991): Cooling and freshening of the subpolar North Atlantic since the 1960's, Nature, 360, 55-57

Rhein, M., A. Sy, A. Putzka, J. Lazier: Time scales of LSW-spreading in the subpolar North Atlantic. Subm. to Nature

Rudels, B., D. Quadfasel (1991): Convection and deep water formation in the Arctic Ocean - Greenland Sea System. J. Mar. Systems, 2, 435-450

Sy, A., J. Lazier, K.P. Koltermann, J. Meincke, U. Paul, M. Bersch: Suprisingly rapid cooling of the intermediate layer in the North Atlantic Ocean. Subm. to Nature

Legend to Figure

Fig.1 Geographical distribution of two components of the North Atlantic Overturning Circulation: The convective regimes and the deep spreading paths. For abbreviations see text. From Fahrbach and Meincke, 1986

Fig. 2 Averages of temperature (T), salinity (S) and volume (V) for water masses of the Greeland Basin from winter '58 (W58) to winter '93 (W93). The water masses are

CFAIW:	Cold and Fresh Arctic Intermediate Water
WSDW:	Warm and Saline Deep Water
GSDW:	Greenland Sea Deep Water

Fig. 3 Time series of smoothed monthly mean temperature in 2000m depth at OWS"M" in the Norwegian Sea (upper curve) and mean temperature between 2000m and the bottom in the central Greenland Sea (lower curve). After Østerhus, Gammelsrød and Hogstad.

Fig. 4 The location of repeat-sections and generalized spreading paths of Labrador Sea Water. Letters denote basin names. From Sy et al, subm.

Fig. 5 Salinity distribution along the section between Greenland and Ireland (see Figure 4). The major water masses are denoted

SPMW: Subpolar Mode Water	LSW: Labrador Sea Water
ISOW: Iceland-Scotland Overflow Water	DSOW: Denmark Strait Overflow Water

After Bersch, 1995

Fig. 6 Salinity difference 1995-1991 along the northern section shown in Fig. 4.

Fig. 7 Longitudinal distribution of differences 1995-1991 of LSW core properties depth, potential temperature, salinity and density. Longitudinal means inserted.

Fig. 8 Basin mean TS diagrams for Sept. 1991 and June 1995.
a) Irminger Basin b) Basins east of Mid-Atlantic Ridge

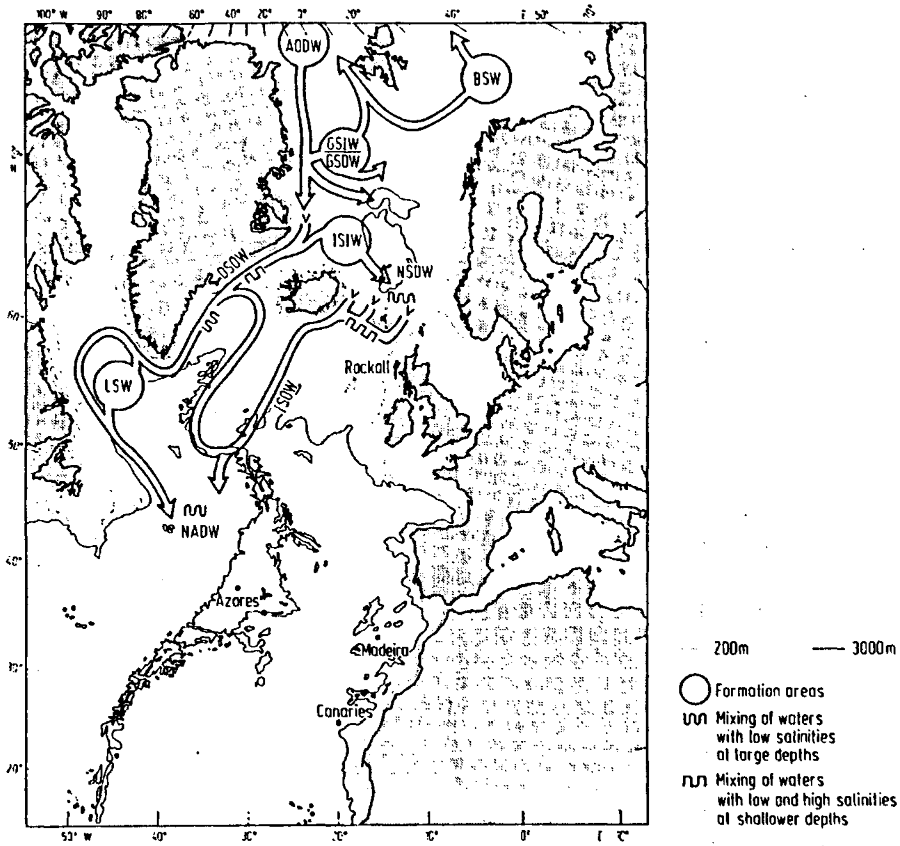
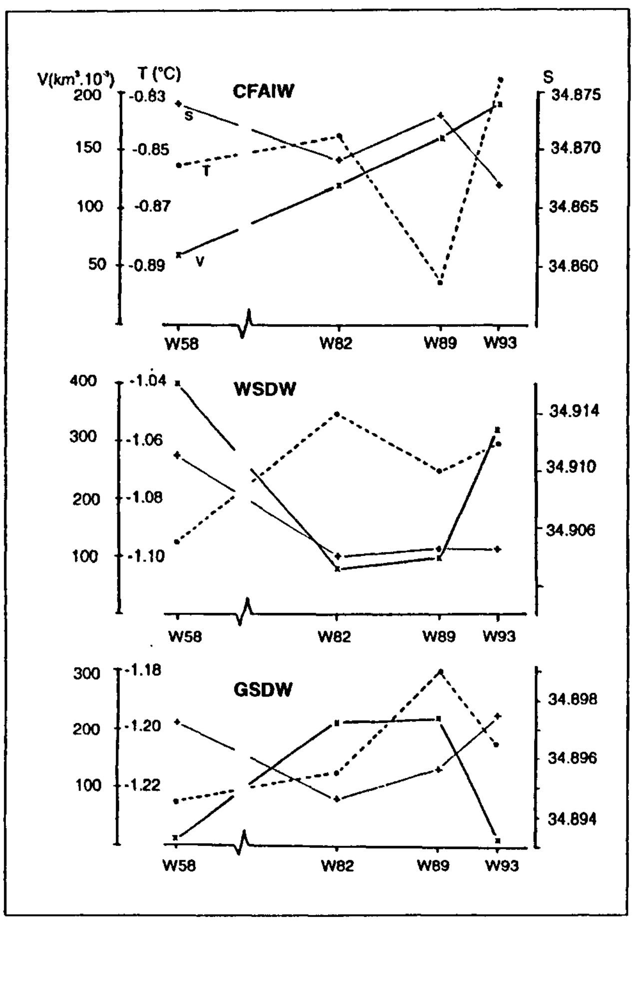


Figure 1



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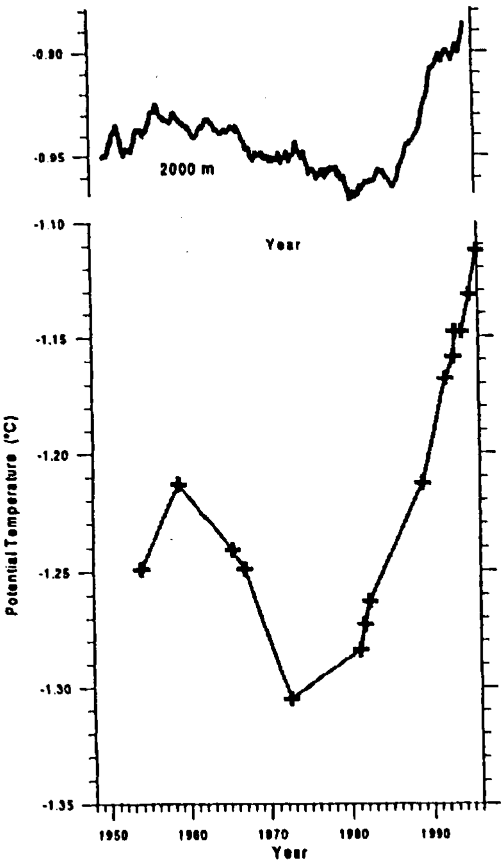

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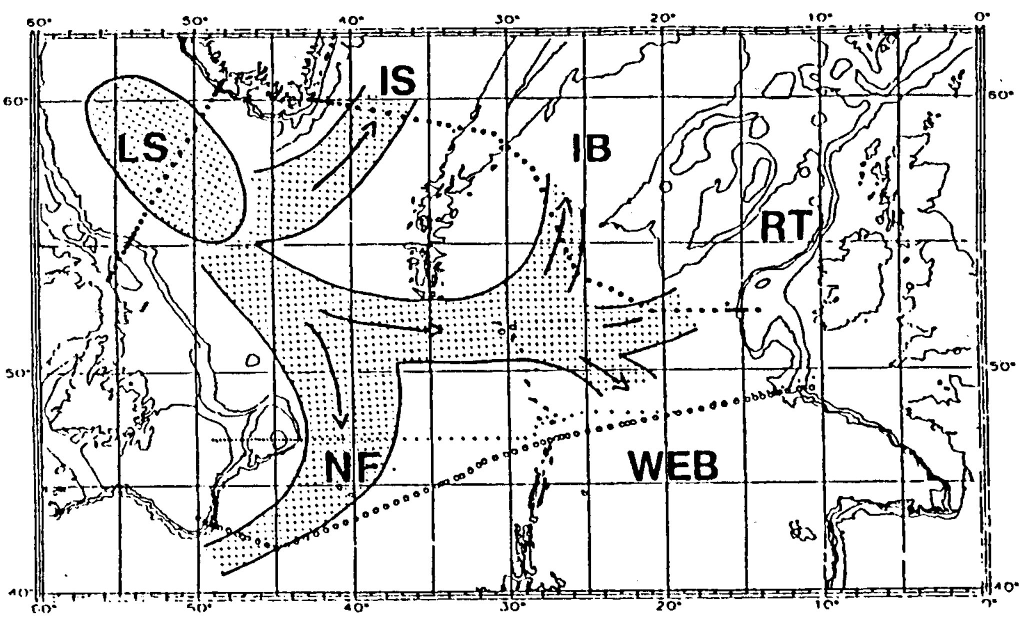


Figure 4

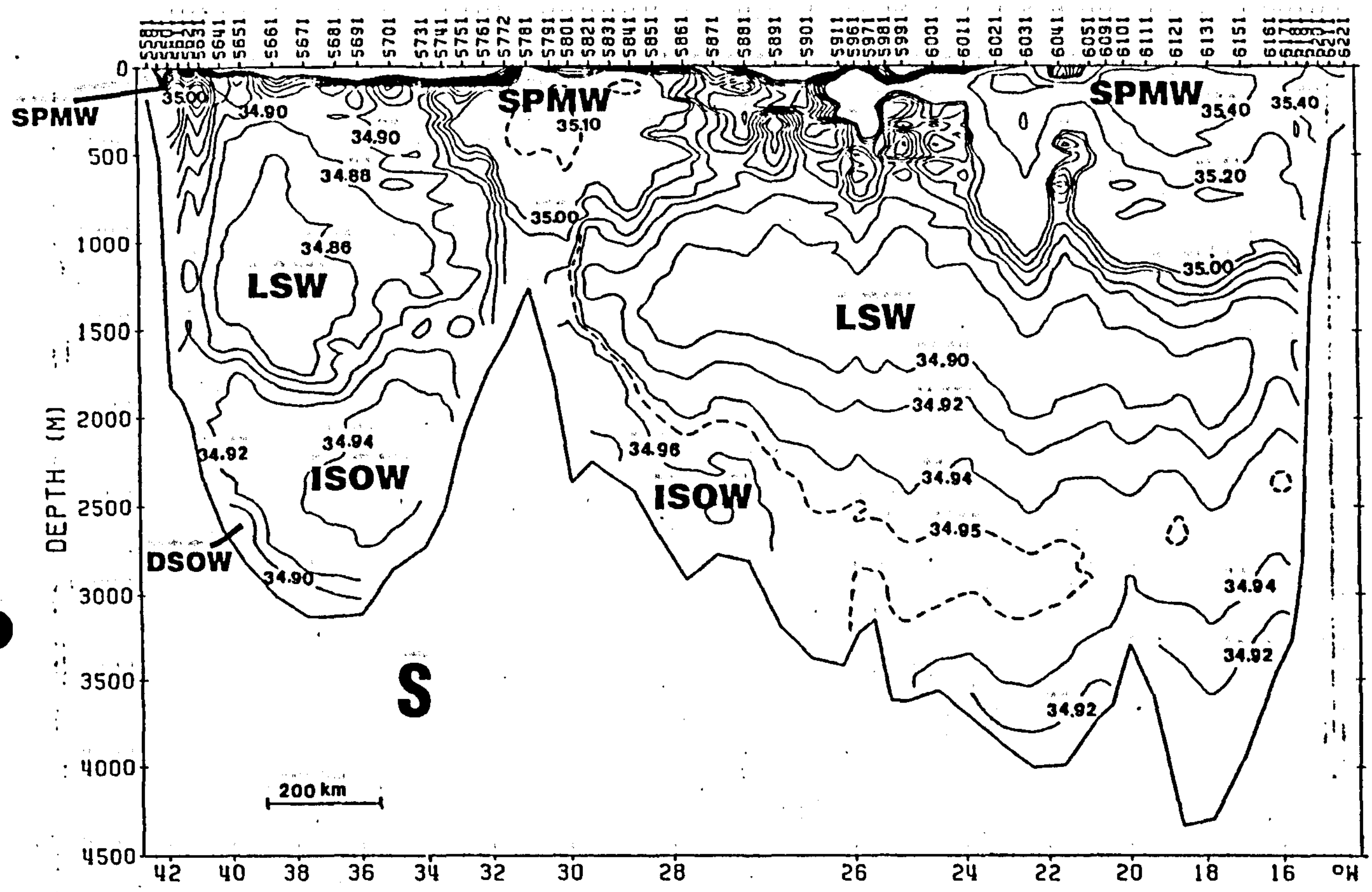
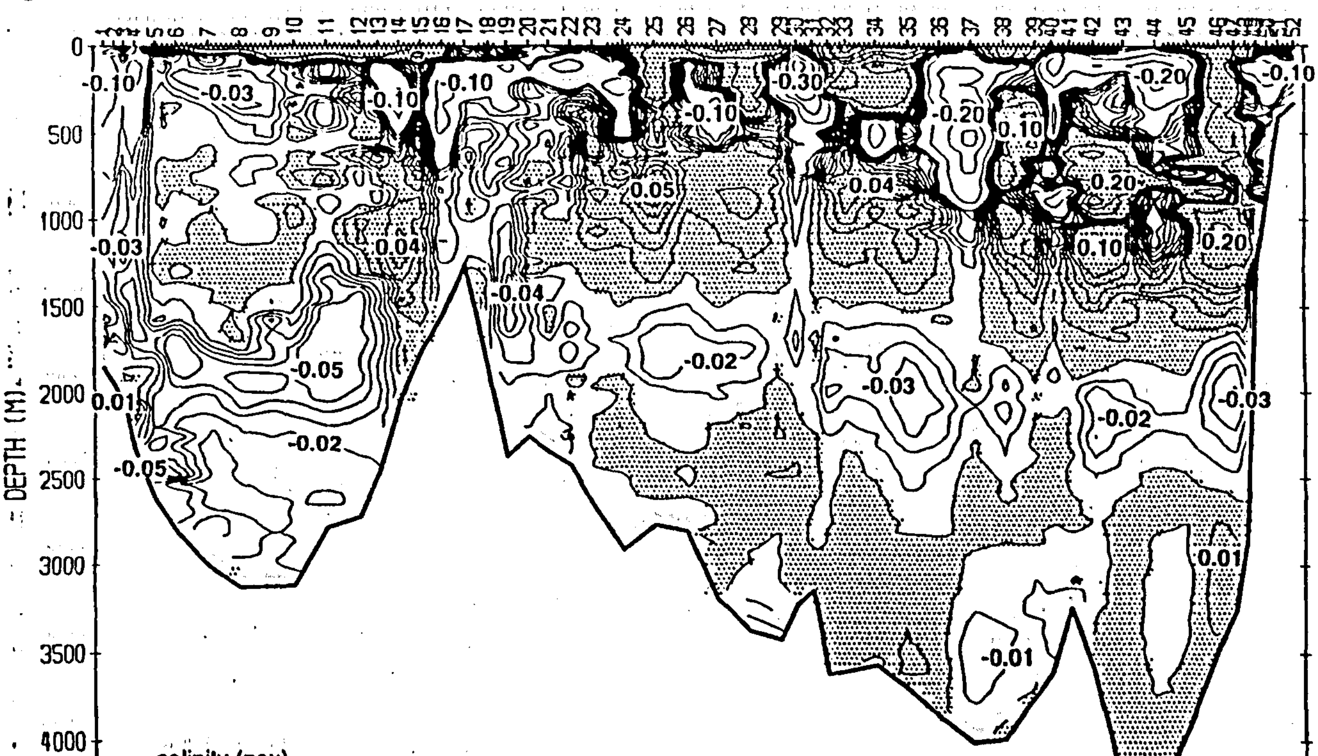


Figure 5



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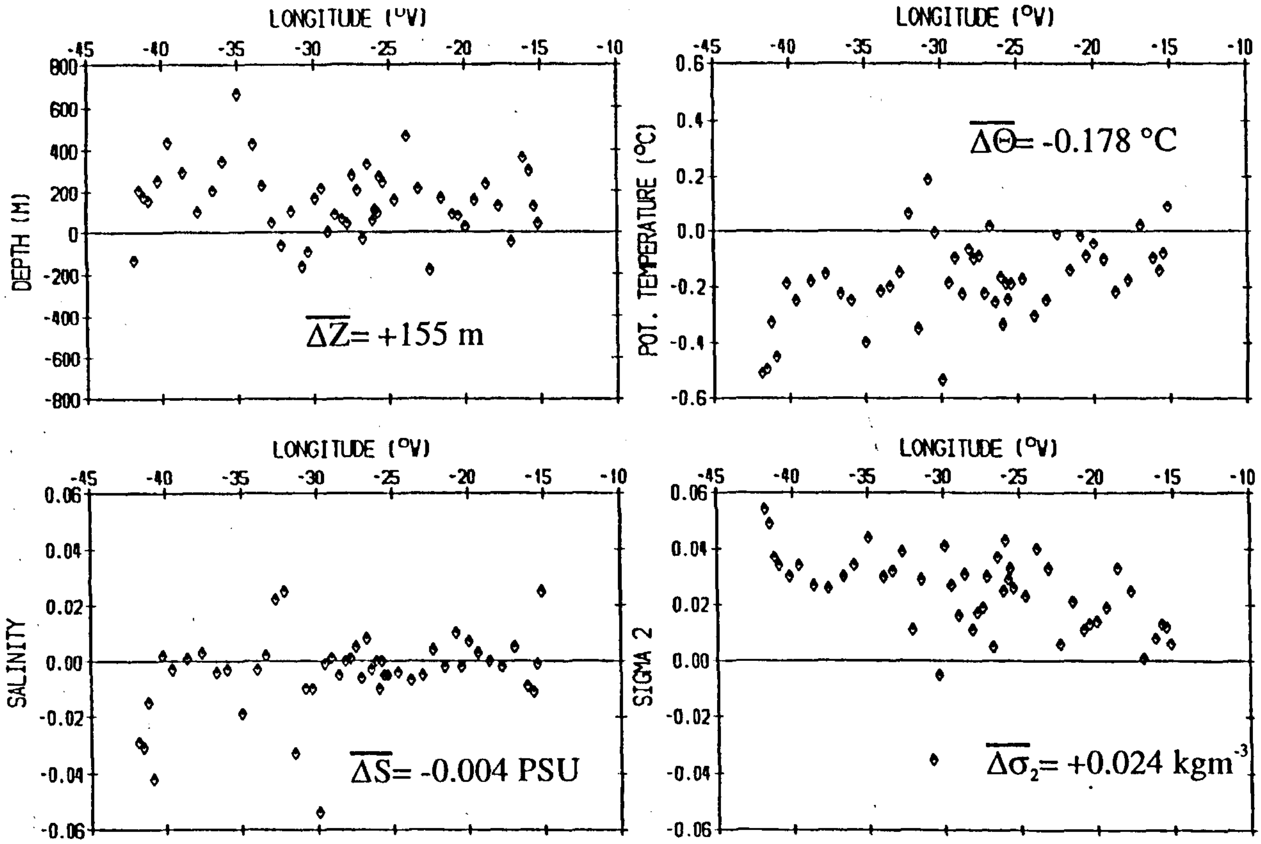

Figure 7

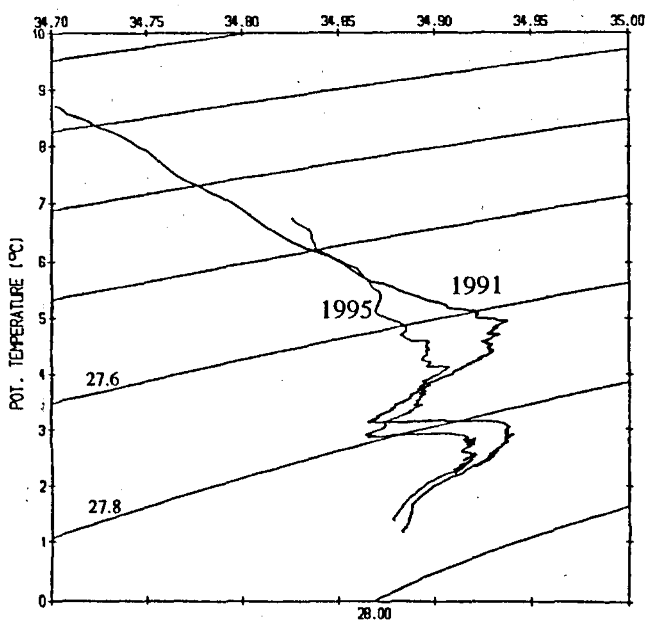

Figure 8a

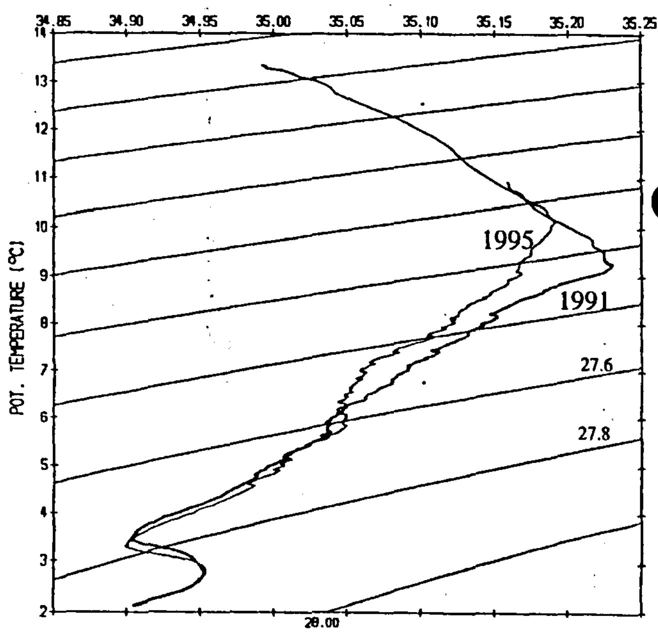

Figure 8b