because interesting additional information to the seismic records can be expected.

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Winter Convection Continues in the Warming Southern Adriatic

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During winters in the eastern Mediterranean, cold winds blow over the waters of the southern portion of the Adriatic Sea, resulting in heat loss of the ocean. This cold surface water becomes denser than surrounding waters and sinks into the deep reaches of the Mediterranean Sea. This forms 'deep water,' or water once at the ocean's surface that now has sunk to depths of 1500 meters and more. The Southern Adriatic Pit (SAP) is the convection site and source for the Eastern Mediterranean Deep Water (EMDW). Since the late 1980s, the SAP has been monitored almost every year because of its importance in driving the eastern Mediterranean deep circulation convection cell.

BY G. CIVITARESE, M. GAČIĆ, V. CARDIN, AND V. IBELLO

This article presents data from a 26 March – 8 April 2005 oceanographic cruise that shows the occurrence of deep convection in this area down to a depth of 800 meters. The article indicates that in the last decade, the water entering the Southern Adriatic from the rest of the eastern Mediterranean has been getting warmer, causing buoyancy to increase.

This increase in buoyancy could play a major role in depressing this convection when the heat loss is limited, such as in mild winters. Indeed, convection did not occur every year during the time span considered in this paper (between 1997 to 2005). However, this study documents that, despite the increase of buoyancy, convection did occur in some winters. The fact that the winter convection continues to take place although the waters are more buoyant suggests a remarkable sensitivity of the SAP to the climatic regime of the area.

Winter Convection in the Southern Adriatic Pit

In the eastern Mediterranean, the southern Adriatic plays a major role in producing new dense waters (Figure 1b). In the center of the SAP (1200 meters deep), winter convection and dense water formation take place. This process is the result of outbreaks of cold continental air from the Balkan Peninsula taking heat from the sea surface layer through cooling and evaporation, and causing movement through the water column in the center of a gyre that rotates counter-clockwise. The movement of this gyre along the ocean floor is governed by bathymetry.

This winter convection rarely reaches the bottom of the sea, varies on a year-to-year

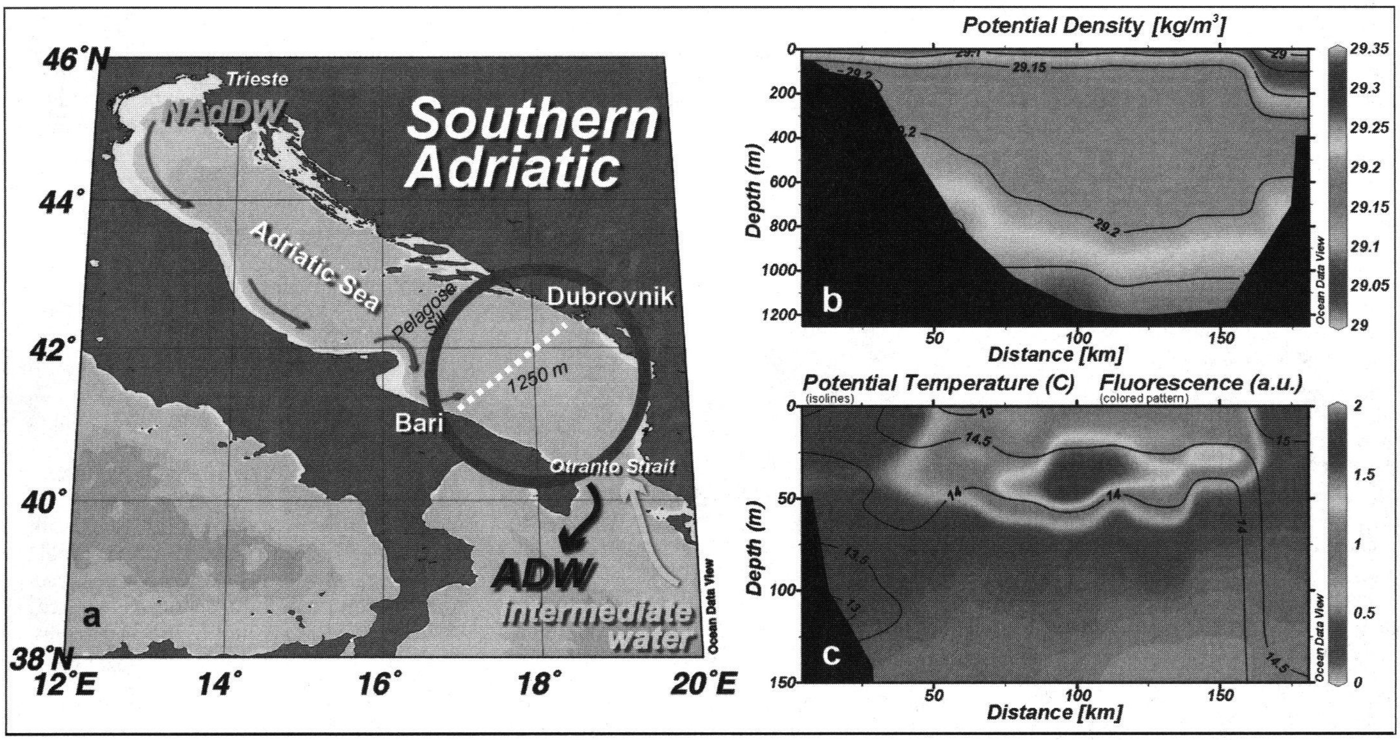

Fig. 1. (a) The winter convection taking place in the Southern Adriatic converts the intermediate water of eastern Mediterranean origin and the local surface water into the Adriatic Dense Water, which feeds the thermohaline cell of the eastern Mediterranean. (b) The potential density distribution along the Bari-Dubrovnik transect on 31 March 2005 shows the homogeneity of the water column down to a depth of 800 meters, indicating the vertical convective mixing prior to the cruise. (c) Fluorescence distribution exhibits a large subsurface maximum that corresponds with the satellite chlorophyll maximum patch.

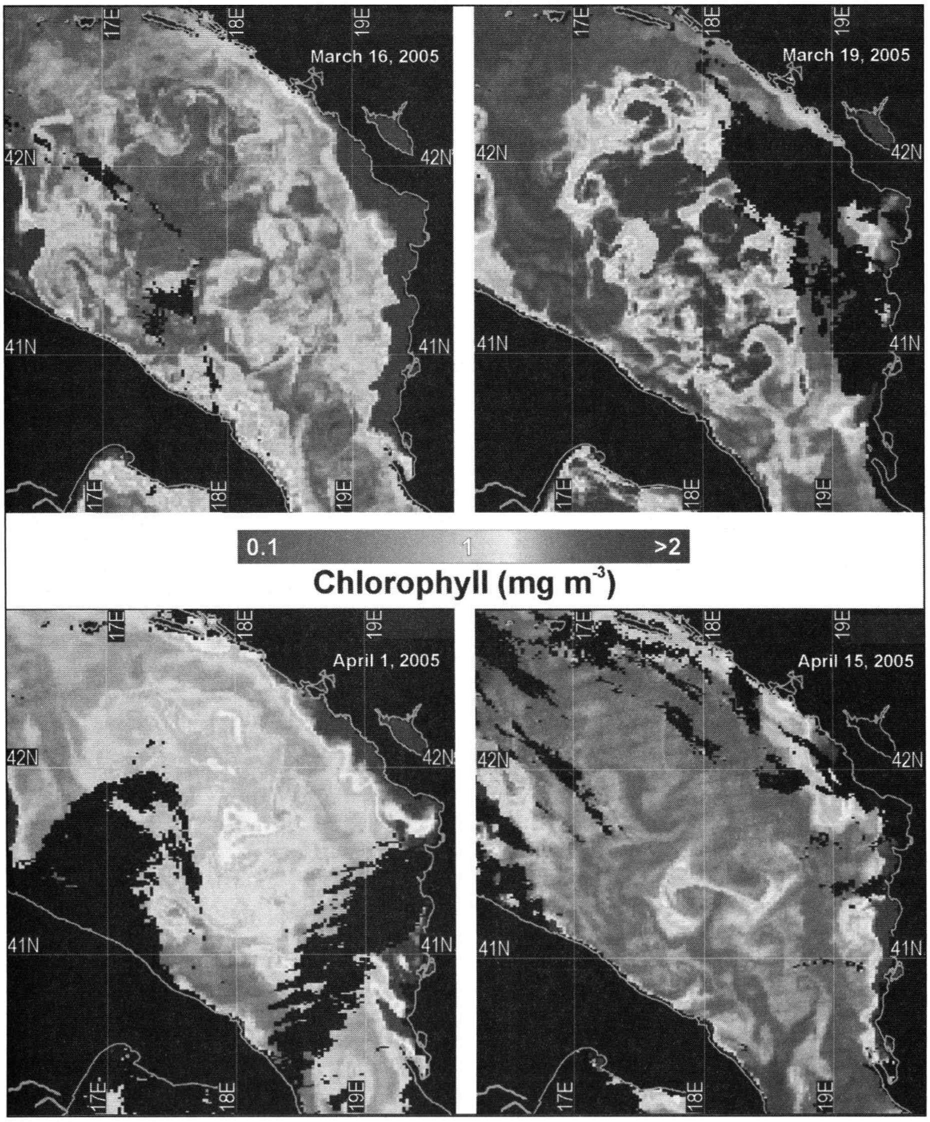

Fig. 2. Spring phytoplankton bloom evolution during the 2005 convective event as seen by MODIS chlorophyll data.

basis, and depends mainly on local climatic conditions, such as the number of outbreaks of continental air from the Balkans, their duration, and their intensity. This convection is also partly determined by the initial vertical stability of the water column, which is dependent upon the inflow of the saltier, warmer, and nutrient-rich intermediate waters from the eastern Mediterranean.

Nevertheless, winter convective mixing almost regularly erodes the deeper nutrient-rich layer and brings nutrients into the upper layer that is illuminated by sunlight. This in turn triggers a spring phytoplankton bloom, which occurs in the center of the mixed patch of water after the mixing ends and the surface layer restratifies.

Thus, the functioning and the efficiency of the biological pump in the SAP—the process of surface organic carbon production and its subsequent transfer to deeper parts of the water column and ultimately to bottom sediments—is determined by the characteristics of the winter convective mixing, such as its vertical extent, energy, and number of episodes [*Gačić et al.*, 2002].

In the past 20 years, more regular SAP monitoring activity has enabled a detailed comprehension of the decadal variability in the seawater properties and of the biological pump in this region [*Civitarese and Gačić* 2001; *Klein et al.*, 2000; *Gačić et al.*, 2002].

Satellite Images and the 2005 Post-Convection Cruise

On 30–31 March 2005, an oceanographic cruise took place on the Italian research vessel *Urania* as a part of the long-term monitoring activities in the SAP. The cruise was timed to occur after seasonal convection ceased. Field work consisted of measuring temperature and salinity and sampling water for nutrients, dissolved oxygen, suspended matter, and chlorophyll. The locations of sampling stations were decided on the basis of the available Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite chlorophyll images prior to the cruise.

The sequence of remotely-sensed chlorophyll concentration maps in Figure 2 shows the evolution of the surface signature of the phytoplankton distribution as the convection evolved. The first image (16 March) shows the minimum level of chlorophyll content found within the surface signature of the vertically mixed water column due to violent mixing of the water layers. At this time, the patch is in its mature phase, as suggested by the presence of four intermediate cyclonic eddies, approximately 30 kilometers in diameter, that had formed along the boundaries of the patch. These eddies contribute to the restratification of the water by exchanging the buoyancy between the mixed patch and the surrounding waters.

The second image (19 March), taken three days later, shows similar patch structure, but this time a maximum of chlorophyll concentration is found within the patch. This pattern clearly implies that a phytoplankton bloom has taken place in the patch after the surface layer had been fertilized with nutrients from deeper water layers, but that this bloom occurred only when there were calm weather conditions and mixing ceased.

A week later (1 April), the chlorophyll concentrations had decreased by a large extent, although the patch was still evident. By 15 April, the surface chlorophyll signature had completely disappeared.

Sampling was carried out along a commonly travelled transect from Bari, Italy, to Dubrovnik, Croatia, allowing the research team to compare the data they collected with results from other cruises. The Bari-Dubrovnik transect (Figure 1a) crosses the SAP close to the area of maximum chlorophyll concentrations, according to satellite data, and, therefore, presumably close to the center of the deep convection patch. Some transects at and north of the Pelagosa Sill, at the break of the Adriatic continental shelf, were also sampled in order to seek for a possible northern Adriatic contribution to the Adriatic Dense Water (ADW).

The in situ sampling was carried out on 30 and 31 March, between the time of peak chlorophyll concentration (19 March) and the time when the situation could still be characterized by its weakened but still evident surface signature (1 April). Thus, the distribution of the oceanographic properties, along the transect that passed through the area delimited by the maximum chlorophyll concentrations, is good evidence of the vertical and horizontal extension of the convective patch. Vertical convection seems to have reached a depth of 800 meters, as suggested by the vertical density distribution (Figure 1b). The subsurface maximum of fluorescence (Figure 1c) that occupies the center of the SAP agrees with the MODIS surface chlorophyll pattern.

Interannual Variations of Thermohaline Properties

The most striking feature revealed by this cruise is the high salinity (>38.8) and rather high temperature (>13.6°C) of the vertically mixed portion of the basin. Since 1997, when

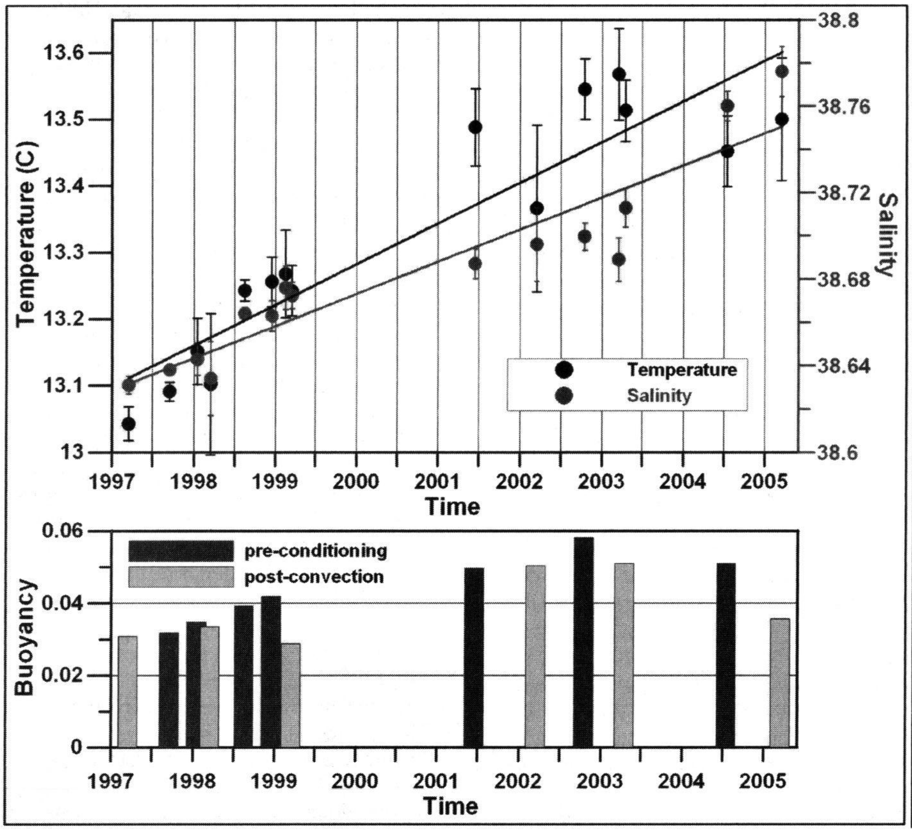

Fig. 3. The top panel shows time series of potential temperature (black dots) and salinity (red dots) averaged over the water column below 200 meters for stations deeper than 800 meters, which was obtained from all available in situ data from the central portion of the Southern Adriatic Pit. The trend of increase in both temperature and salinity is approximated with a linear regression fit. The bottom panel shows a time series of the buoyancy content in the water column. On the interannual basis, an increase in the preconditioning buoyancy content due to prevailing temperature influence is evident.

the Adriatic was reactivated as the source of EMDW, a continuous increase in temperature and salinity of the water has occurred. The temperature data for 2005 show a slight decrease, but the rise in salinity is consistent with the increases that have been evident since 1997 (Figure 3).

The increase in salinity had been considered an essential ingredient for the Adriatic Sea to once again become the source of the EMDW in the late 1990s [*Klein et al.*, 2002]. However, this would be plausible only if the increase in salinity reduces the buoyancy content. But, on the contrary, the preconditioning buoyancy increase took place until 2003, although both salinity and temperature have also increased during this time (Figure 3). Thus, the maintenance of the role of the Adriatic Sea as the EMDW source should require more intense air-sea heat losses, implying the occurrence of more severe winters since 1997.

In 2004, the increase in the preconditioning buoyancy content seems to have slowed down, though the data available (July 2004) could be considered prior to the real preconditioning phase, which is usually thought to occur in autumn. Thus, with the possible exception of this past winter, since the 1980s the air-sea heat fluxes have played a more important role—compared with the characteristics of the water flowing in from the eastern Mediterranean—in determining the occurrence and the intensity of the convection in the SAP.

Further continuous observations in the area could show the importance of the interplay between the preconditioning buoyancy content and air-sea heat fluxes. This could possibly contribute to a better understanding of the functioning of the convective sites and their interaction with the climate.

Acknowledgments

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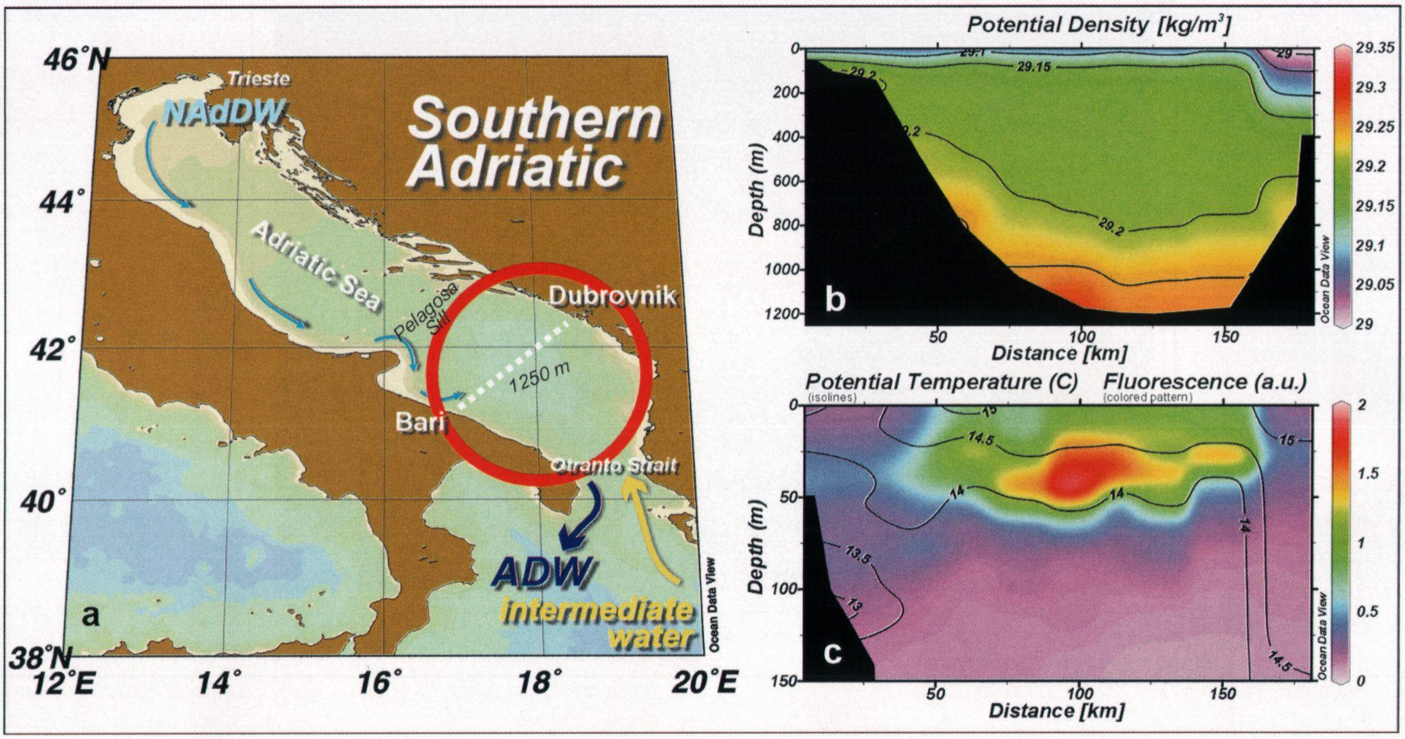

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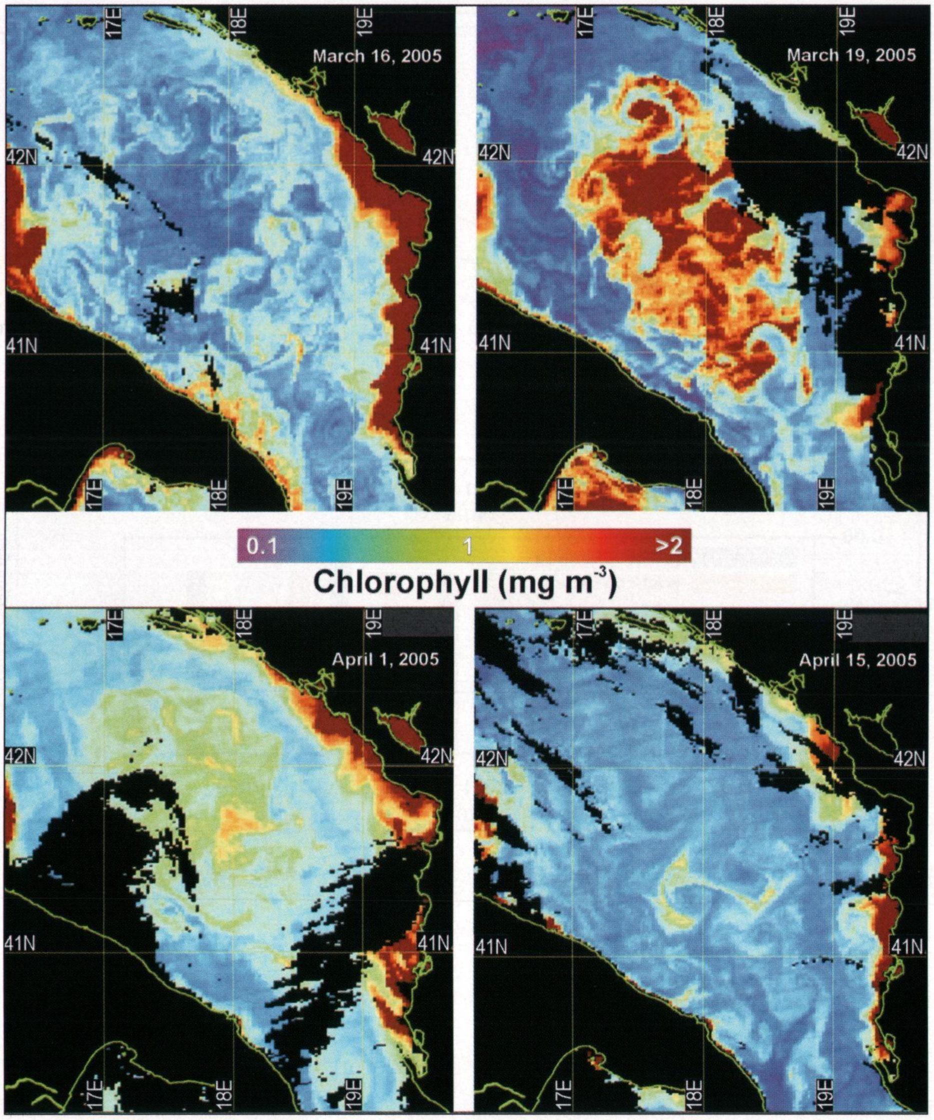

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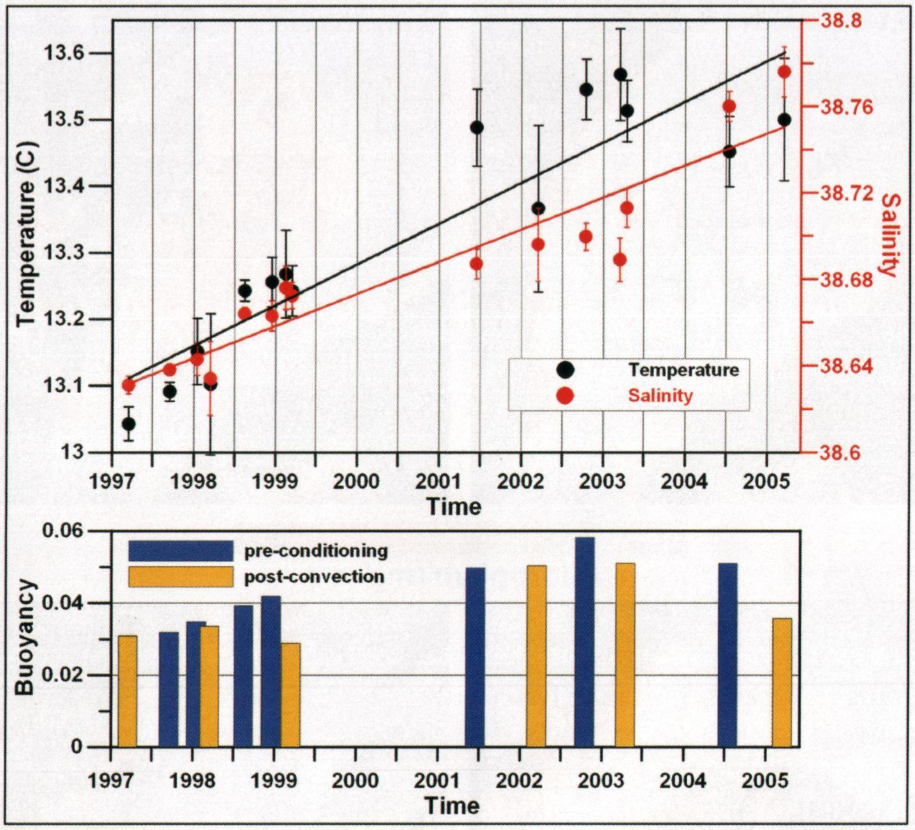

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