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# Time and space evolution of Levantine Intermediate Water in the Otranto Strait area: a 3D graphical visualization

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**Abstract.** The time and space evolution of the Levantine Intermediate Water (LIW) in the area of the Strait of Otranto during the period 1994-1995 is shown by means of a graphical interpolation and display technique. The study reveals both a seasonal and an interannual variability which appears in the LIW volume, position and salinity maximum. Comparisons were also made with data measured in the same area during some POEM cruises performed in the period 1985-1987.

## 1. Introduction

The Otranto Strait connects the Adriatic Sea with the Ionian, and consequently with the entire Mediterranean Sea, and therefore plays an important role in the water exchange between the two basins, as revealed by the results of studies performed in the recent past (Wust, 1961; Ovchinnikov, 1966; Zore-Armanda, 1969, Orlić et al., 1992). However, as these studies were rather more occasional than systematic, a more intense and detailed study (Otranto Project) was recently carried out over the area, with 6 seasonal oceanographic cruises over 15 months, and about 20 months of Eulerian current measurements using instruments moored at 4 to 6 stations across the strait.

The main results are reported by Gačić et al. (1996); however a brief description of the water masses properties in the area will be given here.

In the surface layer the flow through the strait appears to be subject to seasonal fluctuations due to both meteorological factors and thermohaline differences between the Adriatic and Ionian Surface Waters (ASW and ISW). In winter, when the Adriatic waters are denser than the Ionian ones, and south-easterly winds prevail over the region, an inflow (into the Adriatic) of ISW occurs along the Albanian coast and in the central part of the strait, while an outflow of ASW is found along the western side. In summer, when the meteo-oceanographic conditions reverse, outflow predominates along the Italian coast and in the central part of the strait, while the ISW

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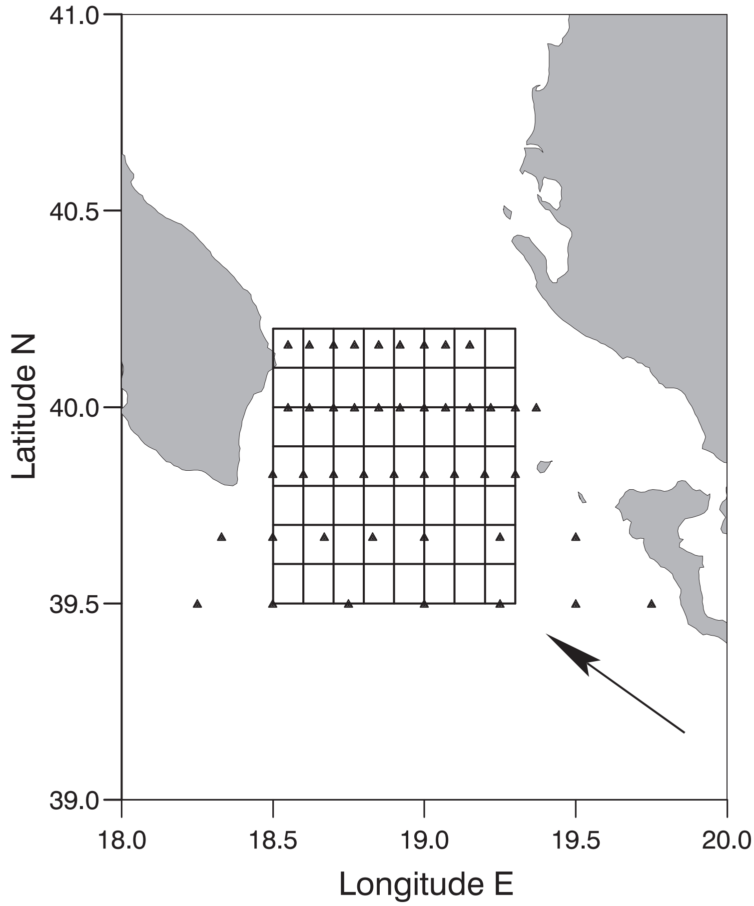


**Fig. 1** - Map of the Otranto Channel area with station positions (black triangles) and interpolation grid. The arrow indicates the direction from which the cube is seen.

inflow is concentrated in a narrow coastal band on the eastern side.

In the intermediate layer, there is an outflow of Adriatic water along the Italian shelf and slope, while an inflow of highly saline Levantine Intermediate Water (LIW) occurs in the remaining part of the strait, its main core being centered at about 300 m depth. The LIW is identified in T/S space by a salinity maximum usually greater than 38.80 and by a temperature of about 14 °C; it is always the saltiest water found in the area and for this reason salinity alone can be employed for its identification: therefore it will be defined throughout the present paper as the water with salinity equal to or greater than 38.75.

Finally, in the bottom layer, the deep water formed in the Adriatic outflows into the northwestern Ionian basin, and subsequently spreads towards and throughout the bottom layer of the Levantine Basin (The POEM Group, 1992). This water mass, the Adriatic Deep Water (ADW), was found to be the main component of the Eastern Mediterranean Deep Water (EMDW) (Pollak, 1951).

The aim of the present paper is to follow the temporal and spatial evolution of the LIW, during the time interval covered by the Otranto Project, by means of a spatial interpolation tech-

**Table 1** - Otranto cruises calendar.

| Cruise | **Otranto 1** | **Otranto 2** | **Otranto 3** | **Otranto 4** | **Otranto 5** | **Otranto 6** |
|---|---|---|---|---|---|---|
| From | 22/02/94 | 17/05/94 | 06/08/94 | 31/10/94 | 07/02/95 | 19/05/95 |
| To | 05/03/94 | 22/05/94 | 16/08/94 | 05/11/94 | 13/02/95 | 24/05/95 |

nique of the salinity field coupled with a 3-d visualization, employing UNIRAS software for gridding, interpolation and display. This was made possible both by the extensive field surveys over the Otranto Strait area, which produced a good quality data-set, and by the sinopticity of the measurements which were always completed within 5 days (8 days for the Otranto 1 cruise).

## 2. Experimental

The grid of the hydrological stations occupied during the 6 oceanographic cruises is shown in Fig. 1. The cruise calendar was as indicated in Table 1.

The thermohaline measurements were performed using a CTD SeaBird 911 during cruises 1 to 5, while during the last cruise a CTD N. Brown Mk III was employed; they were coupled with a 24-bottle Rosette for water sampling. The sensors were calibrated before each cruise and controlled by means of SIS reversing thermometers and frequent discrete salinity determinations by means of an Autosal salinometer.

The CTD data were collected only during the downcast, at a sampling frequency of 24 Hz, while the instrument was lowered through the water mass at a rate of about 1 m/s. The first data processing was carried out onboard: the data were cleaned to eliminate spikes and misrecordings and subsequently averaged over a 1 dbar interval. Salinity was computed from pressure, temperature and conductivity averaged values, according to the UNESCO (1983) algorithm. The final adjustment of temperature and salinity values was performed on land, after having analyzed the data sets coming from thermometer readings and from salinity determinations.

Fig. 1 shows also the area in which the temporal and spatial evolution of LIW was studied; it is delimited by a rectangular grid which was chosen using the following criteria:
- maximum coverage of the investigated area;
- step similar to the station average spacing, both in the X and in Y directions.

According to these criteria, the grid was designed with the following features:
- spatial extension: from 39.5° N to 40.2° N and from 18.5° E to 19.3° E;
- grid nodes: 9 in X-direction (longitude) and 8 in Y-direction (latitude);
- step: 0.1 degree both in latitude and longitude.

The salinity field was subsequently estimated at the grid points from the salinity data. This grid fitting was done using the software AGL/Interpolations (UNIRAS, 1988a), which is a library of several FORTRAN subroutines that together act as a package for gridding and interpolation of mapping data. Since the LIW layer reaches a maximum depth of about 700 m, this procedure was repeated from the surface layer down to this depth, with a vertical step of 20 m. In this

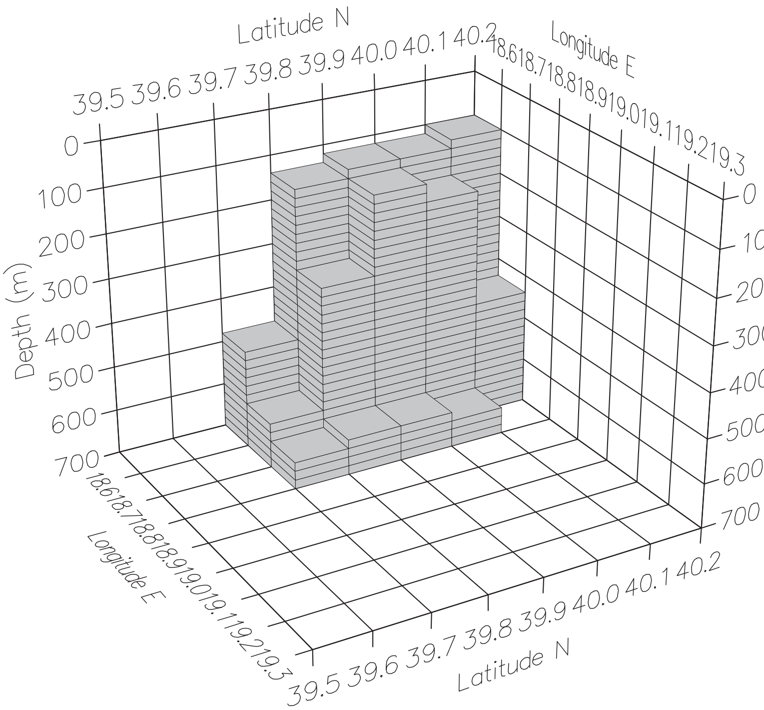


**Fig. 2** - Bathymetry of the area resulting from bottom interpolation.

way a 3-dimensional grid of 2592 nodes was obtained, with a total volume of 3703 $km^3$, 3264 of which occupied by the sea, owing to the bottom topography (see Fig. 2). The subroutine GINTPF was employed for the interpolation and, after a covariance analysis of salinity data, the value of 50 km was chosen as a search radius.

To visualize the 3-D salinity field so obtained, the software AGL/Blocks (UNIRAS, 1988b) was employed. This is a library of FORTRAN subroutines which allow a graphical presentation of spatially varying phenomena using block diagrams. All the maps of the present paper show the resulting “cube” as seen from the southeast, as indicated by the arrow in Fig. 1.

## 3. Results and discussion

The LIW behaviour during the investigated period (Fig. 3) shows not only a seasonal variability but also an interannual one, with features of the sixth Otranto cruise (May 1995) quite different from the previous five. In fact, the situations met during these first cruises do not show remarkable differences: the layer of maximum salinity (from 38.80 to 38.85) is located at a depth ranging from 200 (Otranto 3) to 250 meters (Otranto 5) and occupies the eastern face of the cube, or only its south-eastern corner (Otranto 2), while during the Otranto 4 autumn cruise only this layer is restricted to few “spots”. On the other hand the maximum thickness of the LIW layer varies from a minimum of 220 m to a maximum of about 300 m (cruises Otranto 2 and 5, both performed during the winter period), while it does not reach the western side of the cube again during the Otranto 4 cruise, which appears to be the poorest in LIW.

The LIW features met during the last Otranto cruise show, on the contrary, a sudden change from the previous situations, from three points of view: the salinity maximum value, its position and the volume occupied. In fact the salinity reaches values as high as 38.92, which had never been found before, and the depth of this maximum rises to 150 m. At the same time the LIW layer showed a maximum thickness of about 500 m, the volume occupied increases and appears compressed against the eastern side of the cube. A possible explanation may be found in the strong freshwater discharge - mainly by the Po river - which occurred during the preceeding months, since the freshwater buoyancy input intensifies the general cyclonic circulation over the Adriatic as well as the Ionian waters inflow. The formation of a frontal system in the central part of the strait - dividing the two opposite flows - enhanced the horizontal shear from the surface down to the intermediate layer, and the LIW core was thus forced to intrude into the Adriatic against the eastern slope and at shallower depths than before.

A better and more immediate understanding of the LIW evolution may be easily reached employing an interesting facility offered by the graphical displaying software. This consists in making visible the inner part of the studied volume by simply setting to “undefined” all the grid nodes of the external part: this makes the cells transparent when the grid is contoured. Fig. 4 shows the inner structure of the six cubes, which were made partially transparent to evidence the level of the salinity maximum and the peculiar features found during the sixth cruise.

With this simple contrivance it is also possible to display only the main LIW body, setting to “undefined” all the grid nodes where the salinity is less than 38.75. The results are shown in Fig. 5, where again the different situation of the May 1995 cruise is evident, as well as the minimum LIW volume in the autumn 1994 cruise.

Since several previous cruises had been carried out in the Otranto Strait area, mainly in the framework of the POEM program, this technique was also employed on these data, to analyse the LIW pattern in previous years. The results are reported in Fig. 6, which shows the situations met during the POEM cruises 1 (October 1985), 2 (March 1986) and 5 (August 1987). One can easily see that the LIW volume was always larger than during the Otranto surveys, even if the maximum salinity never reached the high values measured during the May 1995 cruise. On the other hand the LIW layer always reached the westernmost side of the cube, although during the POEM 2 cruise it was limited to a thin vertical layer facing the southern (Ionian) face of the cube.

Finally, the technique of setting “undefined” the values of the non-LIW grid nodes, allows computation of the LIW percentage simply by evaluating the ratio between the unmodified and the total grid node numbers, after having subtracted from the latter the number of nodes occupied by the bottom, as shown in Fig. 2. The results, summarized in Fig. 7, indicate that the LIW volume found during the period covered by the cruises Otranto 1 to 5 (February 1994 - February 1995) ranged with small oscillations from 15 to 22%, while during the second half of the eighties its mean value was higher, ranging from 38 to 49%. This may be due, according to Klein et al. (1998), to the changes occurring after 1987 in the circulation of the eastern Mediterranean: dense Aegean waters outflowed from the sills of the Cretan arc and sunk down to the bottom of the basin, causing an upward displacement of pre-existing bottom waters and a compression of

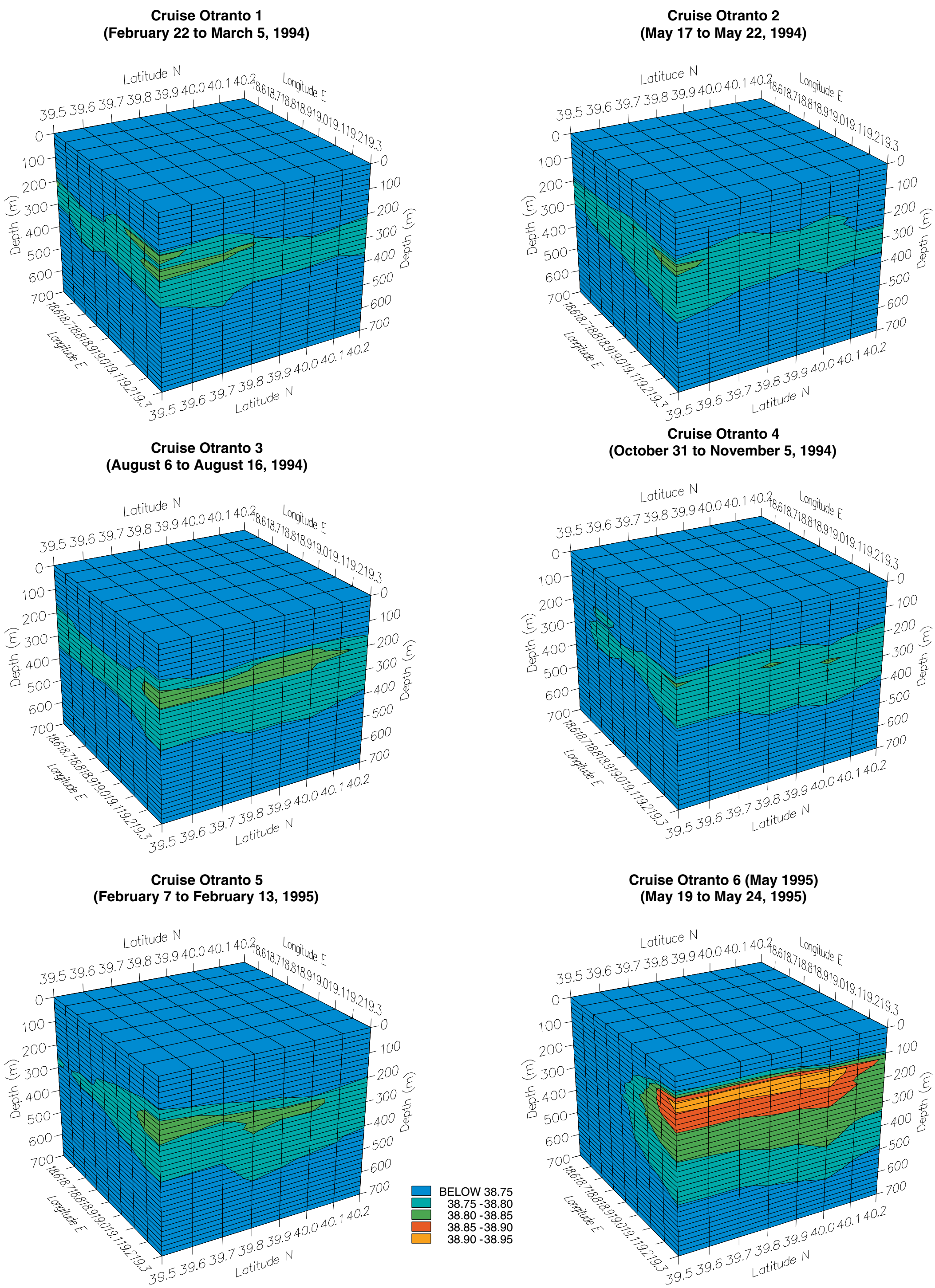


**Fig. 3** - Salinity from surface down to 700 m for the six Otranto cruises.

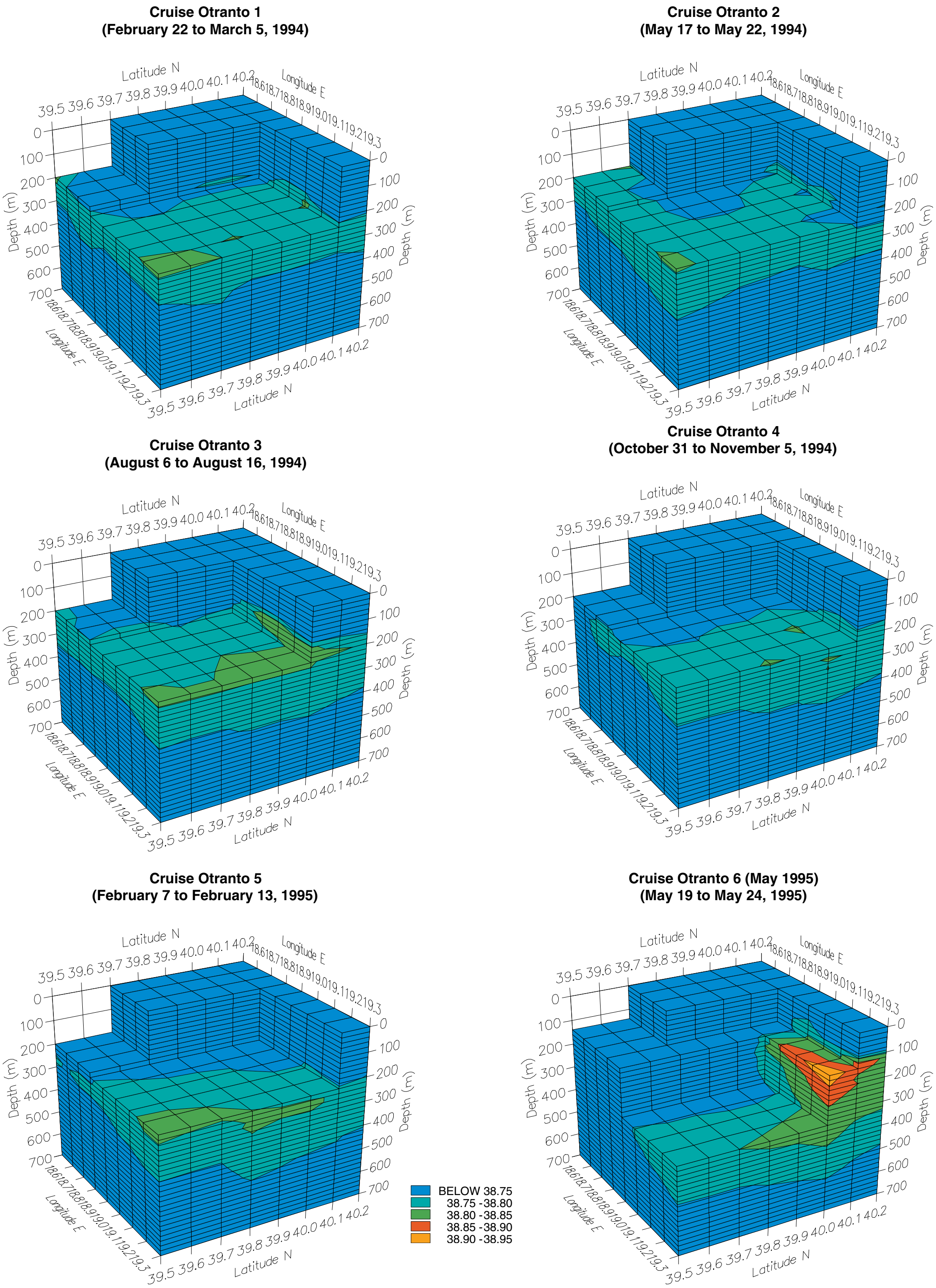


**Fig. 4** - As in Fig. 3, with the inner salinity structure shown.

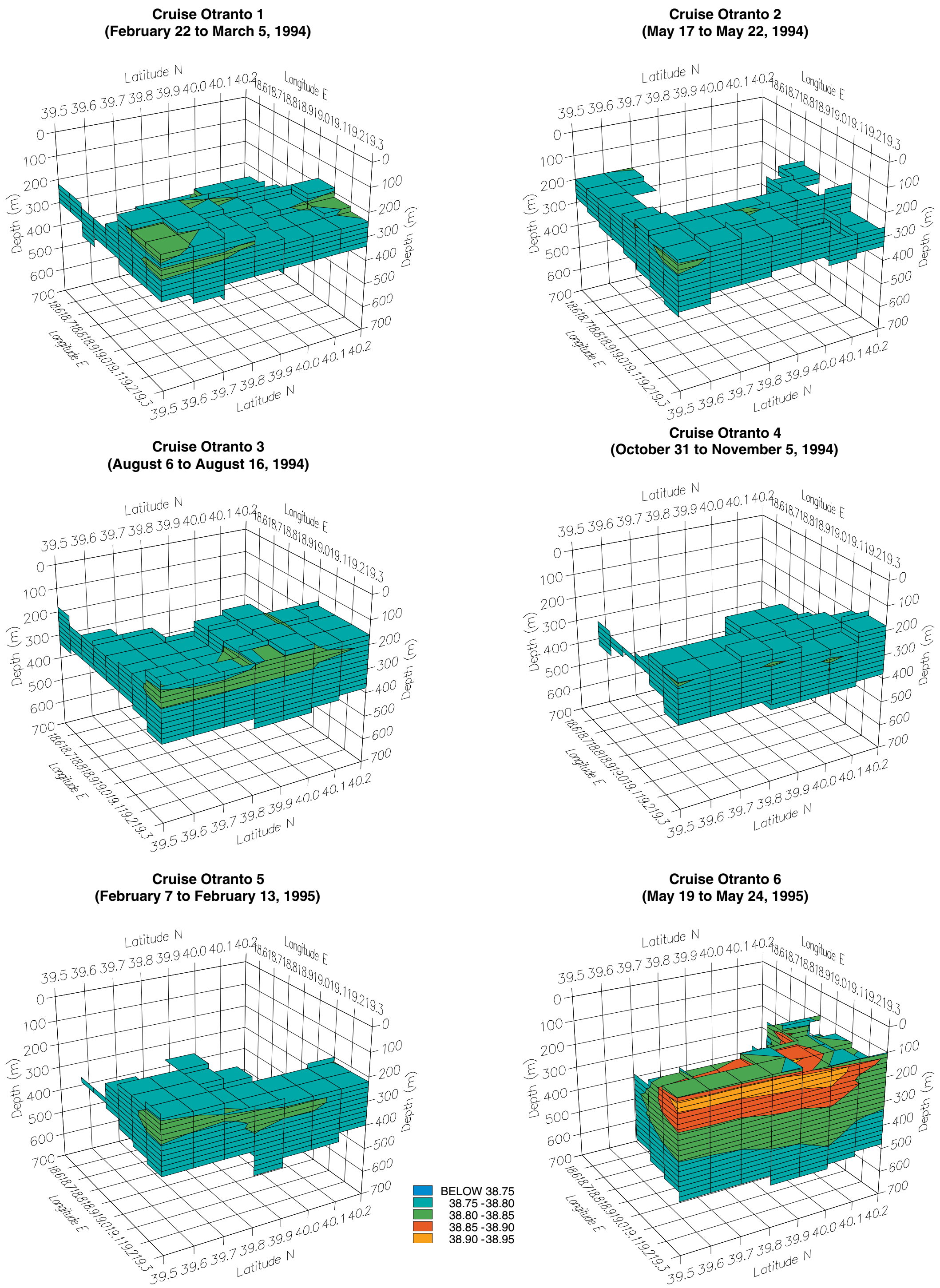


**Fig. 5** - Volume occupied by LIW during the six Otranto cruises.

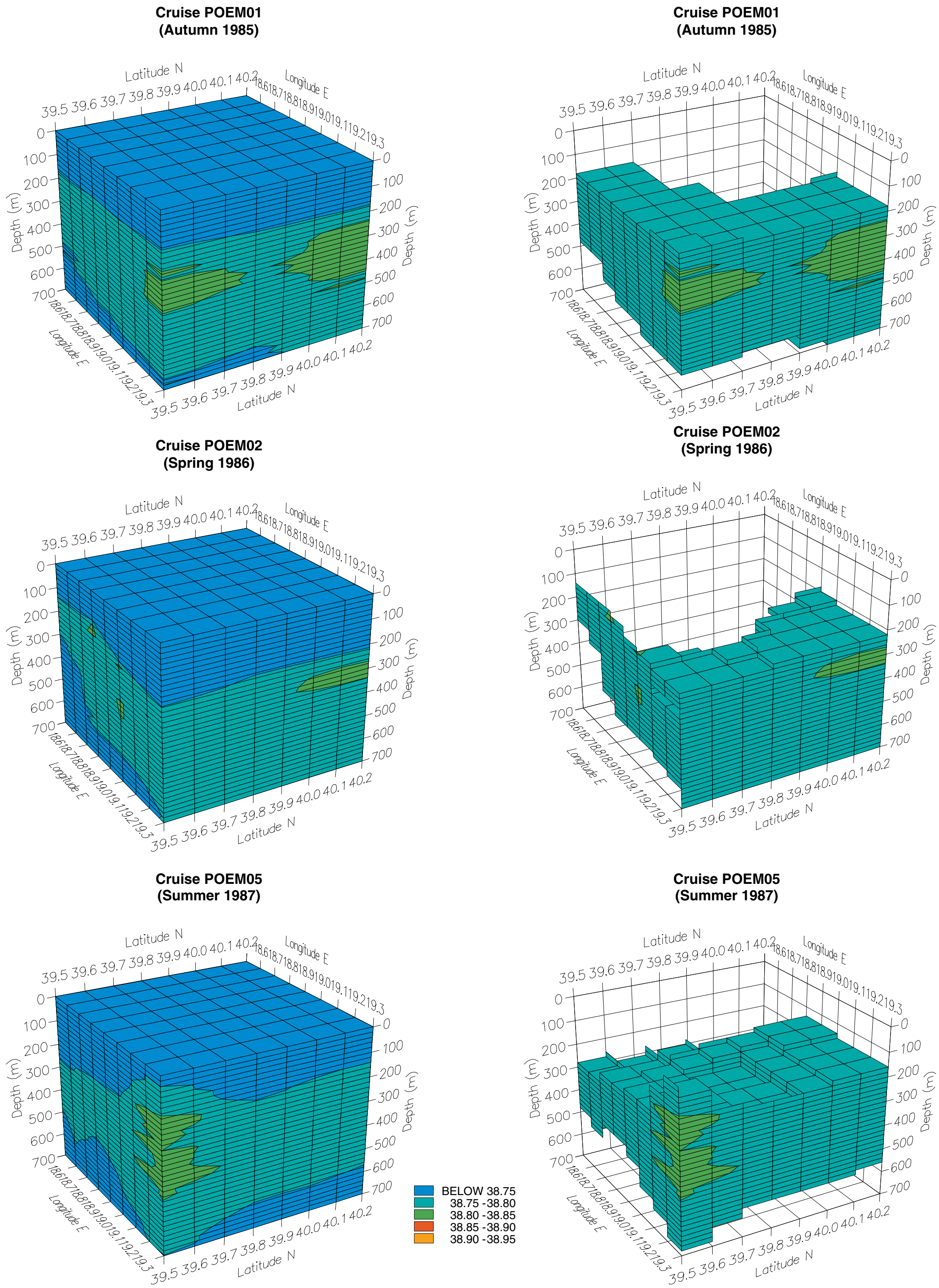


**Fig. 6** - Salinity from surface down to 700 m and volume occupied by LIW for the cruises POEM 1, 2 and 5.

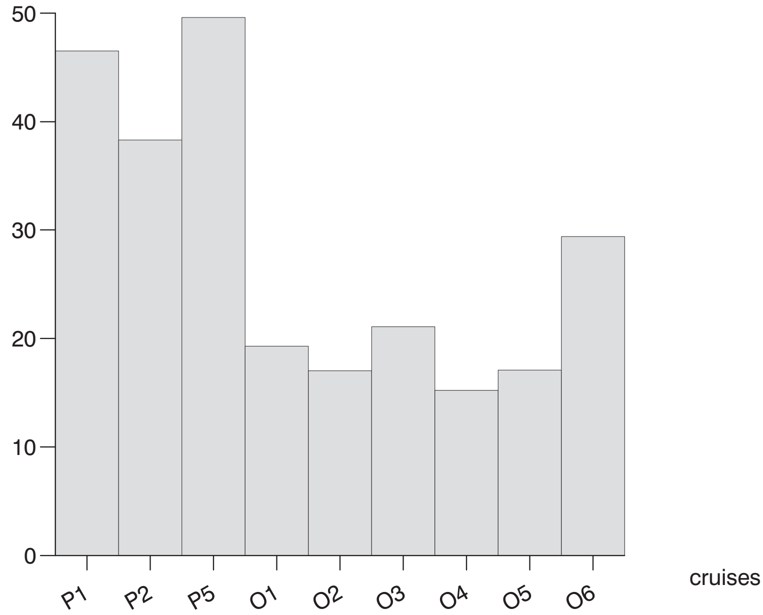


**Fig. 7** - LIW abundance (%) as computed by interpolation for the cruises POEM 1, 2 and 5 and for the six Otranto cruises.

the LIW layer; this can easily be seen by comparison of Figs. 5 and 6, from which the reduced thickness of the layer is evident.

On the other hand there are not enough data to state whether the value of 29% found during the last Otranto cruise of May 1995 indicates the beginning of a new period of increase in the LIW volume or not.

In conclusion, it can be stated that the variability of the Levantine Intermediate Water in the area of the Otranto Strait is both spatial and temporal, the latter being both of seasonal and interannual nature. The variations can be easily followed in terms of LIW volume, position and also maximum salinity value and depth by means of a 3-D representation of the salinity field. This technique gives an immediate and comprehensive idea both of the field extension and structure at any level and/or in any vertical section, thus facilitating the individualization of the water mass.

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