Catalan Sea and Adriatic Sea hydrography during T-ECHO project cruises (years 1993 to 1995)

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SUMMARY : This report presents the results of all the CTD observations carried out in the five cruises conducted within the T-ECHO project: three of them in the Iberian shelf (Catalan Sea), in spring of 1993, 1994 and 1995, and the other two in the North-western Adriatic Sea, at the end of summer of 1994 and 1995. In all these cruises a net of CTD casts was performed, covering the respective areas, and repeated twice in the Catalan Sea. This set of data was intended to describe the background of the pelagic environment found in the surveys. In this report a brief analysis of the different hydrographic features observed, through a first analysis of the data is presented. The results are also briefly discussed within the frame of the particular characteristics of each environment.

INTRODUCTION

Concepts like space and time, which have a clear and definite sense in terrestrial environments, may not always be suitable for description of marine environment. A terrestrial environment can be well defined and described unambiguously, given its spatial coordinates and enough information on time evolution and cycles. This references might also be someway applicable in aquatic environments when studying benthos, but they are insufficient when the object of study is the pelagic environment. The ground of this particular environment is a fluid, water, which is not attached to a fixed point and is submitted to several forcings that modify its characteristics along its way. In such case spatial coordinates are merely one, and not even the most important, of the references needed to precise the pelagic environmental characteristics. Consequently, references have to include other information at least as relevant as spatial position, including the vertical component, and time.

Among the more relevant references required in marine environments are: water temperature, salinity and density. They are conservative, in the sense that their values are not affected by internal processes. They can only be modified by mixing or by external processes, that only act through the sea surface. Temperature and salinity have to be measured and density can be calculated through the sea water equation of state (UNESCO, 1980) using the observed values of temperature, salinity and depth. Density has an important role in the dynamics of the water because it determines the mass distribution and thus the effect of all forces: gravity or weight, internal pressure, etc. It is particularly important for the evaluation of the stability of the water column and the general trends of the circulation at mesoscale level.

According to the conservative character of temperature and salinity a typical way to describe a water mass is through the relationship between these two parameters. In a given sea area, a careful classification of the TS relationships reveals some basic trends of the evolution suffered by the water up to the present situation, which is the first step for environmental descriptions.

Classically this information has been obtained in stations by sampling water at fixed positions and at certain levels (Sverdrup *et al*., 1942). The results could be then extrapolated to the whole area of study. Since early 80's a systematic use of CTD (Conductivity-Temperature-Depth) profilers at the stations has improved the vertical resolution of samples, giving a more detailed and accurate information in this direction (Brown, 1974; Osborn & Cox, 1972). The horizontal interpolation however remained uncovered by this method. Continuous underway TS analysis of surface waters (or at a certain depth through a pump or a towed sensor) have been carried out since the early 70's to obtain detailed horizontal information along the ship track (Ballester *et al.*, 1972). The coupling of both sets of measurements, however, is still not systematic.

Another important information regarding pelagic environment are water motions: the circulation. Currents may be directly observed by several procedures. Among them the most popular are fixed arrays of currentmeters and, more recently, ADCP (Acoustic Doppler Current Profiler), fixed or on board the ships (Regier, 1982). The information of ADCP on board is usually obtained underway so that instantaneous current profiles can be coupled with the rest of information but, again, this is still not systematically solved.

Water circulation is essentially due to several mechanisms such as: mass distribution, wind and bottom frictions, tidal forces, heat transfers, etc. Consequently an observed current may be split into several components associated to the different forcings. One of the most important components, called geostrophic, is associated with the internal pressure field that can be calculated through the density distribution obtained from the analysis of CTD observations.

There are other information and parameters to describe the pelagic environment: dissolved oxygen, nutrients, light penetration, suspended matter and several components of biomass: bacteria, phyto and zooplankton, ichtyoplankton, small pelagics, fish, birds, mammals, etc. In pelagic environment the most important primary producer is phytoplankton. All the remaining stages of food web depend on its abundance which is controlled essentially by two factors: light and nutrients (Margalef, 1974).

Most of the measures concerning the above parameters have to be obtained by specific sampling strategies and analyses: water samples, filtering, fishing with several nets, direct observation or indirect estimates through acoustics, models, etc. A classical way to estimate phytoplankton abundance is the measuring the chlorophyll content of suspended particles in the water through filtering water samples. But, as this pigment produces fluorescence when it is excited by a 410-450 nm light, measures of *in vivo* fluorescence give a good estimate of phytoplankton abundance (Kiefer, 1973). Consequently, a fluorometer included in a CTD probe is used to estimate phytoplankton abundance. There are other sensors designed to be included in a CTD probe: dissolved oxygen, light penetration and transmission, etc.

In this report the results of CTD observations, carried out in the cruises of T-ECHO project, are presented. In all the cruises CTD was equipped with a fluorometer and in some of them a transmissometer and a light sensor were also included.

There are two sets of information: One set covers the vicinity of the Ebro delta and the Iberian shelf (Catalan Sea), at the same season (May) in three consecutive years (1993-95). The other set covers the western half of Northern Adriatic, visited in September of two consecutive years (1994-95). The information of each set is presented by cruises, followed by a general discussion focused as a contribution to the understanding of each one of these pelagic environments. The report ends with a global discussion on the results.

TECHNICAL REPORT ON OBSERVATIONS METHODOLOGY

General characteristics

The CTD used on all the cruises in the T-ECHO project was a SEABIRD-25 model, S/N 257290-0097. It is a quality CTD profiling system, battery powered and is used to record data in solid-state memory, eliminating the need of electrical sea cable (Anonymous, 1992).

The basic Seabird CTD consists of a Seabird's modular SBE-3 Thermometer, SBE-4 Conductivity sensor and SBE-5 submersible pump and a temperature compensated strain-gauge pressure sensor.

The CTD also includes interface electronics and mechanical mounts for optional fluorescence, transmissivity, dissolved oxygen, pH and PAR sensor (Photosynthetically Active Radiation).

Alkaline batteries have been used to provide up to 24 hours continuous operation. The Memory Capacity is of 512K bytes standard RAM. In all cruises recorded data was transferred, after each cast, via RS-232 interface to a PC for storing and processing. Data have been obtained at a rate of 8 scans/sec and averaged data was stored every second to ensure a minimum of 1 datum per meter at a maximum lowering speed of 1 m/s.

Specifications of sensors used on T-ECHO project

The following sensors (standard an auxiliary) were used during the five cruises that composed the T-ECHO project (T for Temperature, S for Salinity, F for fluorometer, Tr for Transmissometer, and P for PAR sensor):

GICS 1 : T, S, P and F.
GICS 2 : T, S, P and F.
GICS 3 : T, S, P and F.
GIAS 2 : T, S, P and F.
GIAS 3 : T, S, P, F, Tr and PAR.

Temperature

It was measured with a SBE-3 thermometer that provides a "fast" response time of 70 milliseconds. It was installed in a standard Aluminium housing rated to 3400 meters.

Technical characteristics of the sensor are:

Range	Accuracy	Resolution
-5 to 35 °C	+0.004 °C	0.00003 °C

Conductivity

It was measured with the SBE-4 Conductivity sensor, that had a frequency output of approximately 3 to 12 Khz corresponding to Conductivity from 0 to 7 Siemens/meter covering the full range of fresh water and oceanic applications.

The flow-through sensing element was a glass tube (cell), with 3 internal platinum electrodes. The cell had a 3400 meters depth capability standard. Water flushes by the action of a pump through the Conductivity cell at a constant rate, which was almost independent of the CTD motions, improving dynamic performance.

Technical characteristics of the sensor are:

Range	Accuracy	Resolution
0 to 7 S/m	+0.003 S/m	0.00004 S/m

Pressure

Pressure was measured with the SBE-29 sensor, a temperature compensated strain-gauge pressure sensor.

Technical characteristics of the sensor are:

Range	Accuracy	Resolution
0 to 1000 m	+0.25%	0.015 %

Fluorescence

It was measured with a SEA TECH fluorometer designed to measure chlorophyll-*a* fluorescence, an *in situ* fluorometer providing high resolution data for assessment of phytoplankton biomass and monitoring of primary productivity in marine waters. While many dissolved substances as well as biopigments exhibit fluorescent properties, the optical filters used in the Sea Tech fluorometer have been selected for optimum measurement of chlorophyll.

The fluorometer excitation filter has a 425 nm maximum peak response and the emission filter maximum is 685 nm. The instrument is stable with time and temperature and has an operating depth limit of 500 meters.

Three signal gains are selectable providing full scale ranges of approximately 3, 10 and 30 mg $/m^3$. The most appropriate range will depend on the chlorophyll concentrations; then we worked, in the area of study, with the intermediate range, 10 mg $/m^3$. Four time constants of 0.1, 1, 3, and 10 seconds are provided to smooth the data. 3 second time constant is the most useful for profiling applications.

Transmissivity

It was measured with a SEA TECH transmissometer, designed to accurately measure beam transmission in a 25 centimetre water path. Transmission is measured using a modulated Light Emitting Diode (LED) and a synchronous detector.

The instrument is not sensitive to ambient light and it is temperature compensated. The range over which suspended mass can be measured accurately is dependant upon the optical properties of the suspended particles and the path length of transmissometer. It has a depth capability of 5000 meters, with the technical characteristics:

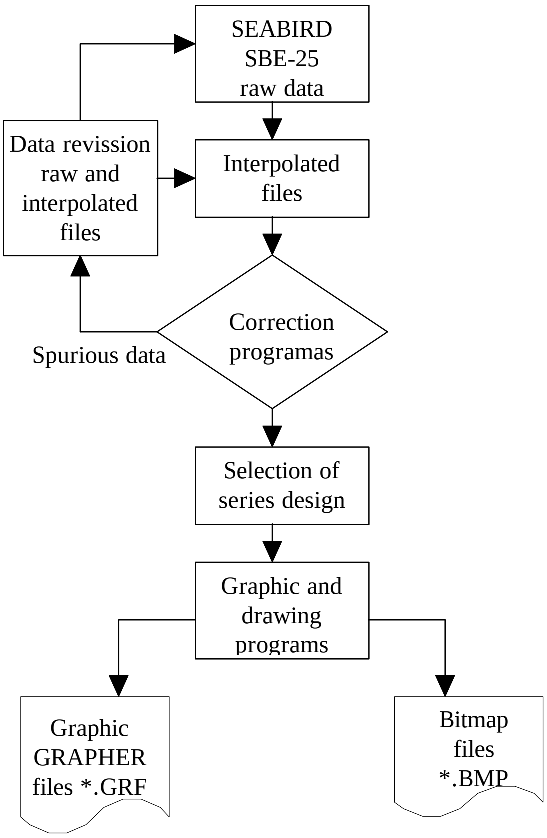
Range	Accuracy	Linearity
0 to 100 %	+0.5 %	+0.1 %

Light

It was measured with a Biospherical QSP 200PD sensor model. This is a Quantum Scalar Profiling Sensor with Photo Diode. It only measures Photosynthetically Active Radiation, between 400 to 700 nm from surface waters to a maximum depth of 1000 m. The sensor provides an output current which comes directly from the photo diode. It has a constant Spectral Response from 400 to 700 nm with a sharply attenuated response over 700 nm and under 400 nm. The spectral response induced errors will cause less than +5 % errors in naturally occurring light fields.

Data reduction and correction

The following scheme shows up dynamics of the above mentioned procedure:



Raw data from CTD, stored in the PC has been converted to physical units to ASCII files, using the SEASOFT Package (SBE, 1992) and the calibration files. CTD sensors have been calibrated every two years in a specialised laboratory, to ensure the precision of the information. After this first step only the way down profile has been saved. Every profile has been submitted to a correction protocol using a battery of programs, designed by our group (Salat, 1994 unpublished). The mission of this process consists essentially on eliminating spurious values and adjusting the time responses of the different sensors. At the end of the process, each CTD profile is presented in a file with a heading showing number of the station, position and time, and the listing of corrected data on: temperature, salinity, density and the other variables when available, at a regular depth interval of one meter, where missing values have been extrapolated over a maximum interval of 4 m. Plots of the profiles of T, S, sigma-t and fluorescence have been produced in bitmap (BMP) format by using GRAPHER software package (Anonymous, 1993).

CRUISES IN CATALAN SEA

A/ GICS-1 (May 1993)

Data

From May 8 to 19, 1993, a total of 69 CTD casts were performed in this cruise. In 4 of them, #003 to #006, CTD showed a general malfunctioning so that these measurements were discarded. The rest were correct in temperature and salinity, but fluorescence failed in 46 casts: #009 to #054. In all casts CTD was lowered up to near the bottom on the continental shelf, or to near 430 m (max 427 m at station #065) when the depth was larger. The studied area (Fig. 1) covered around one half of the Iberian shelf, extending to the continental slope, from 40° 52' to 39° 50' N and from 0° 20' to 1° 24' E, in a rectangle oriented with the coastline. Casts were distributed more or less regularly in the area, spaced about 7.5 nautical miles, following transects perpendicular to the coastline. The cruise was divided into two parts covering the whole area twice: from May 12 to 16, stations #007 to #037 and from May 16 to 19, stations #038 to #069. The first two stations, #001 and #002, were located outside the area: between Barcelona and Tarragona, and in the northern part of the Golf de Sant Jordi respectively, along the travel from Barcelona to the area of study.

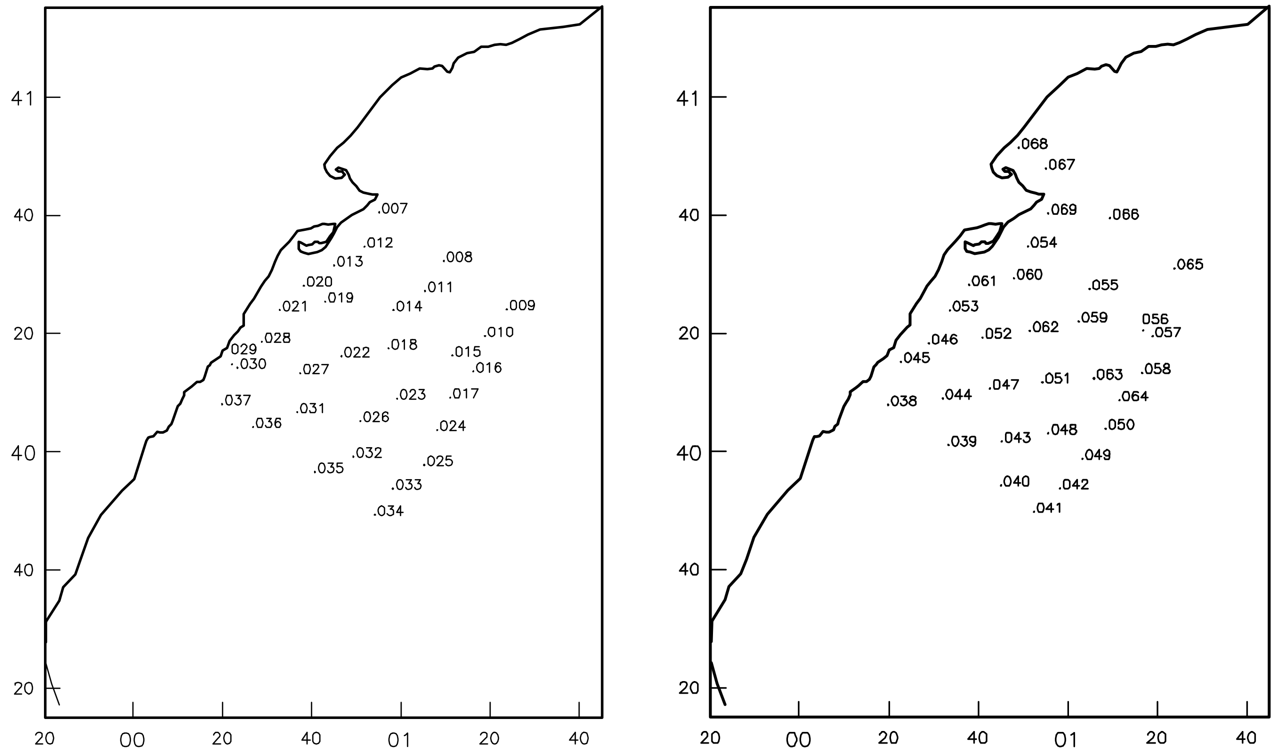
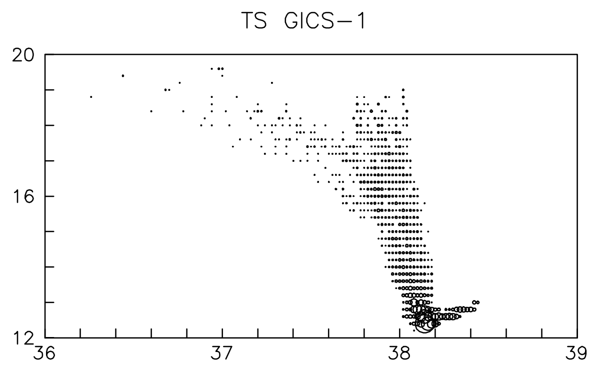


FIG. 1. - Map of the Catalan Sea (Western Mediterranean) area sampled with CTD casts during GICS-1 cruise.
Left map: first coverage (from North to South); right map: second coverage (from South to North).



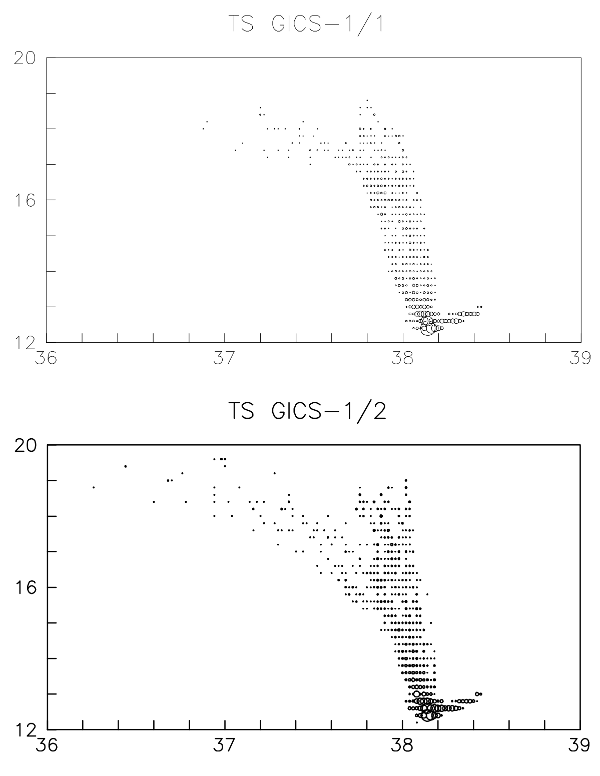


FIG. 2. - TS diagrams of the GICS-1 cruise.
Top left: general; top right: 1st coverage,
and bottom right; 2nd coverage.

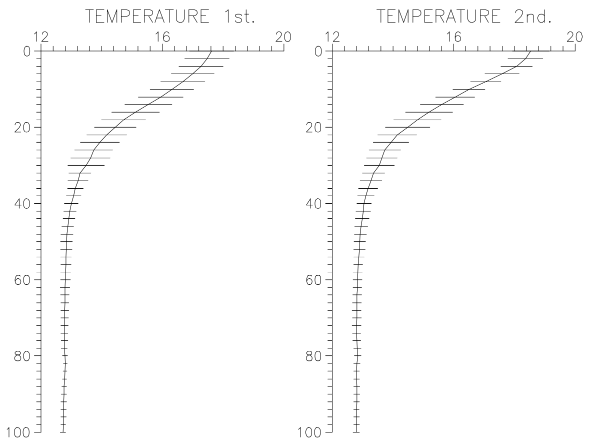


FIG. 3. - Average vertical Temperature profiles during GICS-1 cruise. Left: 1st coverage, and right: 2nd coverage.

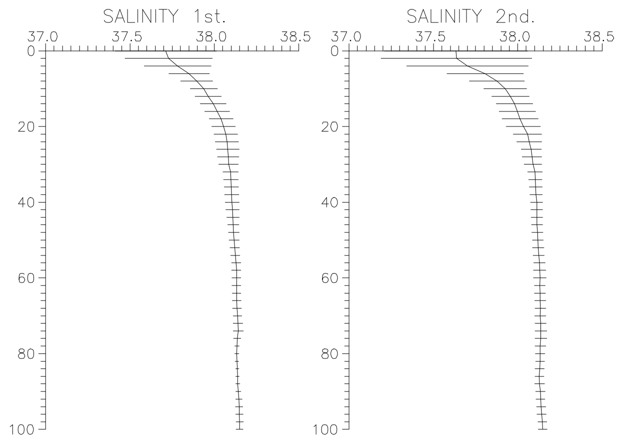


FIG. 4. - Average vertical Salinity profiles during GICS-1 cruise. Left: 1st coverage, and right: 2nd coverage.

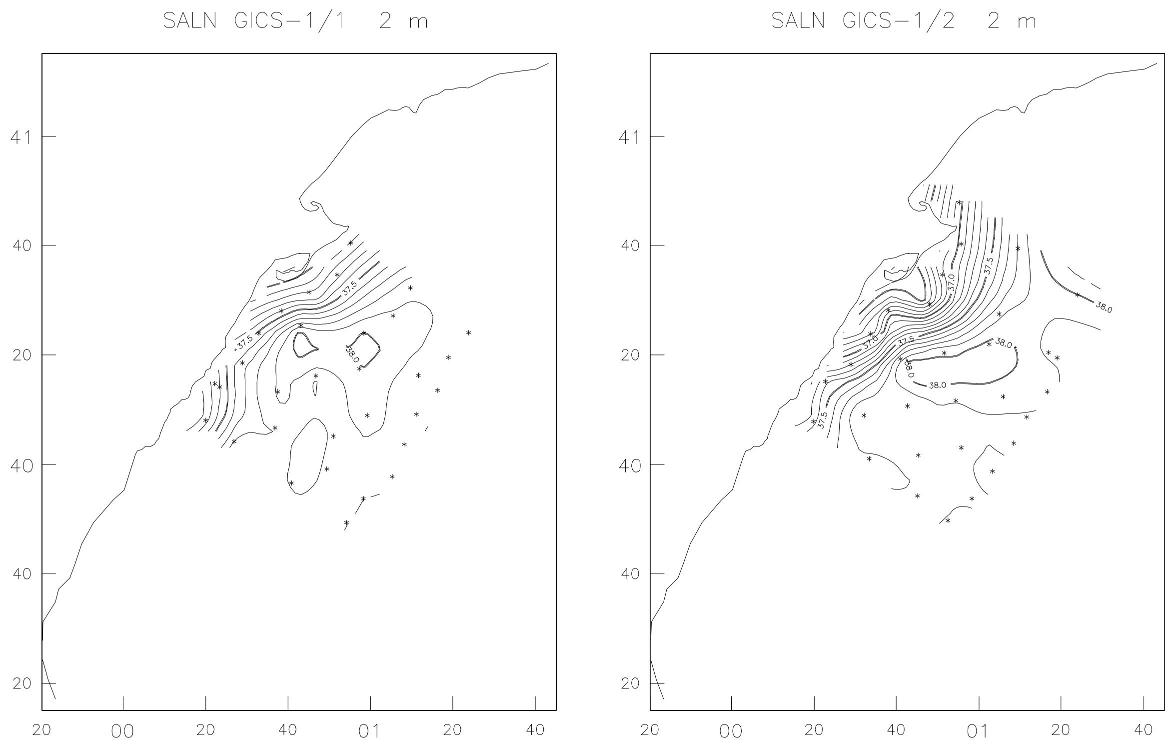


FIG. 5. - Horizontal Salinity distribution during GICS-1 cruise at surface (2 m water depth). Let map: 1st coverage; right map; 2nd coverage

Results

According to the general TS diagram (Fig. 2) the surface layer, down to around a depth of 100 m, was covered by a water mass of continental influence (CW) (Salat & Cruzado, 1981) but not very recent (S > 37.75). Above the thermocline (< 30 m), confined to a narrow strip (10 nautical miles) along the coast, the influence of Ebro river discharges modified salinity to lower values, up to 36.5. The deeper layers were occupied by Winter waters (WW, from now on) and the transition to the Levantine Intermediate waters (LIW, from now on) in a typical depth sequence.

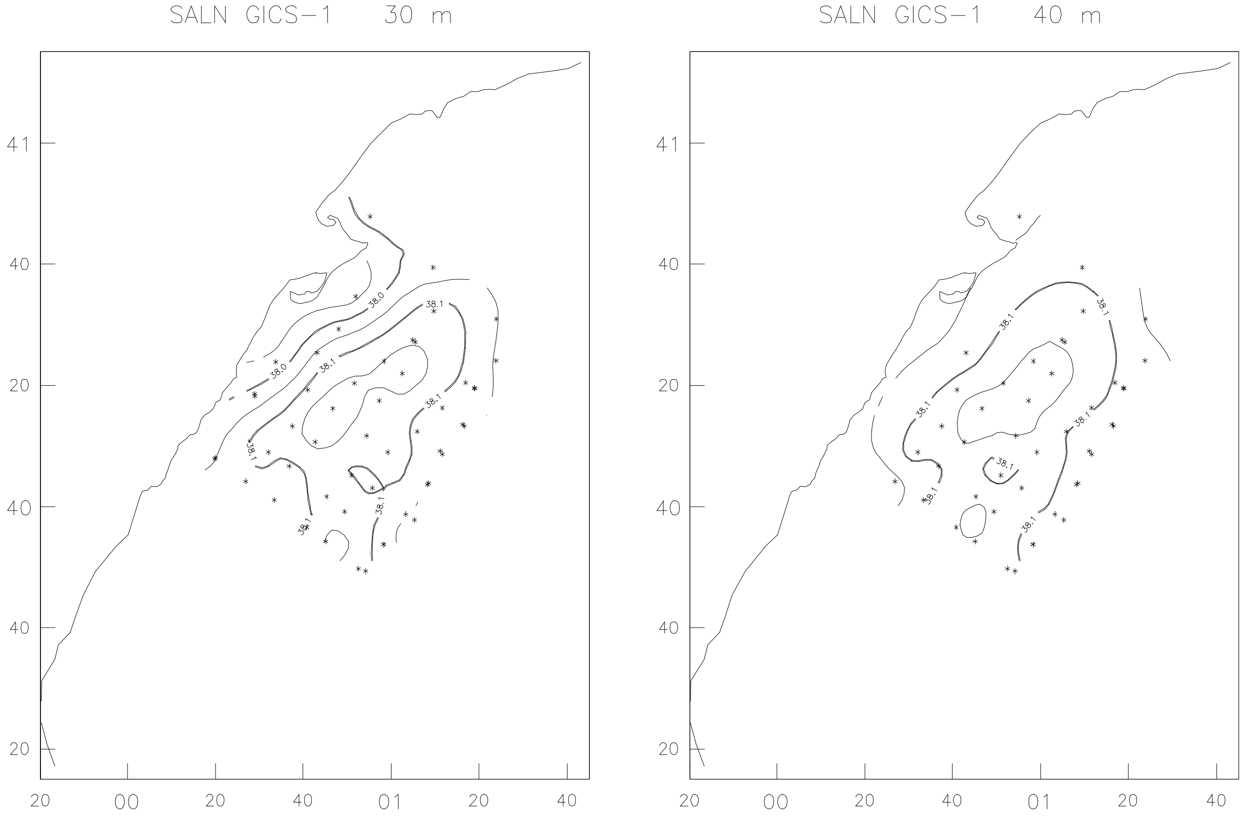


FIG. 6. - Horizontal Salinity distribution below the thermocline during GICS-1 cruise.

However typical TS values for LIW were never reached, suggesting that the whole area was situated in the inner zone of the shelf-slope front (Font *et al.*, 1988). The sampled region just reached the front at the lowest layers, near 400 m, in the offshore stations, particularly in the northern corner of the area (stations #009 and #065).

Vertical structure of temperature shows that the thermocline was not deeper than 30-40 m (Fig. 3). A comparison between average surface temperature at first (around 17°C) and second (around 18°C) parts of the cruise suggest that, during the cruise, surface temperature was increasing at a net rate of 0.2°C per day. Comparison of surface salinities of first and second parts of the cruise (Fig. 4) shows a decreasing of 0.1, in average, but with an increasing variance.

This change is coherent with horizontal salinity distributions at surface (Fig. 5) with a lower salinity patch near the Ebro delta during the second part of the cruise, not present in the first part, suggesting a recent fresh water discharge. Horizontal distributions of salinity below the thermocline (Fig. 6) show slightly higher values in the central part of the area, on the continental shelf, and slightly lower values in the north-eastern corner of the area.

The relative lower salinity may correspond to water advected from the north, beyond the studied area, by the Catalan current. The higher values in the central part are more difficult to justify because the general circulation over the continental shelf uses to be anticyclonic (Font *et al.*, 1990).

A possible explanation is that this water has been upwelled from the south. Temperature and density distributions at the same depths would be consistent with this idea.

Also, the fluorescence profile at station #059 (not shown) has the deep fluorescence maximum higher and deeper than the surrounding stations, but unfortunately this was the only one station lying near this higher salinity area with good fluorometer data.

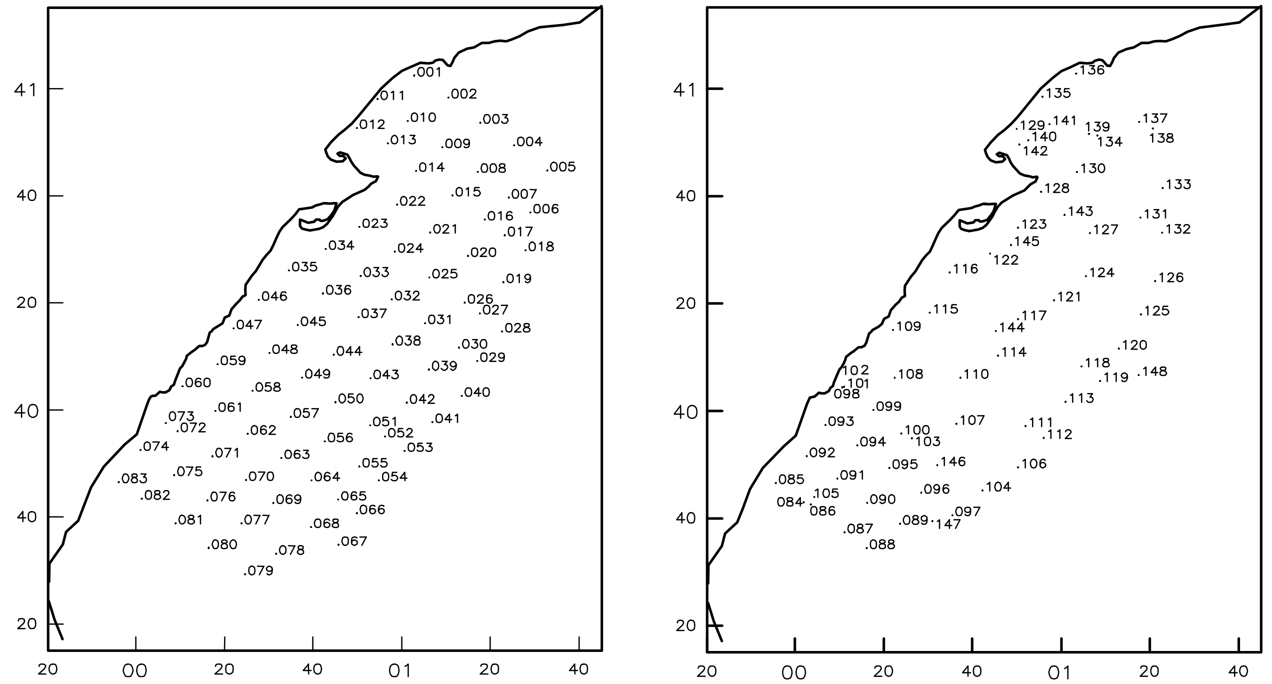


FIG. 7. - Map of the Catalan Sea (Western Mediterranean) area sampled with CTD casts during GICS-2 cruise.
Left map: first coverage (from North to South); right map: second coverage (from South to North).

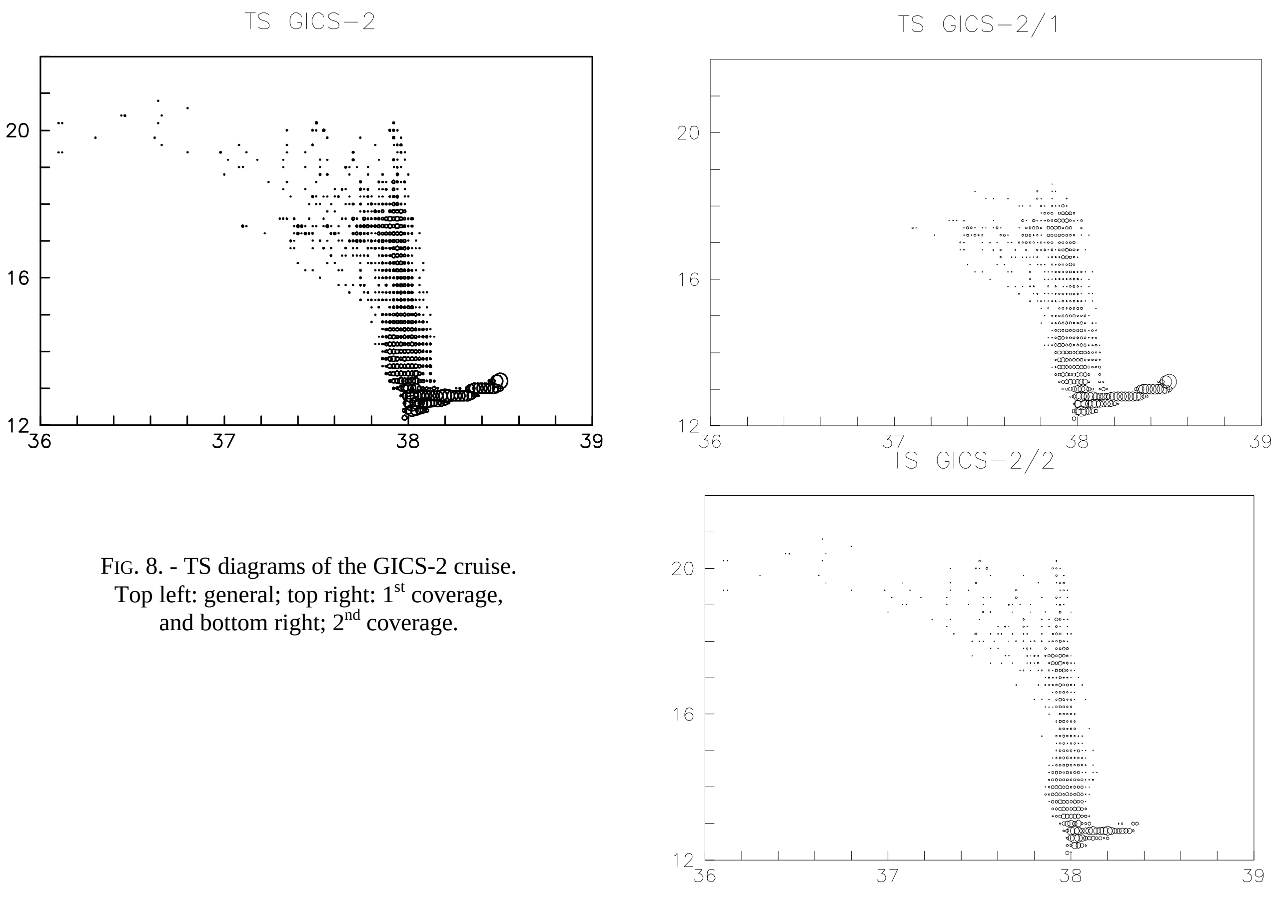


FIG. 8. - TS diagrams of the GICS-2 cruise.
Top left: general; top right: 1st coverage,
and bottom right; 2nd coverage.

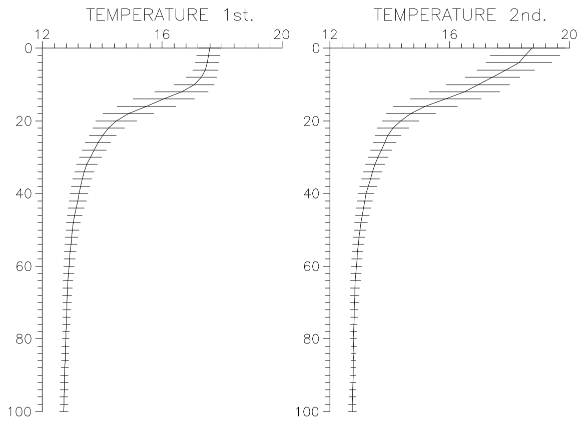


FIG. 9. - Average vertical Temperature profiles during GICS-2 cruise. Left: 1st coverage, and right: 2nd coverage.

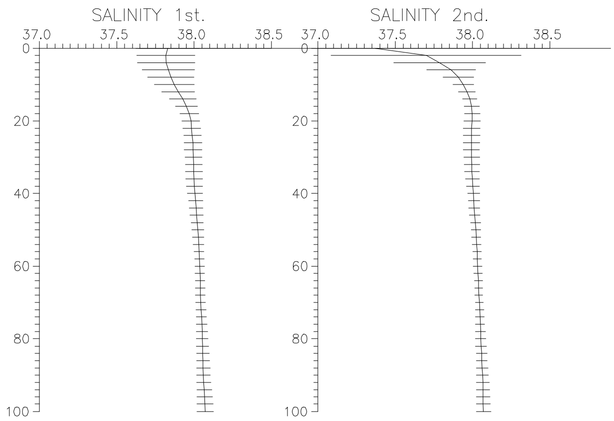


FIG. 10. - Average vertical Salinity profiles during GICS-2 cruise. Left: 1st coverage, and right: 2nd coverage.

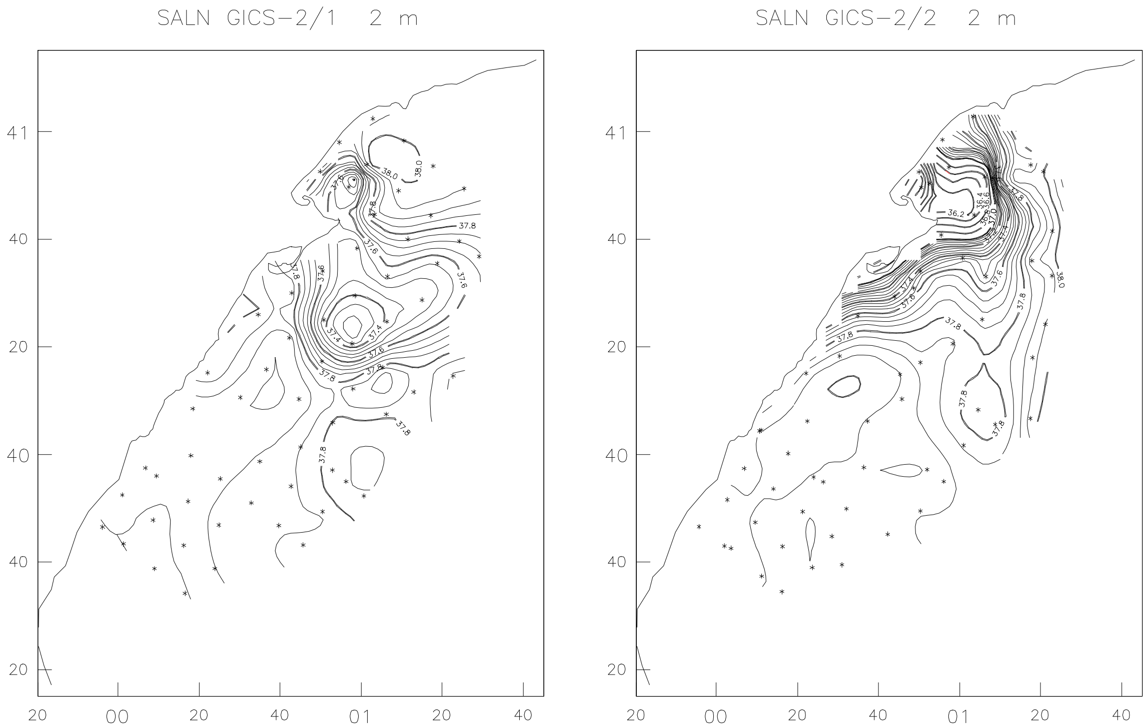


FIG. 11. - Horizontal Salinity distribution during GICS-2 cruise at surface (2 m water depth). Let map: 1st coverage; right map; 2nd coverage.

B/ GICS-2 (May 1994)

Data

From May 12 to 30, 1994, a total of 148 CTD casts were performed in this cruise. In all casts CTD was lowered up to near the bottom on the continental shelf, or to near 500 m (max 495 m at station #028) when the depth was larger.

The studied area (Fig. 7) covered all the Iberian shelf and the Golf of Sant Jordi, extending to the continental slope, from 41° 02' to 39° 30' N and from 0° 05' W to 1° 32' E, in a rectangle oriented with the coastline.
The cruise was divided into two parts covering the whole area twice: from May 12 to 17, stations #001 to #083 and from May 18 to 26, stations #084 to #138.

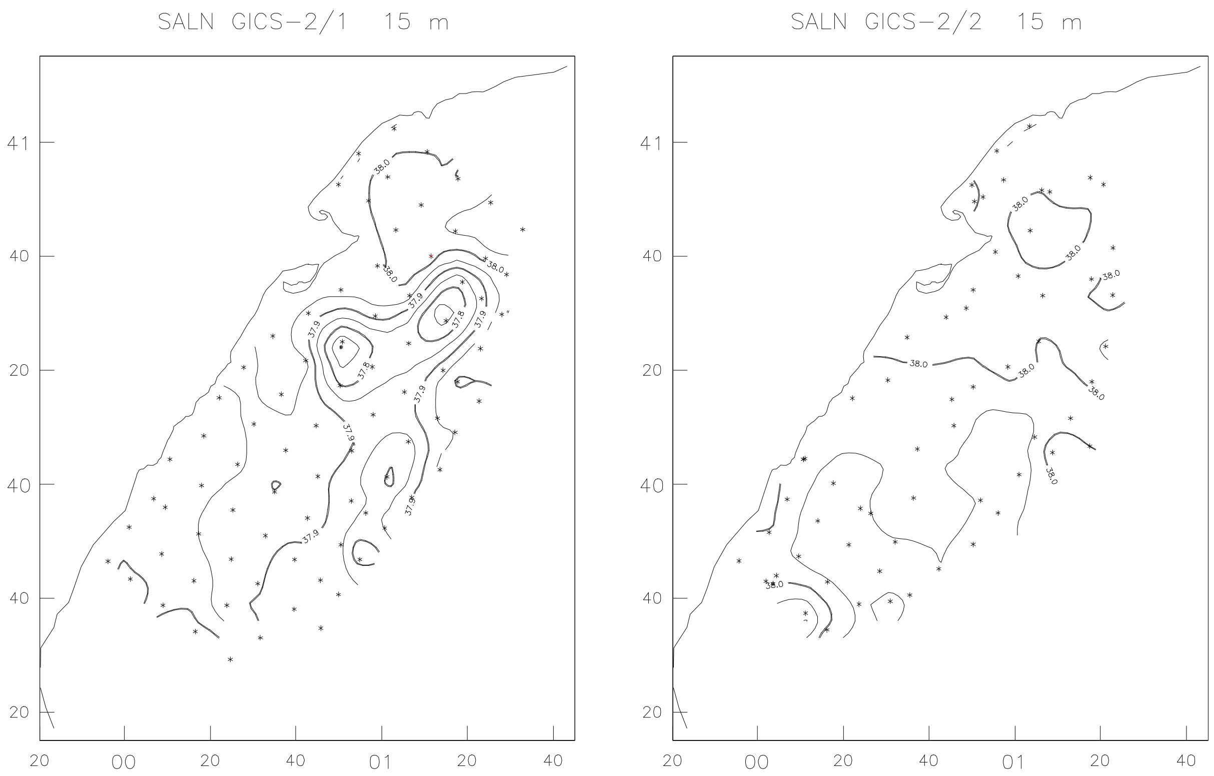


FIG. 12. - Horizontal Salinity distribution during GICS-2 cruise at 15 m water depth.
Left map: 1st coverage; right map: 2nd coverage.

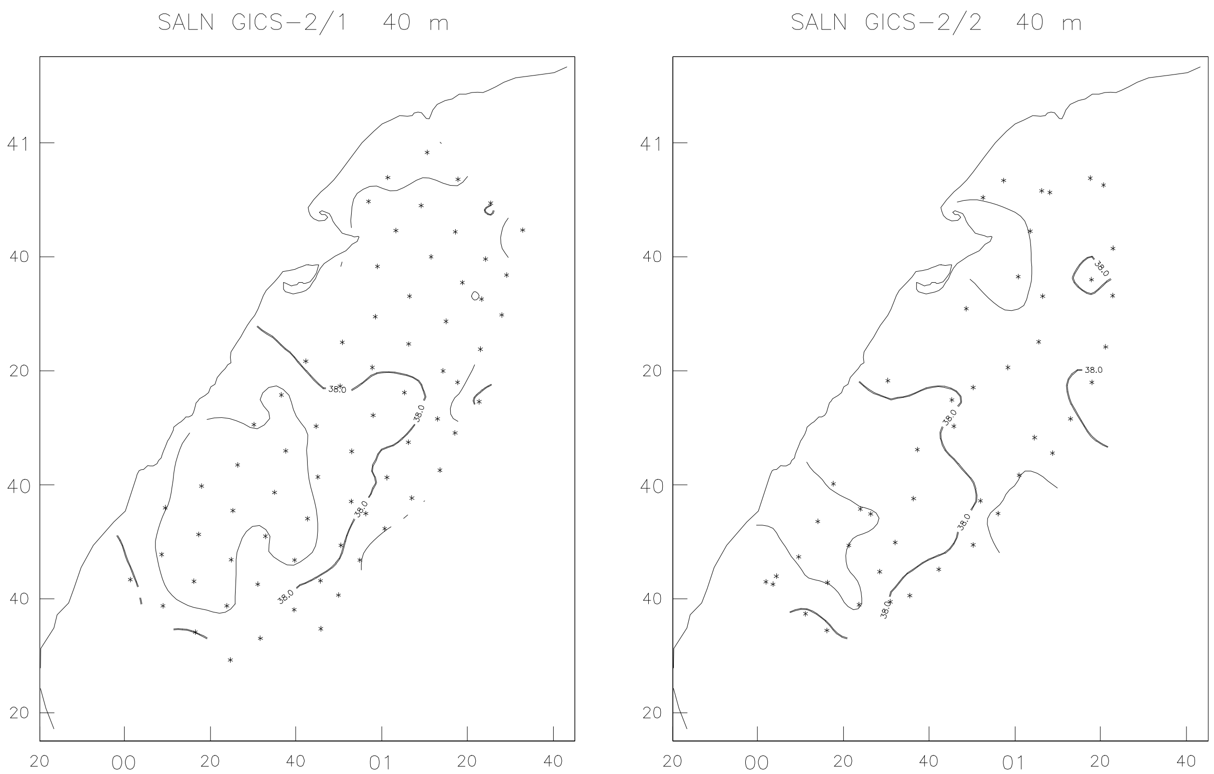


FIG. 13. - Horizontal Salinity distribution during GICS-2 cruise at 40 m water depth.
Left map: 1st coverage; right map: 2nd coverage.

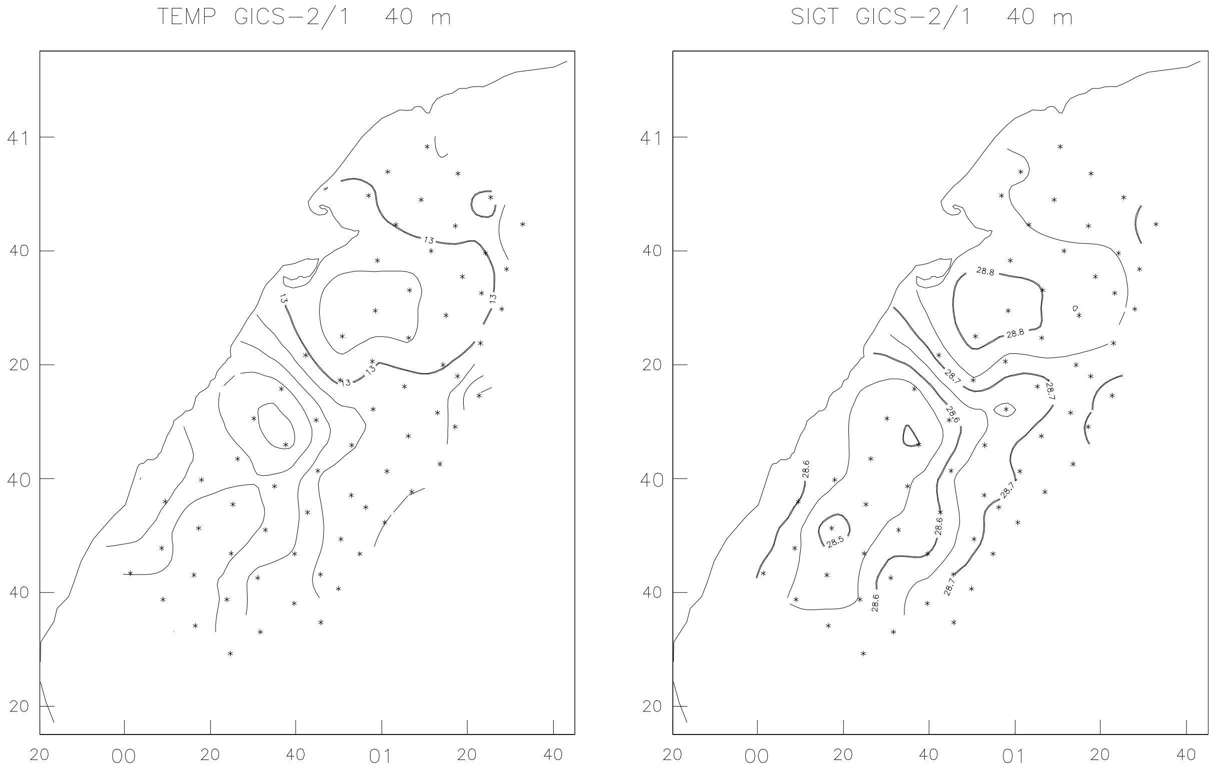


FIG. 14. - Horizontal distribution during GICS-2 cruise at 40 m water depth, 1st coverage.
Left map: Temperature; right map: Density.

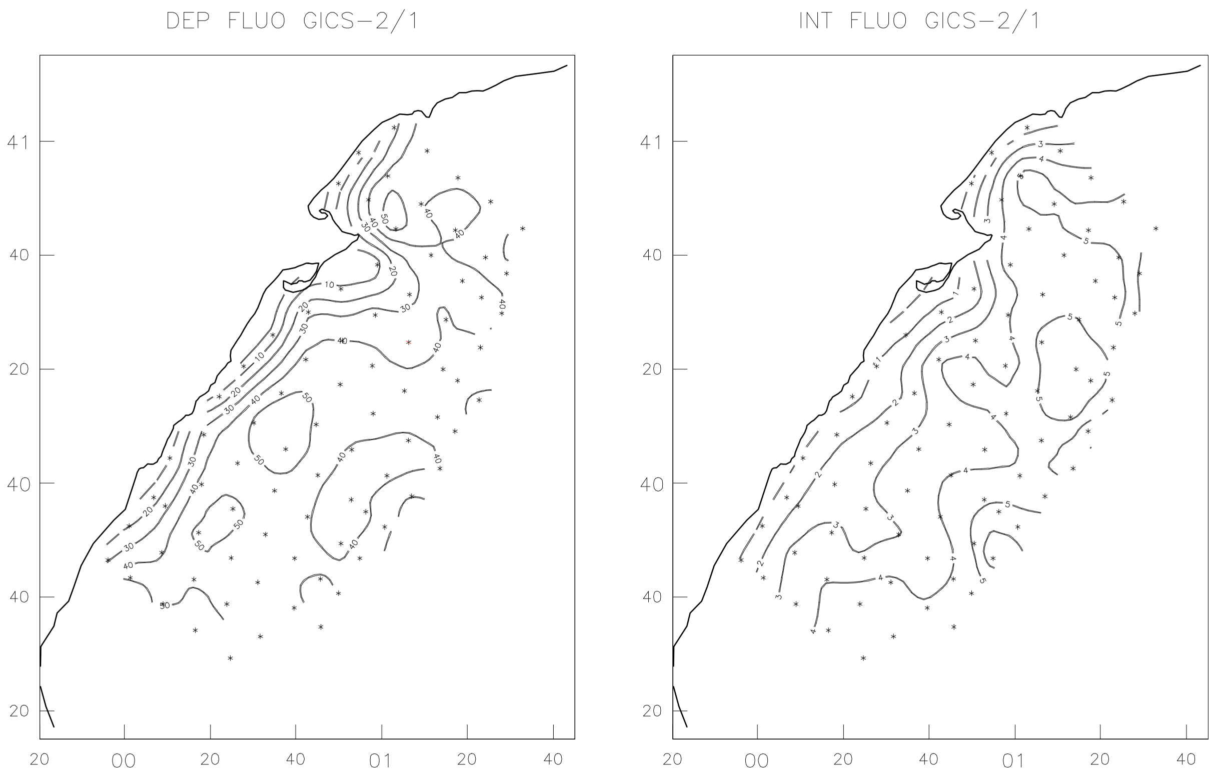


FIG. 15. - Horizontal distribution during GICS-2 cruise at 40 m water depth, 1st coverage.
Left map: Fluorescence integrated value over the euphotic zone; right map: depth of maximum peak of Fluorescence.

In the first part casts were distributed more or less regularly in the area, spaced about 7.5 nautical miles, following transects perpendicular to the coastline.

The sampling strategy of the second part of the cruise was conditioned to other operations so that station sequence was not so regular, but the area was again covered with lower resolution in its central area. The remaining stations #139 to #148, more or less scattered in the area, were performed from May 27 to 30, associated to specific acoustic experiments.

Results

According to the general TS diagram (Fig. 8) the surface layer, up to around a depth of 100 m, was covered by a water mass of continental influence (CW) but not very recent (S > 37.75). In both parts of the cruise, above the thermocline (< 30 m), there was a patch of around 2000 km^2 where the influence of Ebro river discharges modified salinity to lower values. The patch in the first part was detached from the coastline and extended to 30 nautical miles offshore with a salinity minimum of 37.3 at station #032. In the second part of the cruise, the patch was attached to the coast, surrounding the Ebro delta with a salinity minimum, of 32.7 at station #142, located in the northern side of the delta. The deeper layers were occupied by WW and the transition to the LIW was in a typical depth sequence. TS values for LIW were reached at the deepest sampled levels in almost all the external stations.

Vertical structure of temperature shows that the thermocline was not deeper than 30-40 m (Fig. 9). A comparison between average surface temperature at first (around 17°C) and second (around 18.5°C) parts of the cruise suggest that, during the cruise, surface temperature was increasing at a net rate of 0.2°C per day. The mean temperature profile of the first part presented a surface homogeneous layer down to around a depth of 10 m while in the second part there was a continuous stratification from surface to the basis of the thermocline. Comparison of surface salinities of first and second parts of the cruise (Fig. 10) shows a decreasing of 0.4, in average, but with increasing variance. This change is coherent with horizontal salinity distributions at surface (Fig. 11) with the lower salinity patch attached to the Ebro delta during the second part of the cruise, suggesting a fresh water discharge was in course. The core of low salinity patch during the first part of the cruise was located 20 nautical miles south of the Ebro delta and surface salinity was much higher than in the second part. A comparison between the horizontal distributions of salinity at a depth of 15 m (Fig. 12) shows only the presence of the low salinity patch corresponding to the first part. The above results point out to that the low salinity patch found during the first part of the cruise was related to an old fresh water discharge advected offshore to the south and vertically mixed above the thermocline.

Horizontal distributions of salinity below the thermocline (Fig. 13) show slightly lower values in the southern half of the Iberian shelf in both parts of the cruise. However this relative lower salinity waters appear to have been advected southwards and inshore from first to second part of the cruise. The presence of this waters is in a good agreement with the general anticyclonic circulation over the continental shelf. Temperature and density distributions (Fig. 14) at the same depths would be consistent with this description.

The fluorescence profiles show a typical peak at mid depth, usually just below the thermocline, as a clear sign of a deep chlorophyll maximum. The horizontal distribution of the depth of this peak and the integrated values of fluorescence over the euphotic zone (0-100 m) are presented in Fig. 15. The deepest position of the deep chlorophyll maximum corresponded to the centre of the southern half of the Iberian shelf in good agreement with anticyclonic circulation. There were other zones with deep chlorophyll maximum near the edge of the continental shelf and in front of the Ebro delta. These situations just mentioned corresponded to high integrated values of fluorescence and may be associated with fertilising mechanisms such as the shelf-slope front or upwelling, according to the horizontal density distribution.

C/ GICS-3 (May 1995)

Data

From May 10 to 26, 1995, a total of 134 CTD casts were performed in this cruise. The strategy was similar to that in the previous cruises. In all casts CTD was lowered down near to the bottom on the continental shelf, or to near 500 m (max 490 m at station #031) when the depth was larger.

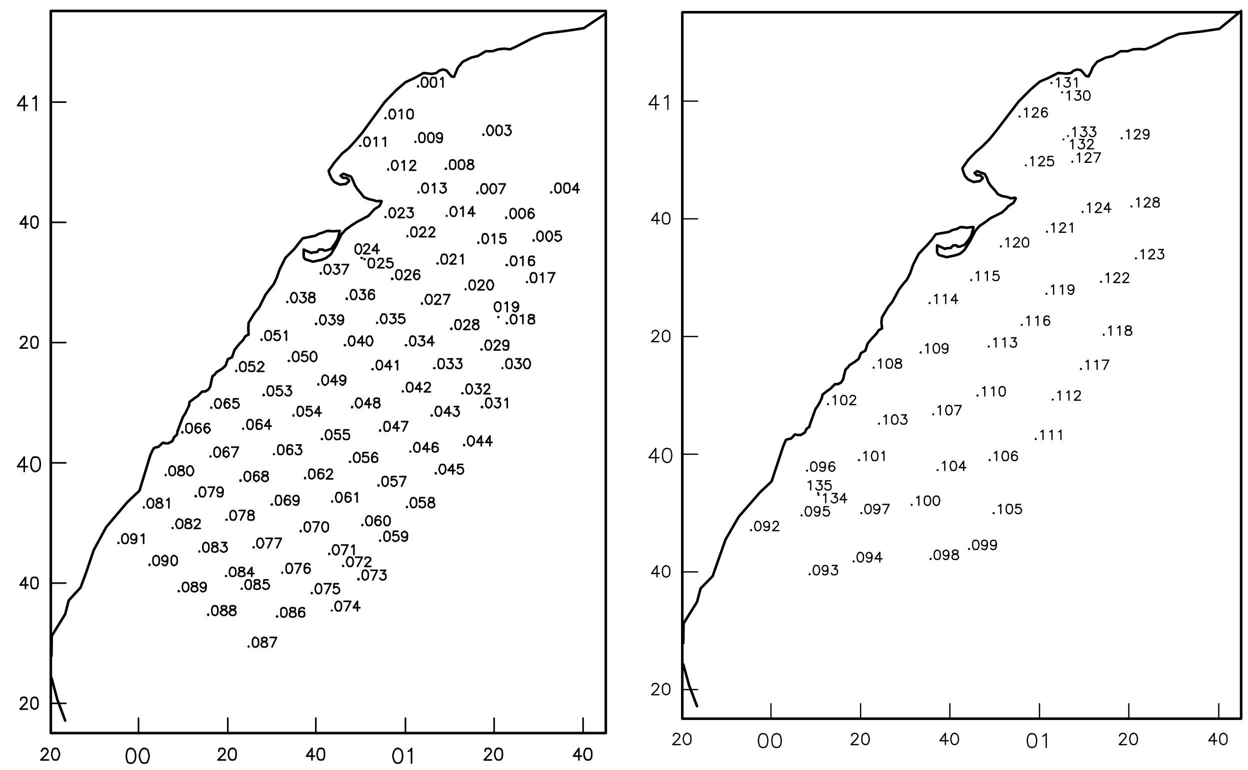
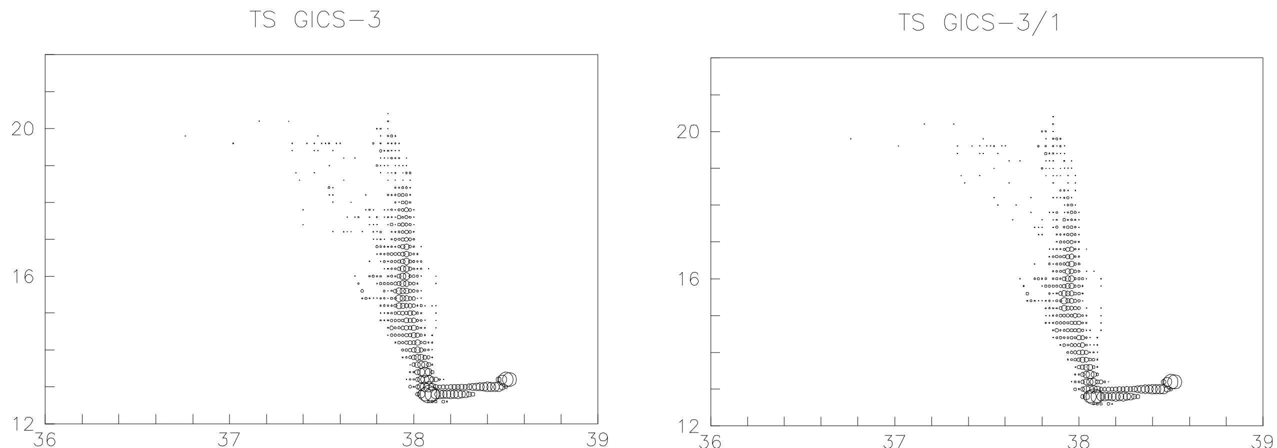


FIG. 16. - Map of the Catalan Sea (Western Mediterranean) area sampled with CTD casts during GICS-3 cruise. Left map: first coverage (from North to South); right map: second coverage (from South to North).



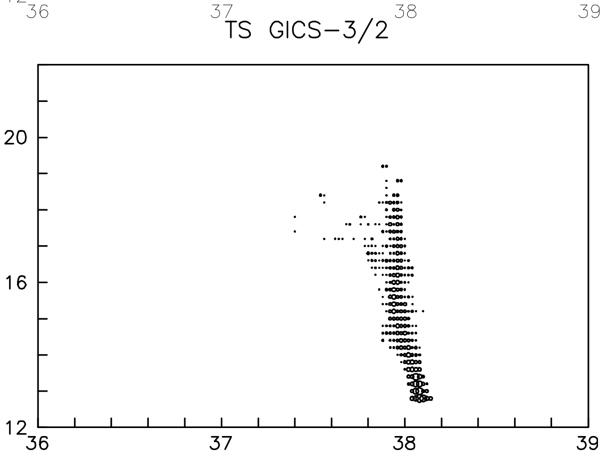


FIG. 17. - TS diagrams of the GICS-3 cruise. Top left: general; top right: 1st coverage, and bottom right; 2nd coverage.

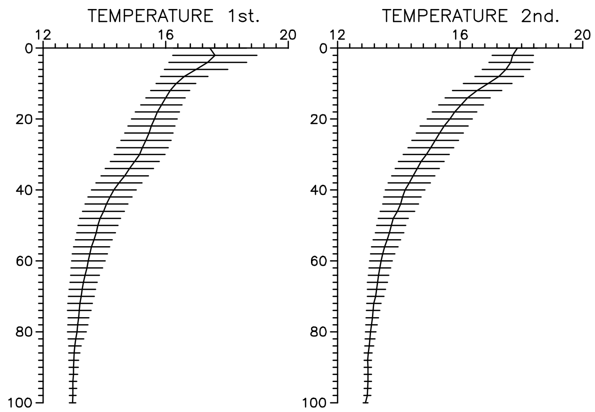


FIG. 18. - Average vertical Temperature profiles during GICS-3 cruise.
Left: 1st coverage, and right: 2nd coverage.

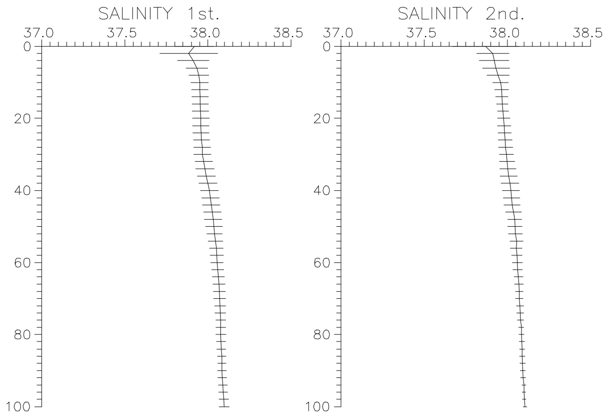


FIG. 19. - Average of 23 vertical Temperature profiles during GICS-3 cruise.
Left: before, and right: after the storm of May 11-13, 1995.

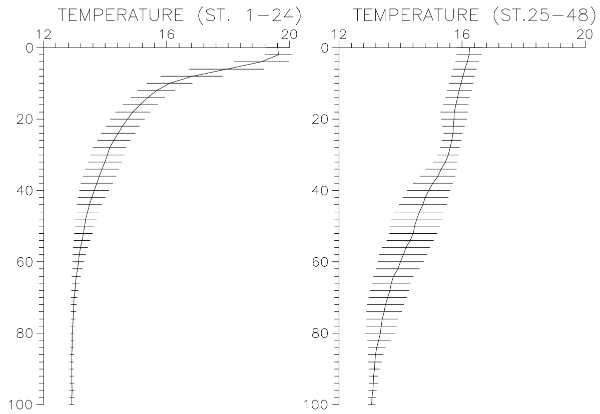


FIG. 20. - Average vertical Salinity profiles during GICS-3 cruise.
Left: 1st coverage, and right: 2nd coverage.

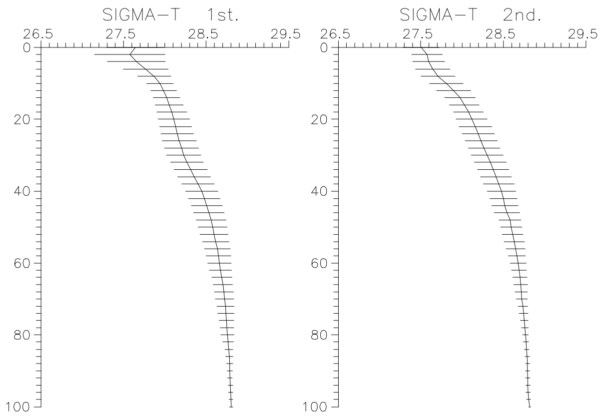


FIG. 21. - Average vertical Density profiles during GICS-3 cruise.
Left: 1st coverage, and right: 2nd coverage.

The studied area (Fig. 16) covered over all the Iberian shelf and the Golf of Sant Jordi, extending to the continental slope, from 41° 03' to 39° 30' N and from 0° 05' W to 1° 33' E, in a rectangle oriented with the coastline. As in the previous surveys, the cruise was divided into two parts covering almost the whole area twice: from May 10 to 18, stations #001 to #091 and from May 18 to 22, stations #092 to #131. Data from station #002 were rejected due to a CTD malfunctioning. In the first part casts were distributed more or less regularly in the area, spaced about 7.5 nautical miles, following transects perpendicular to the coastline. The sampling strategy of the second part was in part conditioned to other operations. In this second part casts were also distributed in transects but restricted to the continental shelf and only 3 casts per transect were obtained. The remaining stations #132 to #135, from May 22 to 26 were associated to specific acoustic experiments.

Results

According to the general TS diagram (Fig. 17) the surface layer, down to around a depth of 100 m, was covered by a water mass of continental influence (CW) but not very recent (S > 37.75). A very superficial (<10 m) patch of lower salinity water (up to 36.7 at station #012) was present in the northern side of the Ebro delta during the first part of the cruise. During the second part and the rest of the cruise, the patch was much less conspicuous (minimum salinity of 37.1 at station #132).

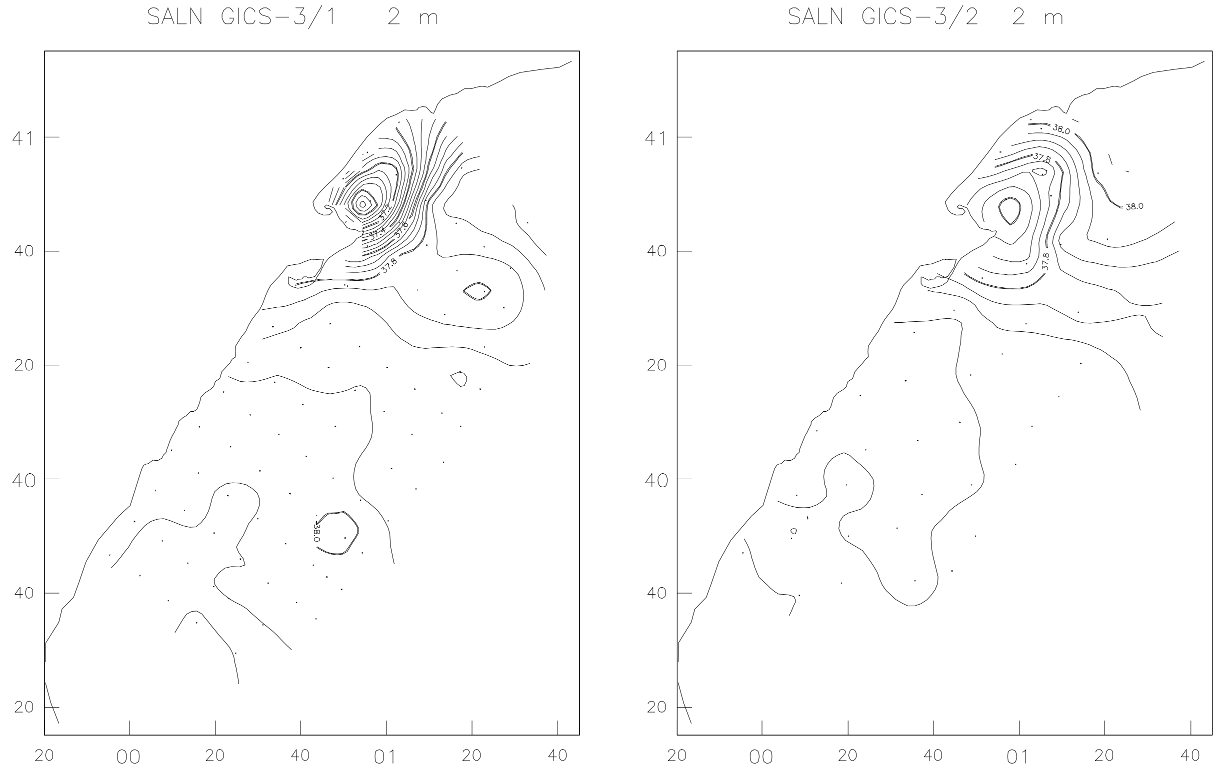


FIG. 22. - Horizontal Salinity distributions during GICS-3 cruise at surface (2 m water depth).
Left map: 1st coverage; right map: 2nd coverage.

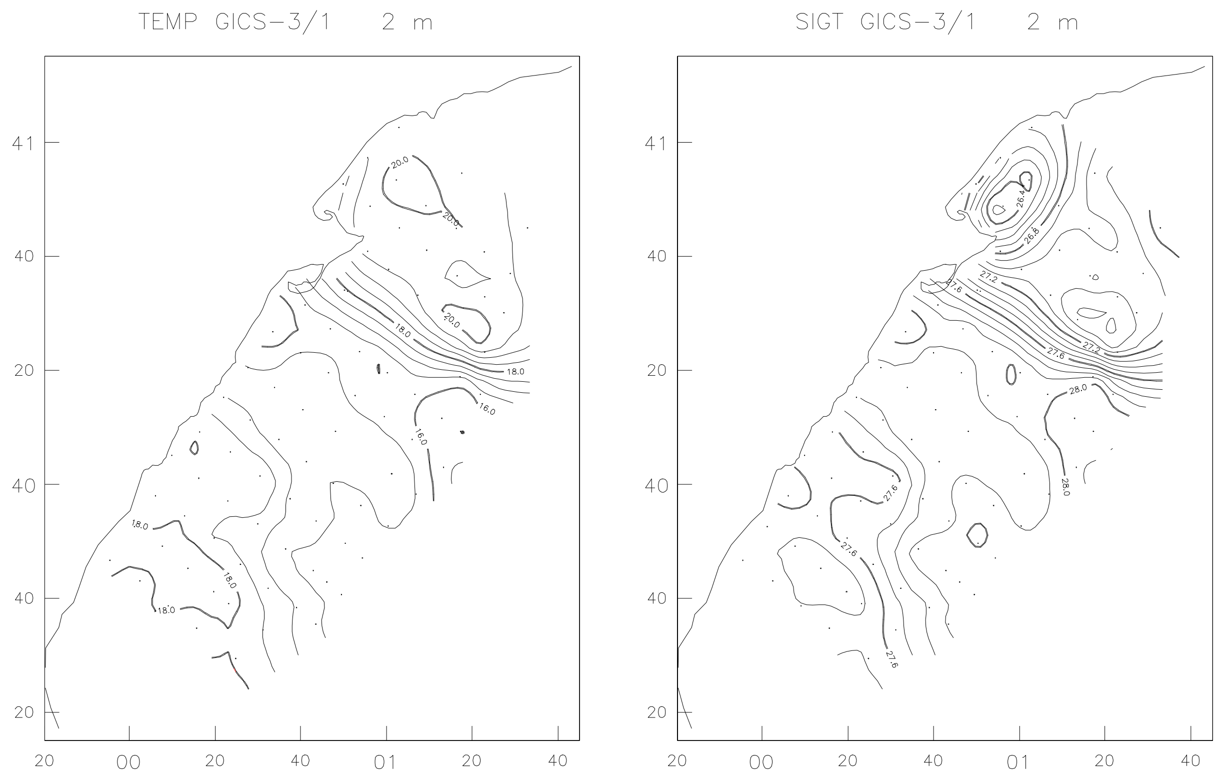


FIG. 23. - Horizontal Salinity distributions during GICS-3 cruise (1st coverage) at surface (2 m water depth).
OF Temperature (left map), and Density (right map).

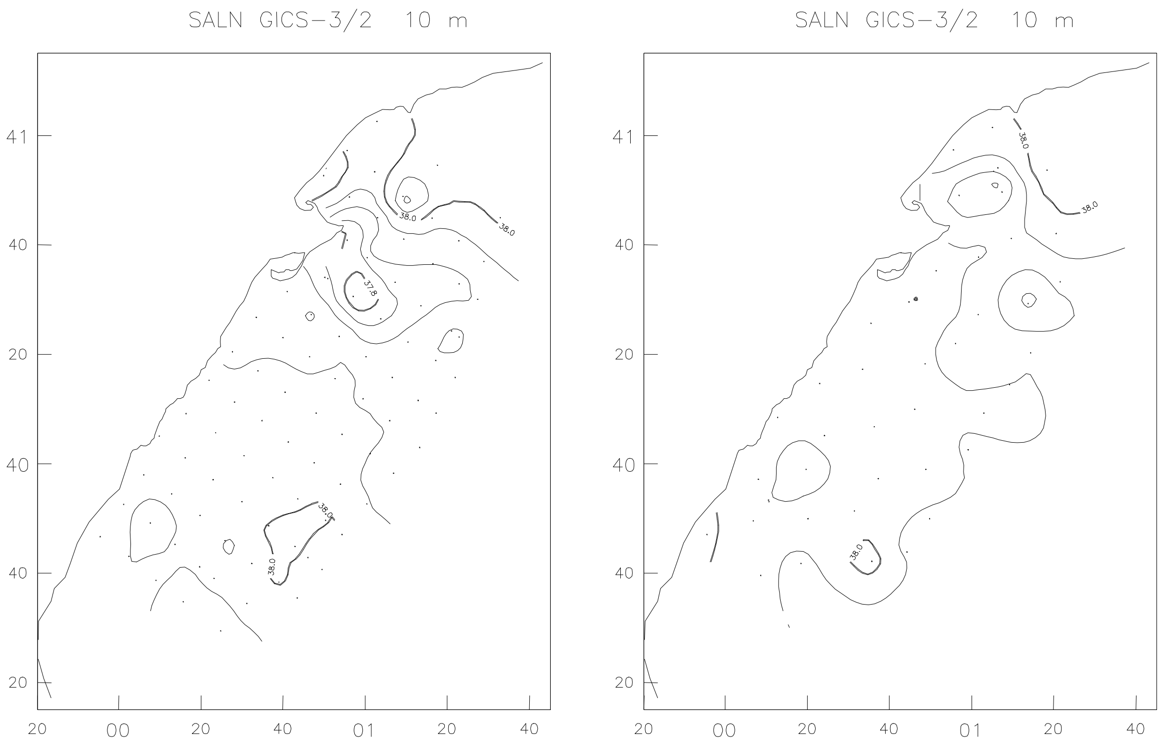


FIG. 24.1. - Horizontal Salinity distributions during GICS-3 cruise at 10 m water depth.
Left map: 1st coverage; right map: 2nd coverage.

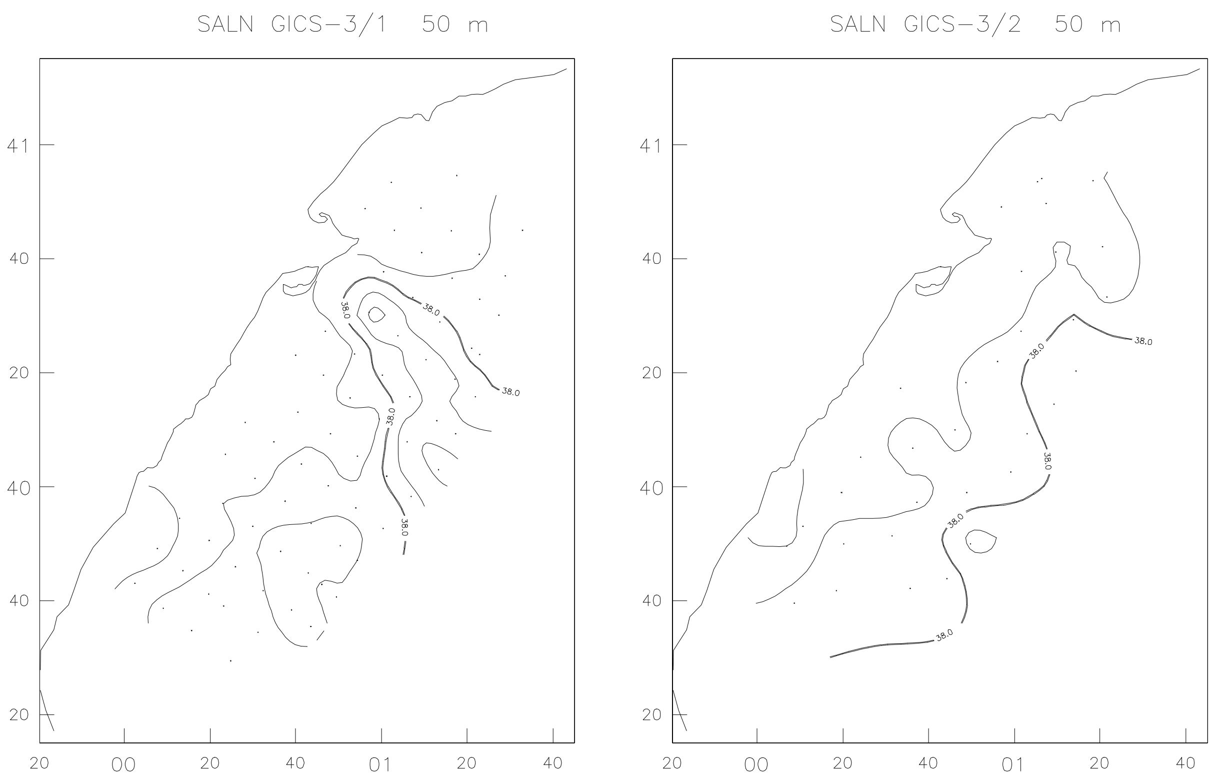


FIG. 24.2. - Horizontal Salinity distributions during GICS-3 cruise at 50 m water depth.
Left map: 1st coverage; right map: 2nd coverage.

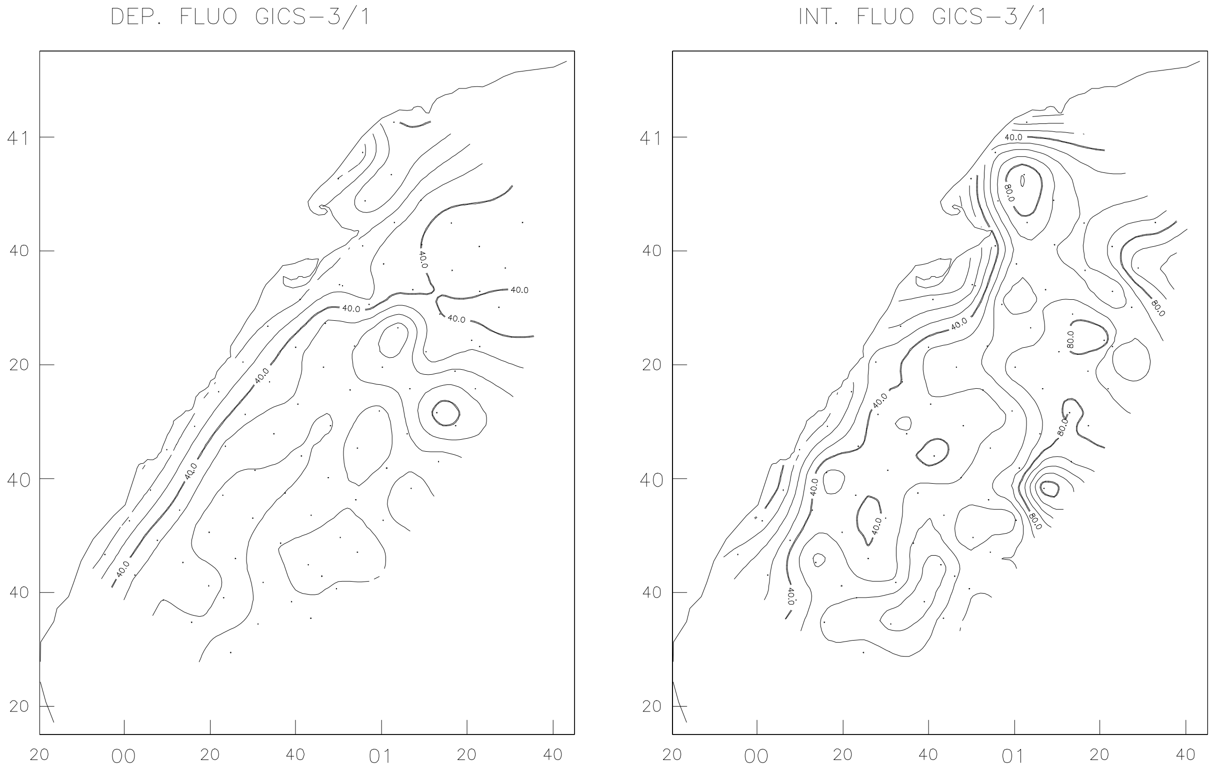


FIG. 25. - Horizontal distributions during GICS-3 cruise.
Left map: 1st coverage, Fluorescence integrated value over the euphotic zone;
right map: 2nd coverage, depth of maximum peak of Fluorescence.

This situation suggested that the last important release of fresh water was just before the beginning of that cruise. During the first part, an important wind storm started the evening of May 11, after station #024, and the cruise had to be interrupted during more than two days. The cruise was resumed the morning of May 14 repeating the last cast. As it will be discussed later, this storm episode had a dramatic influence on water stratification. As a consequence, it not only affect the synoptic interpretation of the first part of the cruise but the whole cruise is marked by this event and may help to understand one of the spreading mechanisms of continental waters.

The deeper layers, as usual, were occupied by WW and the transition to the LIW in a typical depth sequence. TS values for LIW were reached at the deepest sampled levels in almost all the external stations.

Vertical structure of temperature shows a continuous stratification from surface to around 50 m (Fig. 18). A comparison between average profiles at first and second parts of the cruise shows no significant differences during the cruise. The variance, however, was higher during the first part. This is an apparently surprising result as in other cruises temperature presented a continuous increasing trend which was consistent with the spring season.

The key to explain this anomaly is the wind storm of May 11 to 13 (between stations #024 and #025) because the mean profile of the first part consists on a mixing of the two different situations found before and after the storm. A comparison of mean profiles of the 23 stations before and immediately after the storm reveal the importance of this wind episode (Fig. 19), which produced a decrease of more than 3°C in mean surface temperature (from 19.6 to 16.3 °C). Then a comparison of mean temperature of the first part after wind with the second part, reveals the usual rate of temperature increase (around 0.2 °C per day).

Moreover, the thermocline before wind storm was clear and shallow (around 20 m), while after the storm surface water was homogenised down to around 30 m. This represented not only a heat loss but also a redistribution of heat along the water column, the temperature increasing below 20 m (for example, more than 1°C at 30 m).

After the wind, the departure for the typical increase by solar heating was a profile where temperature at lower levels was higher than usual, so that the shape of temperature profile at second part of the cruise shows a continuous stratification instead of the classical thermocline (Fig. 18).

Mean salinity and density profiles (Figs. 20 and 21) for first and second parts of the cruise have similar aspect due to same reason mentioned above. In this case, however, a comparison before and after wind storm is not significative because of their spatial differences: the whole first group of stations lies within a low salinity patch near the Ebro mouth, while the second group of stations lies almost completely out of this low salinity patch. Consequently, the comparison would be distorted by this fact.

Comparison of horizontal salinity distributions at surface (Fig. 22) at first and second parts of the cruise show the surface evolution of the low salinity patch near the Ebro delta and the relative high values in the centre of the Iberian shelf, probably due to the vertical mixing caused by wind. Horizontal surface temperature and density distributions during the first part of the cruise (Fig. 23) may help to the previous interpretation because they show an apparent temperature front, which evidences the difference before and after wind storm, and the higher values of density and lower temperature on the Iberian shelf evidencing vertical mixing. Deeper salinity horizontal distributions (Fig. 24) at 10 and 50 m show two interesting events: (i) offshore spreading of the low salinity waters to deeper layers, and (ii) the time evolution of this process.

The fluorescence profiles show a typical peak at mid depth, around 40 m, as a clear sign of a deep chlorophyll maximum. The horizontal distribution of the depth of this peak and the integrated values of fluorescence over the euphotic zone (0-100 m) are presented in Fig. 25. The deepest position of the deep chlorophyll maximum (60-70 m) was found in the offshore stations, near the shelf break while near the coast the maximum fluorescence was shallower (20-30 m) in good agreement with the vertical mixing induced by strong winds. In the first part of the cruise before the wind storm there were found high fluorescence values at surface in the stations lying in the low salinity patch. Near the shelf slope front the deep fluorescence maximum was, in general, higher and shallower than in the surrounding stations.

Discussion

GICS cruises have been carried out in the area near the Ebro delta which is characterised by a fresh water input from the Ebro river, a wide continental shelf (30-40 nautical miles) and the presence of a shelf slope front contouring the shelf break (Font *et al.*, 1988). From an hydrographic point of view those features are dominating through their interactions. There are also two important sources of nutrients: fresh water and from the interaction of the shelf-slope front with the bottom topography due to the change in the orientation of the continental slope. Strong wind events may also contribute to the fertilisation through intense mixing in shallow areas.

All GICS cruises were coincident in dates, mid spring (May). During this season the thermal stratification is in full developing process and the river input usually reaches its annual maximum (600-1000 m^3/s) due to frequent rain and snow melting from mountains. In such environment a thin surface layer of low salinity can be found in the vicinity of the Ebro mouth that can easily spread due to the stratification (GICS-1 and GICS-2). Surface salinity distributions seem to indicate that there are intermittent high fresh water releases through mechanisms still not known. In such circumstances coastal waters can travel offshore forming fast filaments that can overpass the shelf-slope structure (Wang *et al.*, 1988).

However, as wind episodes contribute to vertical mixing, these low salinity waters may sink to a mid depth (40-60 m) when surface layer has been homogenised by the wind mixing (GICS-3). In such cases this mid-depth water tends to travel offshore to the shelf edge and enhance the shelf-slope front.

The circulation over the continental shelf tends to be anticyclonic when there is no dominant wind. Then the centre of the Iberian shelf use to act as a buffer for coastal waters (as in GICS-2 cruise). This scheme of circulation can change with wind episodes. In the first step there is an enhancement of anticyclonic eddies through inertial oscillations but the second step is vertical mixing and increasing density (as in GICS-3 cruise). After wind, the new density distribution contribute to reversing the sense of the circulation.

The shelf-slope front interaction with the continental shelf has a role bringing deeper waters to the shelf usually at their northern and southern limits. This waters can be traced through its higher density and have been found in the bottom of the Iberian shelf and near the Ebro mouth. This is an alternative fertilising mechanism that may justify local enhancements of the deep fluorescence maximum.

CRUISES IN ADRIATIC SEA

GIAS-2 (September 1994)

Data

From September 10 to 24, 1994, a total of 95 CTD casts were performed in this cruise. In all casts CTD was lowered up to near the bottom.

The studied area (Fig 26) extended over the western side of the continental shelf in northern Adriatic, extending from 43° 00' to 45° 39' N and from 12° 20' to 14° 38' E, in a 40 miles wide strip following the Italian coastline.

The sampling strategy was *a priori* conditioned to the acoustic survey and fishing samples that had to be obtained by the Italian research vessel Salvatore Lo Bianco. However, after few days this strategy was definitely left due to problems of synchronisation. Then every ship followed its own program and hydrographic sampling continued towards the north with the only interruptions due to bad weather episodes. The last days available were dedicated to extend the CTD coverage south of Ancona.

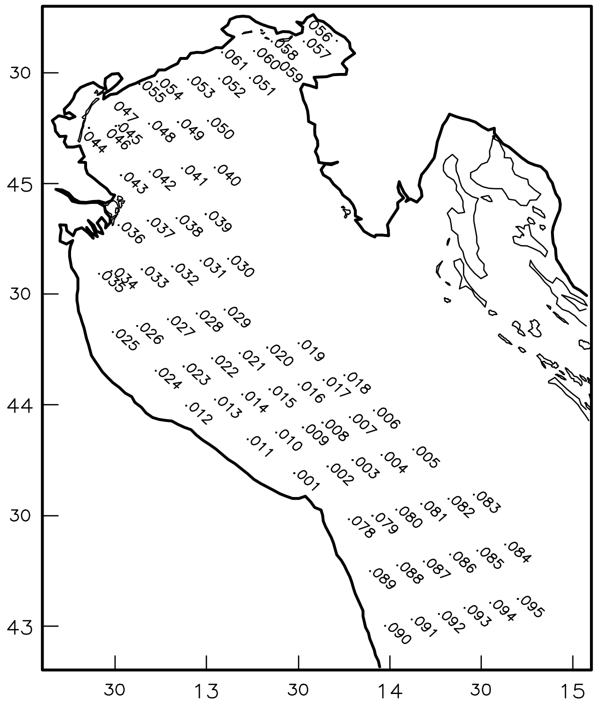


FIG. 26. Map of Northern Adriatic Sea area sampled with CTD casts during GIAS-2 cruise.

Note to FIG. 27.: Parts noted as G1, G2, G3, G4 and G5 correspond to the following groups of CTD casts: G1: 1 to 45; G2: 46 to 55; G3: 56 to 61; G4: 62 to 76 (Magic Square) and G5: 77 to 95 (see the text).

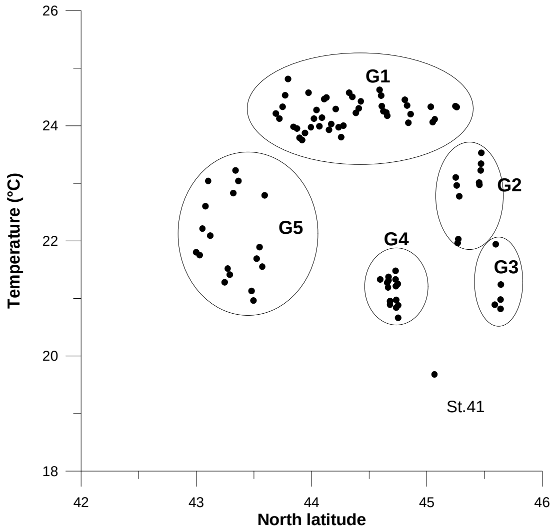


FIG. 27.1. - Sea water temperature *versus* latitude during GIAS-2 cruise at 10 meter depth.

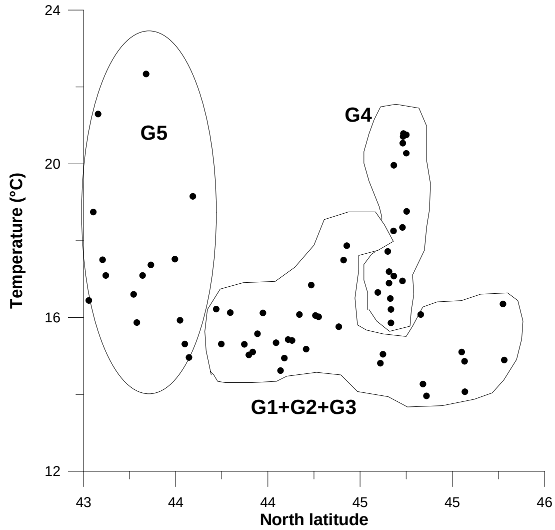


FIG. 27.2. - Sea water temperature *versus* latitude during GIAS-2 cruise at 25 meter depth.

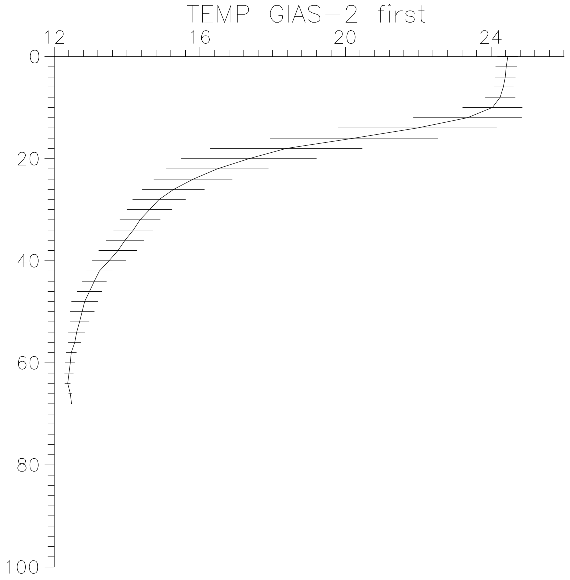


FIG. 28. - Average vertical Temperature profile during the first part of the cruise GIAS-2, before storms (G1 group of casts in Fig. 27). See also the note of Fig. 27.

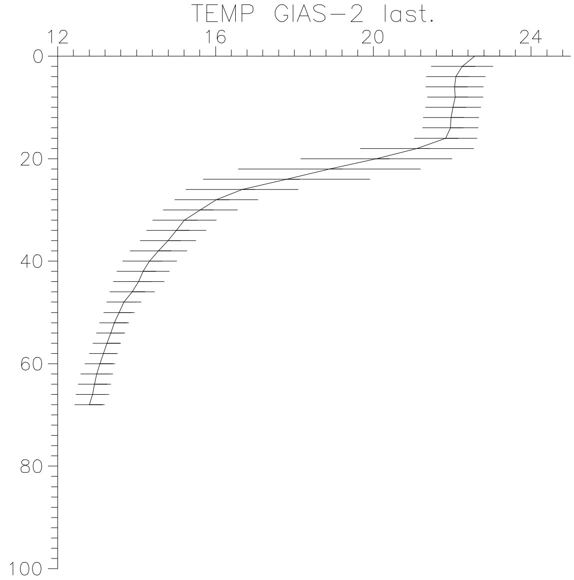


FIG. 29. - Average vertical Temperature profile during the last part of the cruise GIAS-2, after storms (G5 group of casts in Fig. 27). See also the note of Fig. 27.

The cruise was divided into five parts, with three interruptions due to bad weather conditions and one acoustic experiment (Magic Square).

CTD casts were distributed more or less regularly in the area, spaced about 7.5 nautical miles, following transects, separated around 12 miles, roughly perpendicular to the coastline, up to the limit of Italian waters.

The cruise started at Ancona and continued to the north. The first part covered the area from Ancona to Venezia, stations #001 to #045, from September 10 to 13. The second part covered two transects off Venezia, stations #046 to #055, from September 16 to 17, when sampling had to be stopped again due to bad weather. On September 20 the rest of the northern part was sampled, stations #056 to #061.

The cruise continued to perform the time/space small scale experiments into the so called "Magic Square", a suitable box located SE of the Po delta.

During the experiment repeated CTD sampling were obtained at the corners of the Magic Square, stations #062 to #077, during September 21 and 22. The last part of the cruise consisted on three transects south of Ancona, from September 22 to 24, stations #078 to #095.

Results

The time gap, 13 days, between the first and last parts (north and south of Ancona) and the significant changes produced by storms of September 14 and 18 have a strong influence in difficulting a synoptic interpretation of the total results of the cruise. Fig. 27 shows a scheme of the temperature evolution at 10 m and 25 m depth with stations grouped in the five different parts, which shows the above mentioned difficulties for a synoptic interpretation.

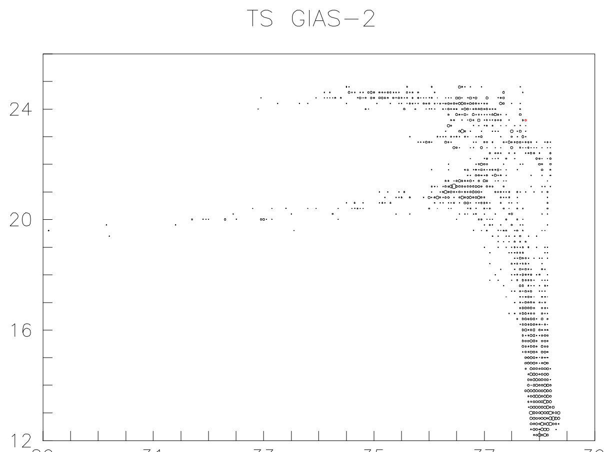


Fig. 30. - General TS diagram of the GIAS-2 cruise.

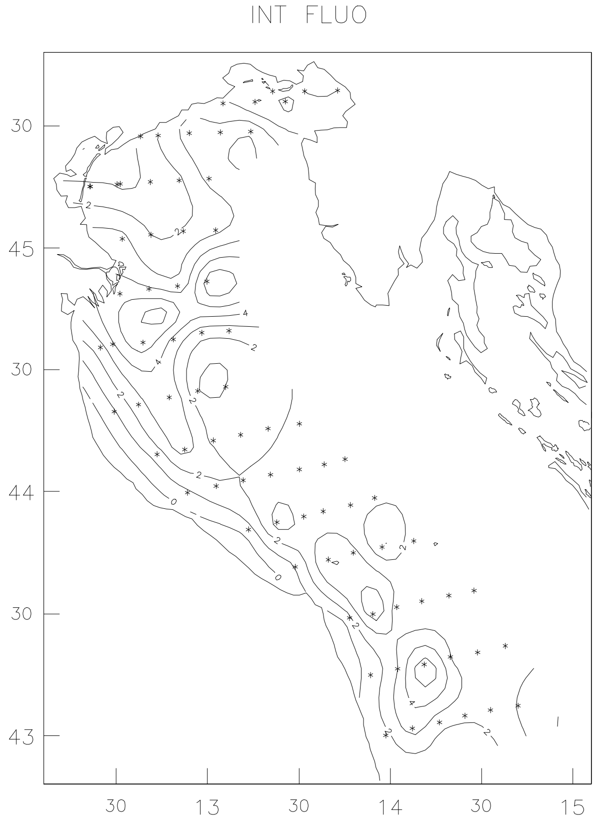


Fig. 32. - Horizontal Fluorescence distribution during GIAS-2 integrated over the euphotic zone.

At the beginning of the cruise a typical late summer situation was found with a well developed surface mixed layer and thermocline (around 30 m) with high surface temperature (>23°C) (Fig 28). This situation changed progressively to an autumn situation after each one of the wind storms.

The vertical temperature distribution at the end of the cruise revealed lower surface temperature, deeper surface mixed layer, still with a conspicuous thermocline, and frequent surface temperature inversions, sometimes higher than 3°C (Fig. 29), where surface salinity was low in the area influenced by the Po river plume.

TS diagram of the whole cruise (Fig. 30) shows the different TS relationship at the different passages through the Po river plume. The rest of the diagram shows the characteristic Adriatic shelf water free of direct continental influence, with salinity around 38.

In spite of the problem of the lack of synopticity, the Po river plume has been mapped at several levels (Fig. 31) showing a straight offshore penetration at surface and southward spreading along the Italian coast at lower levels, up to 20 m.

Fluorescence profiles show a typical signature of the deep fluorescence maximum just below the thermocline at most of the stations. This maximum, however, is low if it is compared with higher values found at surface associated with the Po river plume. The distribution of fluorescence values integrated vertically (Fig. 32) shows a good correspondence with the influence of the Po river plume as shown by horizontal salinity distributions.

GIAS-3 (September 1995)

Data

From September 5 to 19, 1995, a total of 123 CTD casts were performed in this cruise. In all casts CTD was lowered up to near the bottom. The studied area (Fig. 33) extended over the western side of the continental shelf in northern Adriatic, extending from 43° 00' to 45° 38' N and from 12° 22' to 14° 38' E, in a 40 miles wide strip following the Italian coastline. The cruise was divided into two parts.

The first part consisted on the systematic survey with a net of CTD casts distributed more or less regularly in the area, spaced about 7.5 nautical miles, following transects, separated around 12 miles, roughly perpendicular to the coastline, up to the limit of Italian waters. The cruise started at the southern limit of the area and continued to the north with a technical stop at Ancona. This first part covered the whole area, stations #001 to #075, from September 5 to 12 with an interruption of 40 hours between September 7 and 9. The second part consisted on an acoustic experiment along a so called “Spiritual Line” in front of the Po delta. CTD casts, from #076 to #123, were repeated along the line, 20 miles long, oriented NW-SE, during 5 days, from September 13 to 19. In contrast with the previous year survey this time data has been collected sequentially without significant changes due to bad weather. This time then synoptic data analyses can be conducted.

Another important improvement of the systematic CTD survey, in this cruise, consisted on the availability of light penetration and transmission data together with fluorescence and the primary data of temperature and salinity. This cruise, the last of the project has proportioned the most complete data set of hydrographic survey.

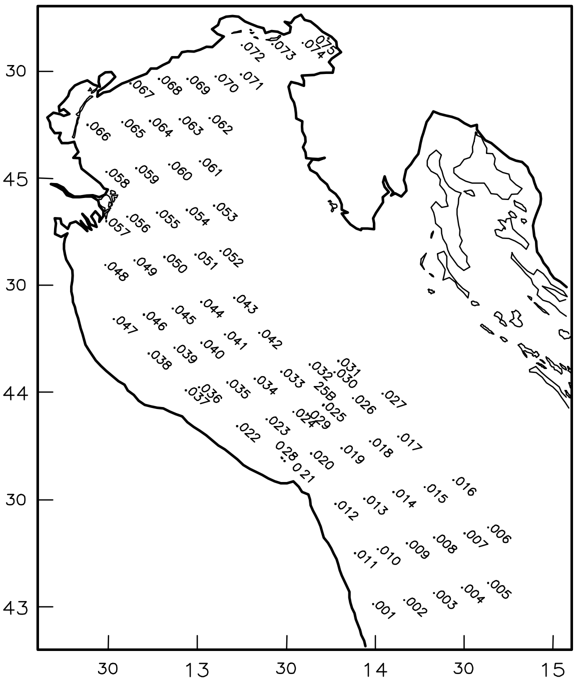


FIG. 33. - Map of the Northern Adriatic Sea area sampled with CTD casts during GIAS-3 cruise.

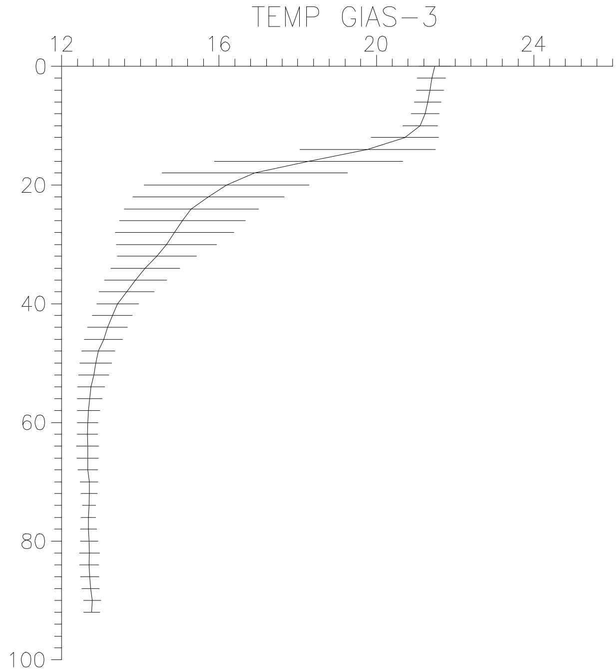


FIG. 34. - Average vertical Temperature profile during the cruise GIAS-3.

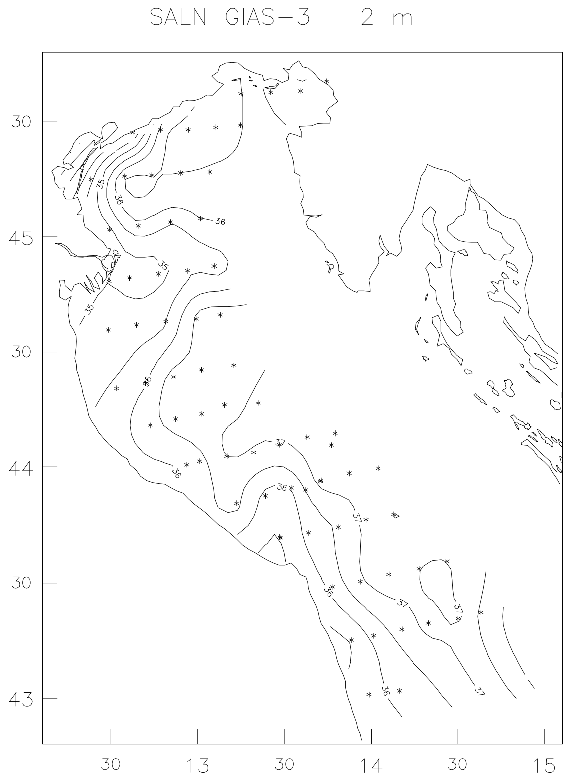


FIG. 35. - Horizontal Salinity distribution during GIAS-3 cruise, at 20 m water depth.

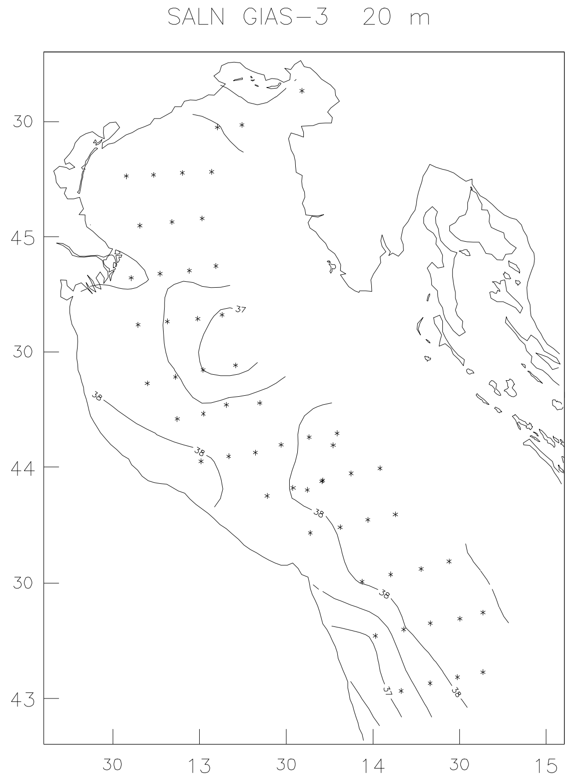


FIG. 36. - Horizontal Salinity distribution during GIAS-3 cruise, at surface (2 m water depth).

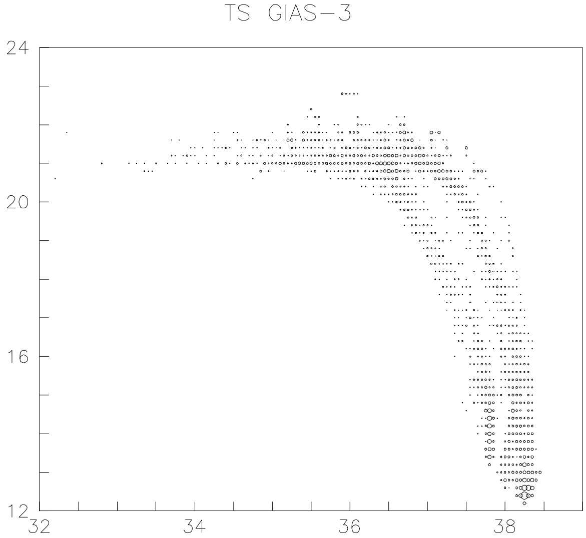


FIG. 37. - General TS diagram of the GIAS-3 cruise.

Results

The CTD coverage during the first part of the cruise was performed sequentially, from the south to the north, with the only interruption of around 40 hours at Ancona.

By contrast with the previous survey in Adriatic, GIAS-2, this time a synoptic view of the North-western Adriatic was obtained due to different weather condition.

The temperature profiles were typical of the end of summer with surface temperatures slightly lower than at the beginning of the previous year (<23°C) and a well developed thermocline, more then 7°C difference, around 20-30 m depth (Fig. 34). The Po river plume, as shown by surface salinity distribution (Fig. 35), was spreading directly offshore from the river mouth, but the direct influence of the river discharges, expressed in low salinity waters, was also present in a narrow strip, less than 10 miles offshore, along the coast at both sides of the Po delta. Further southward, near Ancona, another zone of low salinity appeared near the coast.

Direct continental water influence was observed at surface while at depths lower than 15 m this influence had both, a marked patchy character offshore and a marked tendency to generate salinity gradients parallel to the coast in the southern part (Fig. 36).

TS diagram of the whole first part of the cruise (Fig. 37) reveals a great uniformity over all the area. This diagram shows that the penetration of river discharges is produced through the surface mixed layer, at temperatures ranging between 21° and 22°C, up to salinities of 36.7-36.8. Then a progressive mixing at the thermocline drive salinities to the background (oceanic) values of 38.2-38.5. The above process is related to the salinity distributions found in the deeper (>15 m) layers.

The fluorescence profiles show, as in the previous cruise, the typical deep fluorescence relative maximum and also a surface absolute maximum associated with the Po river plume (Fig. 38). The surface fluorescence maxima were much higher (2-5 times) than the deep ones. The integrated fluorescence (Fig. 39) is dominated by the surface fluorescence values where they are important and show an offshore gradient very well correlated with the salinity distributions at deeper layers (>15 m).

Light transmission profiles are in good agreement with fluorescence profiles indicating that most of the suspended particles were phytoplanktonic. A careful study comparing profiles of fluorescence, light transmission and PAR (during day time), especially during the second part of the cruise (Spiritual line) would give more details about the above mentioned relations, but it is out of the scope of this report.

Discussion

The most important features in Northern Adriatic are the input of continental waters from Po (Po+Adige) river, draining almost the whole southern side of the Alpine mountains and the northern side of Apenine mountain range, and the large continental shelf with depths lower than 60 m. GIAS cruises were conducted at the end of summer; this season is usually characterised by a deep surface mixed layer and the transition to autumn.

The day-light period shortens and irruptions of colder air are more frequent than in summer (especially in GIAS-2). Water was still well stratified but the balance air/sea temperature started to change from high to low values enhancing surface cooling and mixing. The GIAS-2 cruise show a dramatic sequence from late summer to full autumn, in the northern part, it being smoother in the southern part. By contrast, the whole GIAS-3 cruise occurred in classical late summer conditions.

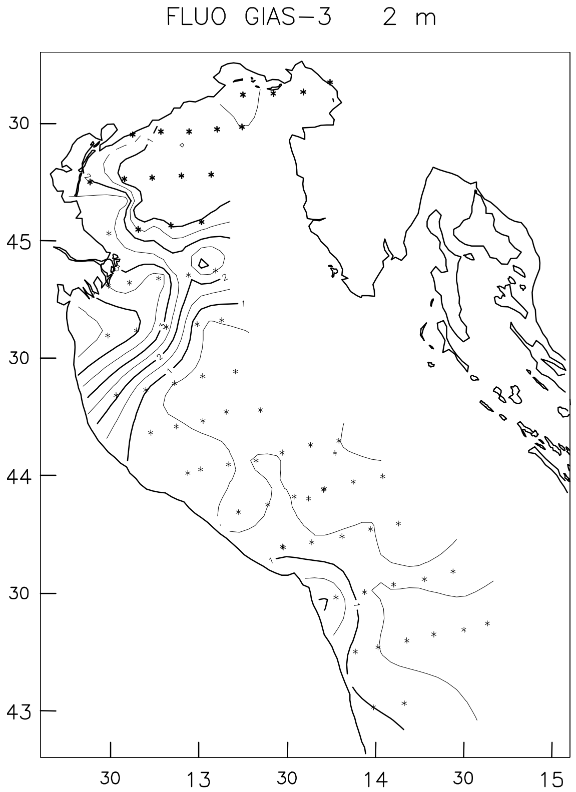


FIG. 38. - Horizontal Fluorescence distribution during GIAS-3 cruise, at surface (2 m water depth).

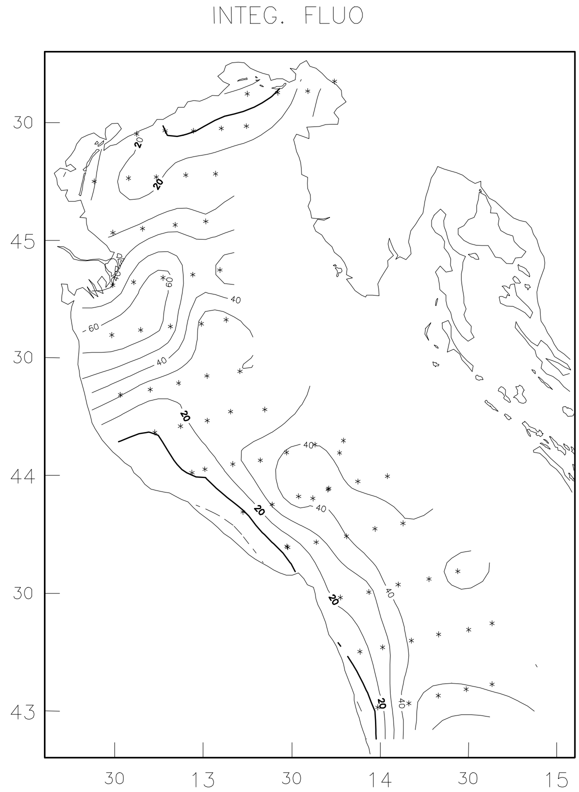


FIG. 39. - Horizontal Fluorescence distribution integrated over the euphotic zone, during GIAS-3 cruise.

In both cases however the well developed thermocline give a strong stratified structure with an homogeneous surface mixed layer.

This conditions combined with the important amount of Po river discharges affect the penetration, spreading and stability of continental influenced waters. This, in turn, should have an important effect supporting phytoplanktonic populations at surface levels near the main river plume. A secondary region with relatively high fluorescence was found near the coast at Ancona in coincidence with a relatively lower salinity area along the coast.

GENERAL DISCUSSION

T-ECHO cruises covered two different Mediterranean regions with some common characteristics, from the hydrographic point of view: the presence of an important input of continental water and a relatively large continental shelf. There are also some differences not only regarding the regional characteristics but also the season in which the cruises were conducted.

The GICS series, in the Catalan Sea, were conducted in mid spring when the stratification is rapidly developing and the continental inputs are high due to rain and snow melting.

By contrast GIAS series were conducted at the end of summer near autumn, when the stratification is fully developed and water starts the homogenisation process loosing heat.

Concerning the regional differences, the most important are in terms of scale: both the dimensions of the area and the volume of continental inputs from the Po river, in the Adriatic are larger if compared with Iberian shelf and the Catalan Sea with Ebro river input. Other differences are that the Adriatic sea is semienclosed, it is like a prolongation of the Po valley surrounded by mountain ranges and, then, the climate has an important component of "continentality" (Buljan & Zore-Armada, 1976). By contrast the Catalan Sea is open to the Western Mediterranean basin. This climatic difference is especially relevant in winter, but also at the end of summer and should explain the changes found in 1994.

Despite the above mentioned differences the most important features concerning the pelagic environment in both areas are the processes related to the influence of continental waters that are responsible of the relatively high phytoplankton biomass in these regions. The differences in water volumes, however, explain the magnitude and distribution of fluorescence values: higher in the Adriatic with a dominant surface layer, while in the Catalan Sea they were lower and with a dominant deep maximum.

The mixing and spreading process of continental waters follow similar patterns in both areas. The differences are related to water volumes involved and to the state of stratification in the water column. For instance, in the Adriatic, lower salinity waters covered almost all the surface layer without significative temperature difference while in the Catalan Sea there is a limited spreading and a tendency to sink after a mixing process.

The interaction with the shelf-slope front, along the continental margin in the Catalan Sea region, plays a role in limiting the exchange between coastal and offshore waters, but also contributes to enhance the deep fluorescence maximum along the shelf break. In the whole Northern Adriatic, only coastal waters are present and the above mentioned interaction with offshore waters is only perceptible in the southern part, where traces of a deep fluorescence maximum can be observed.

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