Diurnal mesoscale patterns of 50 kHz scattering layers across the Ligurian Sea front (NW Mediterranean Sea)

Sound scattering layers
Mediterranean Sea
Ligurian Sea front
Cyclothone braueri (gonostomatidae)

Couches diffusantes sonores
Mer Méditerranée
Front ligure
Cyclothone braueri (gonostomatidae)

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ABSTRACT

Between March and June 1988, a series of diurnal acoustic records was carried out using a 50 kHz echosounder on a transect crossing the density front of the Ligurian Sea, off Villefranche-sur-Mer (Mediterranean Sea). The depth, thickness and pattern of the sound scattering layers were studied with respect to physical (temperature, salinity and density) and biological (chlorophyll *a*) measurements made along the acoustic transect. Seasonal differences were observed. A surface scattering layer (SSL), from 0 to 100 m, and a main deep scattering layer (MDSL), located between 250 and 550 m, occurred permanently during the study. In spring, an intermediate scattering layer (ISL), about 50 m thick, occurred between the SSL and the MDSL. The ISL, a permanent feature at this time of the year, was characterized by rapid horizontal changes in vertical distribution in the front and, away from the front, in the central zone. Significant differences in patterns of the SSL and MDSL occurred likewise in these two areas. The similarities of response in two different hydrological zones lead us to conclude that the deviating acoustic patterns observed during springtime are mainly consistent with the distribution of chlorophyll biomass in the Ligurian front.

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RÉSUMÉ

Structures diurnes à moyenne échelle des couches diffusantes détectées à 50 kHz au niveau du front de Mer Ligure (Méditerranée nord-occidentale)

De mars à juin 1988, des enregistrements acoustiques diurnes ont été effectués, avec un échosondeur fonctionnant à 50 kHz, sur une radiale traversant le front de densité de Mer Ligure, au large de Villefranche-sur-Mer (Mer Méditerrannée). La profondeur, l'épaisseur et la structure des couches diffusantes ont été étudiées en relation avec des mesures physiques (température, salinité et densité) et biologique (chlorophylle *a*) réalisées le long du transect acoustique. Des différences saisonnières ont été observées. Une couche diffusante de surface (SSL), de 0 à 100 m, et une couche diffusante profonde principale (MDSL), localisée entre 250 et 550 m, ont été observées en permanence pendant cette étude. Au printemps, une couche diffusante intermédiaire (ISL), épaisse d'environ 50 m, est apparue entre la SSL et la MDSL. La ISL, caractéristique à cette période de l'année, était marquée par des changements horizontaux rapides de sa répartition verticale dans le front, et au large du front, dans la zone centrale. Des différences significatives dans les structures de la SSL et de la MDSL existaient de même dans ces deux zones. Les similarités de réponse au sein de deux zones différentes d'un point de vue hydrologique, nous conduisent à conclure que les structures acoustiques atypiques observées au printemps résultent essentiellement de la distribution de la biomasse chlorophyllienne au niveau du front ligure.

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INTRODUCTION

There have been few studies of deep scattering layers in the Mediterranean Sea using high frequency echosounders. Some authors have reported general descriptions of variations in depth, number and intensity of scattering layers in the Western Mediterranean (Frassetto and Della Croce, 1965; Thiriot, 1967, Chapman *et al.*, 1974). Others have studied the influence of physical variables such as light (Boden and Kampa, 1958) or temperature distribution (Frassetto *et al.*, 1962), but no link has actually been established between the spatial distribution of sound scattering layers and both physical and biological parameters.

Hydroacoustic methods appear to be powerful tools to study the spatial patterns of organisms within the ocean. Frontal zones constitute unique ecosystems where the patchiness of marine populations is generally increased due to the complex physical environment. The changes in patterns of the sound scattering layers in a front can be related to faunal and water mass differences (Conte *et al.*, 1986; Nero and Magnuson, 1989; Arnone *et al.*, 1990; Nero *et al.*, 1990; Sprong *et al.*, 1990), and thus a source of considerable information.

A permanent geostrophic front, located in the offshore part of the Ligurian current (defined as the primary circulation), occurs in the Ligurian Sea (Northern Mediterranean Sea). The frontal zone is characterized by a rapid change in the horizontal density gradient, increasing seaward and separating the coastal peripheral zone from the central zone of the Ligurian Sea (Fig. 1). The peripheral, frontal and central zones present different hydrological characteristics. The front is characterized by tilted isopycnals with depth. The peripheral zone is linked mainly to the Ligurian current, flowing southwestward in the northern part of the basin. The distribution of the Intermediate water (S = 38.55, T° = 13.55) is deeper in the peripheral zone than in the front. The central zone is characterized by a low vertical stratification (Boucher *et al.*, 1987). The occurrence of the Ligurian front is a permanent feature throughout the year. The horizontal gradients characteristic of the front can be observed at the surface during winter and below the thermocline in other seasons. The horizontal difference of surface density across the front ranges typically from 0.6 to 1 in summer and from 0.2 to 0.4 in winter (Boucher *et al.*,1987). The secondary circulation, associated with the front, is organized in divergent and convergent cells. Due to the vertical component of the circulation bringing nutrients to the surface, biological activity is increased locally. Maximum concentrations of both chlorophyll biomass and zooplanktonic populations are observed in the frontal zone with highly anisotropic distributions (Boucher, 1984; Boucher *et al.*, 1987; Ibanez and Boucher, 1987). A noteworthy feature is the occurrence of a downwelling transport of organic matter along tilted isopycnals from the euphotic layer to deep levels and from the front to the coast. The occurrence of populations of midwater filter feeders (salps and appendicularians) below 400 m is therefore explained by a rapid downwelling of autotrophic living microphytoplankton in the front (Laval *et al.*, 1989 *b*; Gorsky *et al.*, 1991). The vertical distribution of macroplanktonic and nektonic populations is, however, difficult to assess with a sufficient resolution using conventional nets, especially in frontal zones where small-scale variability occurs. Acoustic imaging presents two advantages over net sampling: it samples a greater volume of water and it provides a continuous two- dimensional record.

This paper illustrates the distribution of 50 kHz sound scattering layers and shows how they are linked to the physical and biological structure of the Ligurian front. The main purpose is to demonstrate that the pattern of the scattering layers reflect part of some physical and biological processes such as deep vertical mixing, downwelling of organic matter and phytoplanktonic biomass distribution.

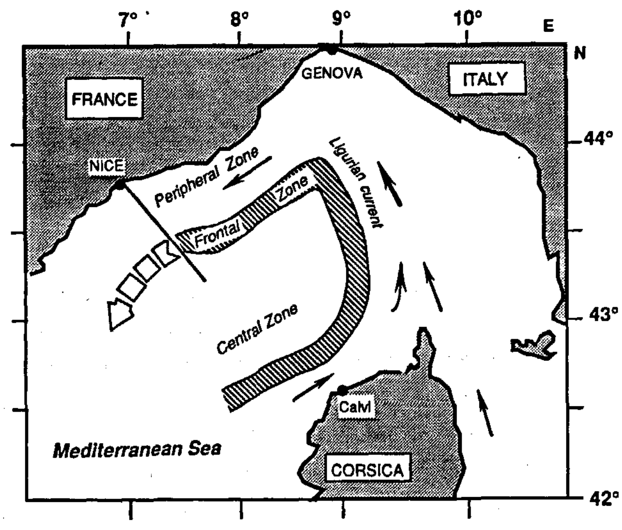


Figure 1

Schematic map of horizontal circulation in the Ligurian Sea with the relative locations of the peripheral, frontal and central zones. Variations of strength of the Ligurian current are represented by different thickness of arrows (from Boucher et al., *1987).*

Carte schématique de la circulation horizontale en Mer Ligure montrant les positions relatives des zones périphérique, frontale et centrale. Les variations d'intensité du courant ligure sont matérialisées par des flèches d'épaisseur variable (d'après Boucher *et al.*, 1987).

Table

Dates and distances of the 50 kHz acoustic records made during Frontal-T *transects and* Tomofront-1 *cruise from March to June 1988. The 19 May acoustic transect was made during the* Migragel-2 *cruise. The number of hydrographic stations corresponding to each acoustic record is indicated. The distances of both acoustic transects and hydrographic stations are in nautical miles from Cape Ferrat. Hours are in local time. Note that: a) the eight hydrographic stations corresponding to the 18 April acoustic transect were collected during 18 to 21 April, 1988; b) the acoustic profile from 10 March was interpreted from the six stations made on 14 March.*

Dates et distances des enregistrements acoustiques réalisés à 50 kHz au cours des radiales *Frontal-T* et de la campagne *Tomofront-1* de mars à juin 1988. La radiale acoustique du 19 mai a été réalisée dans le cadre de la campagne *Migragel-2*. Le nombre de stations hydrographiques correspondant à chaque enregistrement acoustique est indiqué. Les distances de début et de fin des radiales acoustiques et des stations hydrographiques sont exprimées en milles nautiques depuis le Cap Ferrat. Les heures sont en heure locale. Noter que: a) les huit stations hydrographiques correspondant au transect acoustique du 18 avril ont été effectuées entre les 18 et 21 avril 1988; b) le profil acoustique du 10 mars a été interprété d'après les 6 stations réalisées le 14 mars.

Date	**Distance offshore**		**Time**		**Hydrographic stations**			**Cruise or**
	Start	**End**	**Start**	**End**	**Number**	**From**	**to**	**transect**
March 10	28	4	14 h 24	17 h 04	6	3	28	*Frontal-T*
March 28	4	28	10 h 16	17 h 06	6	3	28	*Frontal-T*
April 12	4	28	9 h 39	12 h 43	-	-	-	*Tomofront-1*
April 12	28	10	12 h 44	14 h 53	-	-	-	*Tomofront-1*
April 14	4	28	10 h 28	13 h 20	11	10	28	*Tomofront-1*
April 20	4	16	9 h 40	11 h 18	8	10	25	*Tomofront-1*
April 22	4	18	9 h 48	11 h 24	4	12	18	*Tomofront-1*
April 28	4	16	9 h 02	10 h 17	-	-	-	*Tomofront-1*
May 19	5	21	9 h 12	11 h 08	-	-	-	*Migragel-2*
June 1	4	28	10 h 22	18 h 47	6	3	28	*Frontal-T*

METHODS

Hydrographic and acoustic data were collected aboard R/V Korotneff during the *Frontal-T* and *Tomofront-1* experiments (part of the France-JGOFS program) between March and June 1988 (Tab.). Sampling was made along a single transect oriented NW-SE, direction 123°, from the French Riviera coast (Cape Ferrat) to 28 nautical miles offshore (*see* Fig. 1). The seaward and return transect were made on the same ship way.

Acoustic records

Acoustic images were recorded during daytime using the onboard echosounder, Koden CVS 8805/T type, with a 50 kHz hull-mounted (downward-looking) transducer and a beamwidth of 8°, a pulse length of 2.70 ms and a maximum output power of 10 kW. The sounder operated continuously during each seaward transect. The speed of the ship was constant at 9 knots. Note that, on 28 March and 1 June, acoustic data were recorded semi-continuously, between the successive hydrographic stations.

Echoes were displayed on a colour cathodic screen using eight intensity levels ranging from blue (no signal detected) to red (maximum signal). A pixel of the screen was equivalent to a resolution of about 1.70 m on the depth axis. The echograms were made with a depth range of 0 (the face of the transducer) to 700 m, though backscattered signals were rarely detected below 600 m. The echosounder allowed the strength of displayed echoes to change by 2dB steps. The gain setting was high (13 on a 0 to 15 scale) due to the deep vertical distribution of the scattering layers and the frequency used. No adjustment of TVG was made during the study. For comparative purposes, all the settings of the echosounder were maintained constant from one transect to the other.

Photographs of the screen of the echosounder were taken at constant time intervals. Each picture represented about 3 nautical miles and for each transect, the successive pictures were then reconstructed and juxtaposed in the laboratory, thus reproducing a continuous two-dimensional record of backscattered signals. To simplify the data processing of acoustic images and in order to obtain rather smooth classes of strength distributions, we used only four intensity levels: no signals detected (dark blue); low to middle (blue to white colour); middle to high (green to orange colour); and very high (red colour). The contours of the upper and lower limits of the various scattering layers were smoothed by hand (using the four classes of intensity as defined above) with an accuracy of ± 5 m, digitized and stored on magnetic tapes using a Hewlett-Packard model 9816 computer. However, the lower limit of the deeper scattering layer was difficult to smooth precisely, probably because of decreasing acoustic power with depth and electronic noise.

Hydrological and biological measurements

Hydrographic stations were made on the same transect to measure temperature, salinity, density and chlorophyll *a* biomass. During the *Frontal-T* transects (28 March and 1 June), the hydrographic stations were made on the seaward transect and on the return transect during *Tomofront-1*. The time delay between acoustic records and hydrographic measurements did not exceed 10 hours on 28 March, 14 and 22 April and 1 June. However, we used the hydrographic data collected between 18 to 21 April to refer to the acoustic images of 20 April. Acoustic images of 10 March were interpreted likewise from the hydrographic data collected on 14 March.

Six stations, 5 miles apart, were sampled from 3 to 28 miles offshore during the *Frontal-T* transects.

Phytoplankton biomass was sampled with 5 litres Niskin bottles at 10 depths from the surface to 200 m (filtration on Whatman GF/F filters, extraction in the laboratory with methanol, measurement of chlorophyll *a* by the spectrofluorimetric method as described by Holm-Hansen *et al.*, 1965). During *Tomofront-1* cruise (spring 1988, 12-28 April), the sampling stations were set 1, 2 or 3 miles apart, from 10 to 28 miles. *In vivo* chlorophyll *a* fluorescence was estimated with pumped water flowing through a Turner Design model 10 fluorometer from 200 m to the surface. In addition, water samples were taken from the flow of pumped water to measure the chlorophyll *a* biomass and to calibrate the fluorescence signal.

Continuous vertical profiles of temperature, salinity and density were made from 0 to 800 m with a CTD probe (Guildline, model 8705) at each station both during *Frontal-T* transects and *Tomofront-1* cruise.

RESULTS

Two permanent sound scattering layers were found in the studied water column (0-600 m): a surface scattering layer (SSL), occuring from 0 to about 100 m with very high strength signals near the surface, and a main deep scattering layer (MDSL) located between 250 and 550 m with a maximum backscattering strength (middle to high strength) at 300-400 m. Additionally, an intermediate scattering layer (ISL) was found during springtime, in some parts of the transect, between the SSL and MDSL. The ISL was some 50 m thick with low to middle strength and locally patches of middle to high strength (Fig. 2 ,4 and 6). Depth and thickness of the various scattering layers varied over the transects. However, the general daytime patterns were stable (*see* Fig. 4 *a-b* of daytime record during seaward and return transects).

The hydrological structure encountered throughout the study was quite similar to expectations. The horizontal haline and density gradients typical of the Ligurian front were indicated and the three main hydrological zones (peripheral, frontal and central zones) were recognized (Fig. 3, 5 and 7). However, during *Tomofront-1*, the peripheral zone was not studied. The stratification of the water column was low in winter (Fig. 3 *b-c*), but due to springtime warming from early April, a superficial stratified layer established (Fig. 5 *b-c-f-g* and 7 *b-c*), leading to the phytoplanktonic bloom. High chlorophyll *a* biomass was measured in the frontal and central zones with a maximum ranging from 4 to 9 mg.m^{-3} (*see* Fig. 3 *h*, 5 *d-h* and 7 *d*). Figures 5 *d-h* and 7d suggest that there was a downwelling of chlorophyll 'a' in the frontal zone and show that its vertical distribution was deep within the central zone. The chlorophyll *a* biomass decreased to a maximum near 1 mg.m^{-3} in June (Fig. 7 *h*).

Seasonal differences were noted in the diurnal patterns (depth distribution and thickness) of the scattering layers. In winter (Fig. 2 *a*), the MDSL became deeper (from 250 m to 400 m) and disappeared completely about 18 miles offshore, whereas the SSL thickness was irregular offshore (ranging from 20 to 100 m). Springtime was characterized by an increase in the backscattering strength of scattering layers, and by the occurrence of the ISL. In the coastal part, the ISL remained close to the MDSL. A different pattern of the ISL was observed in the frontal and central zones where a rapid horizontal change of the ISL depth distribution occurred. Typically, the scatterers of the ISL ascended more than 50 m within a small distance (1 or 2 miles) away from the coast and we have called this typical diurnal pattern of the ISL the "cap scattering structure" (CSS).

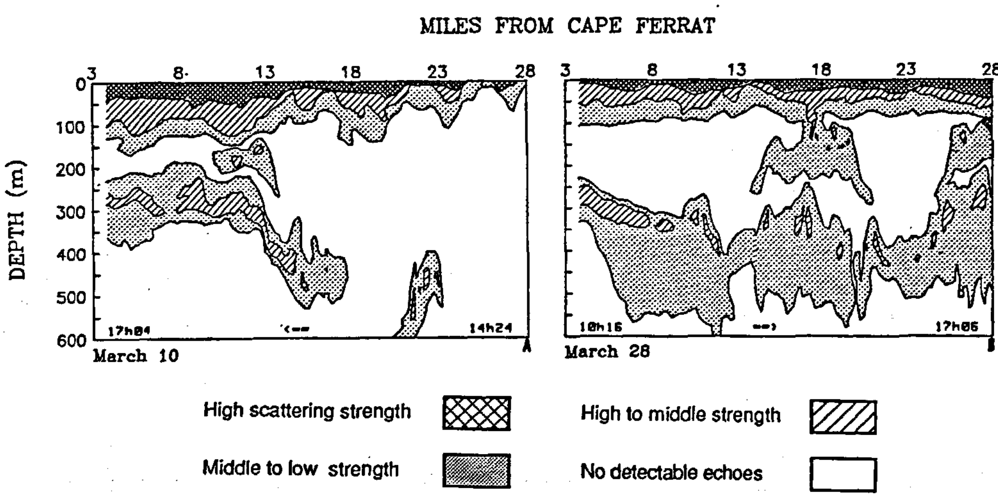


Figure 2

Spatial patterns of sound-scattering layers recorded at 50 kHz, 10 March (A) and 28 March (B), 1988, during Frontal-T *transects. Time of start and end of acoustic records, indicated at the bottom of each drawing, are in local time. Acoustic records are made during seaward (==>) or return (<==) trips. Symbols of backscattered signals, see under the figure.*

Structures spatiales des couches diffusantes sonores enregistrées à 50 kHz les 10 mars (A) et 28 mars (B) 1988, au cours des radiales *Frontal-T*. Les heures de début et de fin des enregistrements acoustiques, indiquées au bas de chaque dessin, sont en heure locale. Les enregistrements acoustiques sont, soit réalisés pendant le parcours aller (==>), soit au retour (<==). Les symboles utilisés pour représenter l'intensité des échos sont présentés sous la figure.

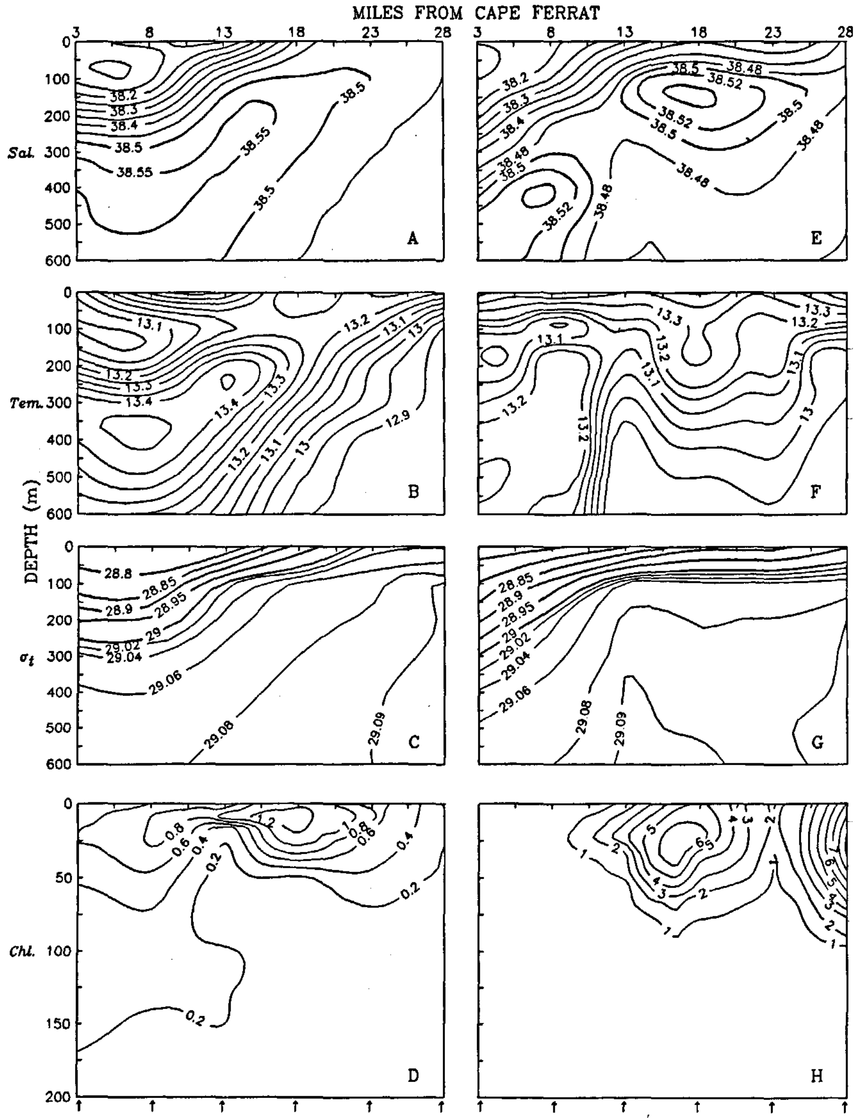


Figure 3

Vertical distribution of hydrological parameters from 0 to 600 m and chlorophyll a *from 0 to 200 m, 10 March (A to D) and 28 March (E to H), 1988, during* Frontal-T *transects. From top to bottom: salinity, temperature (° Celsius), density and chlorophyll* a *biomass (mg.m^{-3}). The vertical arrows at the bottom of each drawing indicate the positions of each hydrographic station. The deep maxima of salinity, corresponding to the occurrence of Intermediate water, are drawn with heavy isolines (38.50 to 38.55).*

Distribution verticale des paramètres hydrologiques de 0 à 600 m et de la chlorophylle *a* de 0 à 200 m au cours des radiales *Frontal-T* du 10 (A à D) et 28 mars (E à H) 1988. De haut en bas : salinité, température (° Celsius), densité et biomasse en chlorophylle *a* (mg.m^{-3}). Les flèches verticales au bas de chaque dessin représentent les positions de chaque station. Les maxima profonds de salinité, correspondant à la présence d'eau Intermédiaire, sont représentés par des isolignes en gras (38,50 à 38,55).

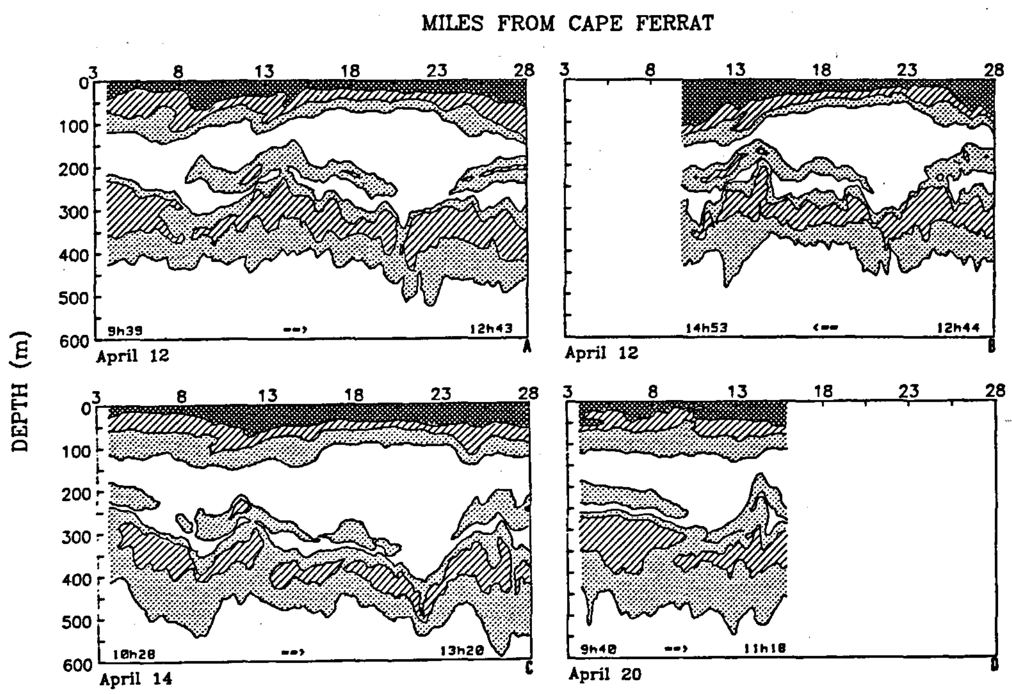


Figure 4

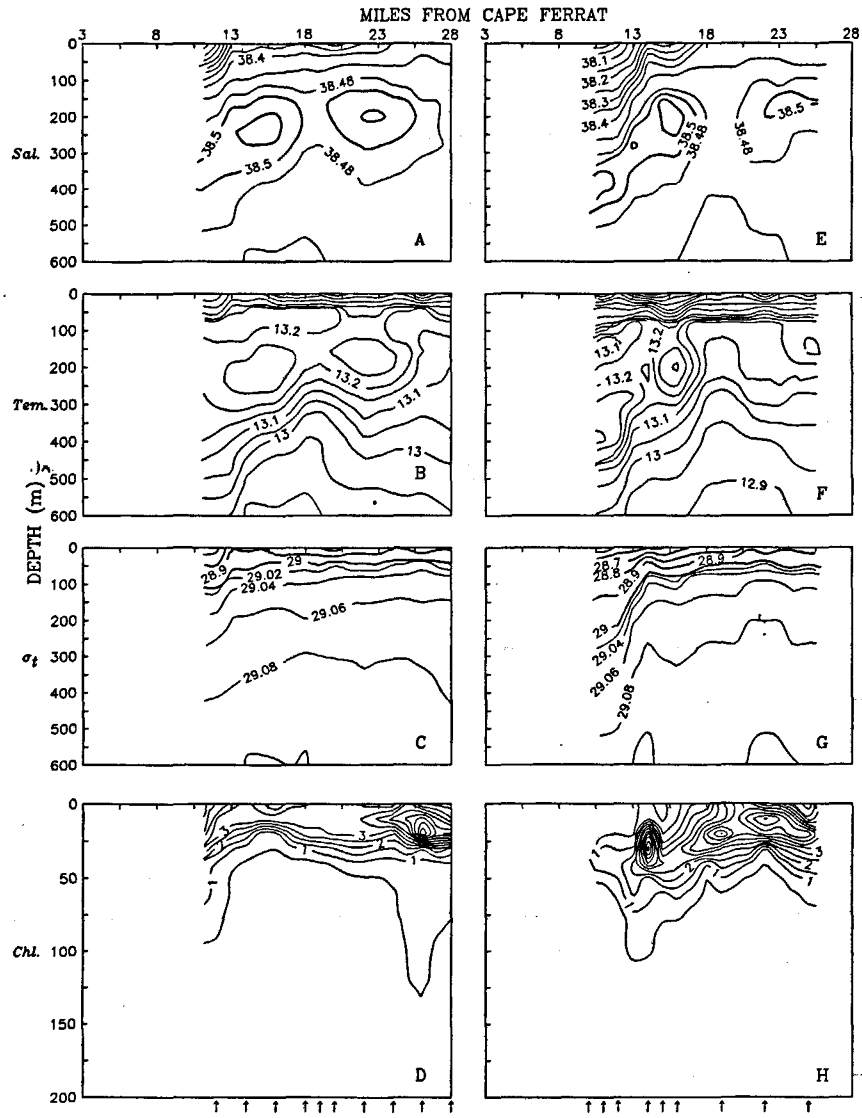
Acoustic records on 12 April (A and B), 14 April (C) and 20 April (D), 1988, during Tomofront-1 *cruise. Symbols as in Figure 2. The day-time stability of the 50 kHz acoustic patterns is indicated by the similarity of echograms during seaward and return trips on 12 April (A and B), despite the time delay between the two records.*

Enregistrements acoustiques les 12 (A et B), 14 (C) et 20 avril (D) 1988 au cours de la campagne *Tomofront-1*. Mêmes symboles que dans la Figure 2. La stabilité à l'échelle de la journée des structures acoustiques à 50 kHz , est indiquée par la similarité des échogrammes aller et retour du 12 avril (A et B), en dépit du décalage temporel existant entre les deux enregistrements.

Figure 5

Same captions as Figure 3 for 14 April (A to D) and 18-20 April (E to H) 1988, during Tomofront-1 *cruise.*

Mêmes légendes que pour la figure 3 les 14 (A à D) et 18-20 (E à H) avril 1988 au cours de la campagne *Tomofront-1*.



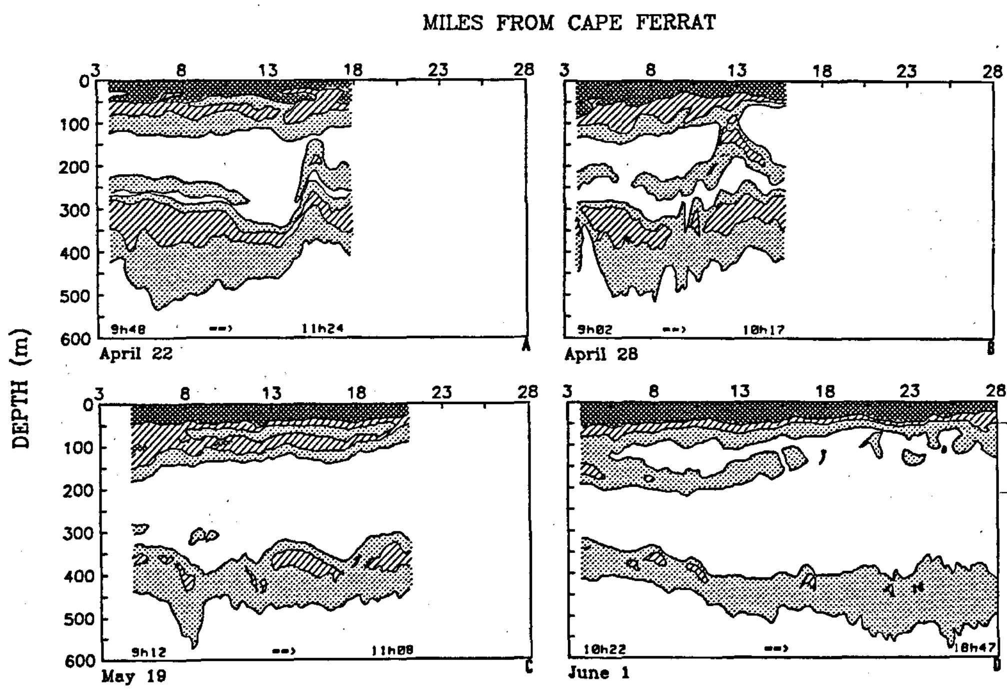


Figure 6

Acoustic records on 22 April (A), 28 April (B) during Tomofront-1 *cruise, 19 May (C) during* Migragel-2 *cruise and 1 June (D) during a* Frontal-T *transect, 1988. Symbols as in Figure 2.*

Enregistrements acoustiques les 22 (A) et 28 (B) avril 1988 pendant la campagne *Tomofront-1*, le 19 mai 1988, pendant la campagne *Migragel-2*, et le 1[er] juin 1988 au cours d'une radiale *Frontal-T*. Mêmes symboles que dans la figure 2.

The SSL and MDSL also show changes in depth distribution in the frontal and central zones. The upper limit of the MDSL was shallow in these two zones. SSL superficial structures, sloping downward to the coast, were observed near the front and the thickness of the SSL increased in the central zone (Fig. 4 *a-b* and *c*).

The MDSL appeared to be "thinner" (rarely more than 100 m) and less intense in May and June than in April and the ISL completely disappeared (Fig. 6 *c-d*). The SSL thickness was irregular in June further than 18 miles offshore.

Comparison of diurnal patterns of the scattering layers with the hydrological zones of the front shows that the rapid modification caused by the frontal structure lead to disturbances in the distribution of 50 kHz acoustic patterns. Similarities exist between the acoustic patterns in the frontal zone and in the central zone during springtime. A good fit seems to occur between the location of high chlorophyll *a* biomass and the deviating diurnal patterns of the scattering layers in these two zones.

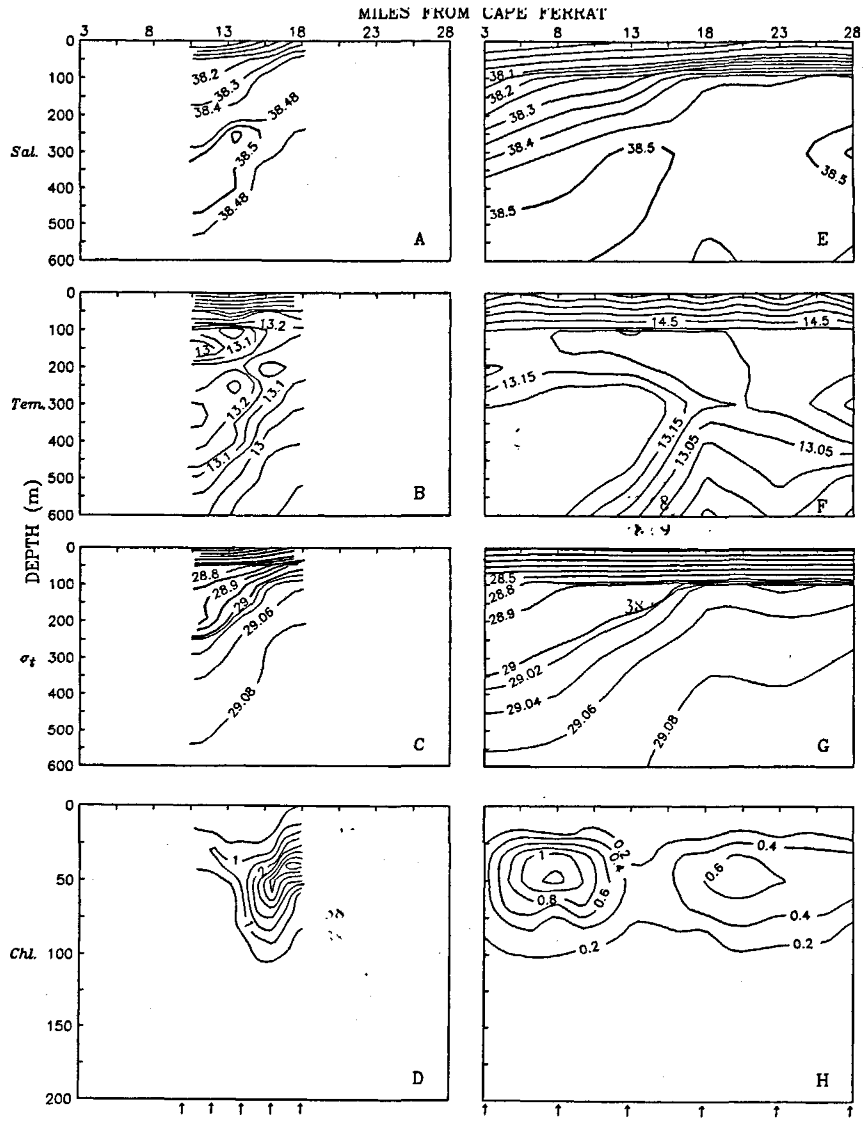


Figure 7

Same legends as Figure 3 for 22 April (A to D, Tomofront-1 *cruise) and 1 June (E to H,* Frontal-T *transect) 1988.*

Mêmes légendes que la figure 3 les 22 avril (A à D, campagne *Tomofront-1*) et 1er juin (E à H, radiale *Frontal-T*) 1988.

DISCUSSION

Replicate transects made from one day to another (*i. e. see* Fig. 4 *a-b* and *c*) during springtime (April) provide evidence that the patterns observed are stable indicators of pelagic processes occurring in the Ligurian front. However, the patterns of the scattering layers show seasonal differences. In winter, the depth distribution and occurrence of the MDSL appeared to be modified, away from the front, by the low vertical stratification in the water column, suggesting that the MDSL scatterers need stable hydrological conditions to occur. The small thickness and lower backscattering strength of the MDSL and the absence of the ISL during May and June suggest that: a) the densities of the MDSL's scatterers were lower after spring; and b) a change in marine populations, or in their spatial distribution, occurred during springtime, leading to the ISL patterns. Masson (1990) reported changes in the depth distribution of the MDSL upper limit observed at 38 kHz across the Ligurian Sea front, involved a close relation with the distribution of the Intermediate water (IW). Our data suggest that there is an influence of the chlorophyll distribution on the sound scattering layer patterns. Increased phytoplanktonic biomass is found in the neighbourhood of the frontal zone and away from the front, in the central zone, due to the deep input of nutrients by the secondary circulation associated with the front. We found the typical CSS of the ISL and associated disturbances in the patterns of the SSL and MDSL in these two hydrological zones (Fig. 8 *a*).

The high hydrological differences between the frontal and central zones (density gradient and tilted isopycnals in the front, low stratified water column in the central zone) are such that they can not explain the similarities of acoustic patterns observed in these two zones. Likewise, if a relationship seems to occur in the peripheral zone between the location of IW and the depth distribution of the MDSL, the MDSL scatterers leave the IW offshore so that one can exclude the role of this water mass in the patterns observed. Rather, a close correspondence exists between the location of relative chorophyll *a* maximum and the CSS (Fig. 8 *b*). The stations where the CSS occurs are characterized by unusual chlorophyll *a* profiles: a deep secondary maximum is found at 190 m in the frontal zone (12 miles), suggesting downwelling, and a rather homogeneous layer up to 0.5 mg.m-3 extends to deep levels from 50 to 160 m in the central zone (24 miles). We assume that the high concentration of particulate matter (Barillier, 1988) and the presence of

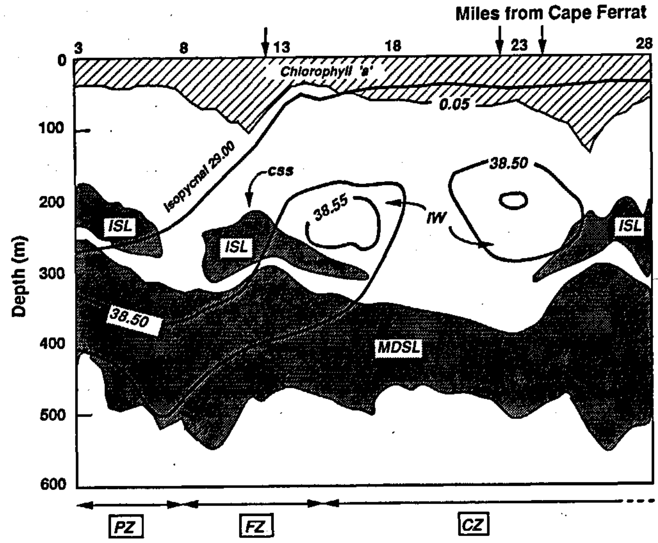


Figure 8 *a*

Schematic drawing of the spatial relations between the 50 kHz acoustic patterns and the three different hydrological zones of the Ligurian Sea front as observed during springtime 1988 (made from 14 April acoustic record). Surface acoustic patterns of the SSL are not represented for clarity of the scheme. The arrows at the top of the drawing indicate the positions of stations 12, 22, 24 miles (see *Fig. 8* b). *PZ = Peripheral Zone, FZ = Frontal Zone, CZ = Central Zone- MDSL = Main deep scattering layer, ISL = Intermediate scattering layer and CSS = Cap scattering structure- IW = Intermediate water. Similarities of acoustic patterns in the FZ and in the CZ do not support the idea of the single running influence of the hydrological differences between these two zones. Rather, the patterns are consistent with the distribution of chlorophyll biomass as represented by the 0.05 isopleth.*

Représentation schématique des relations spatiales entre les structures acoustiques à 50 kHz et les trois différentes zones hydrologiques du front de Mer Ligure au cours du printemps 1988 (d'après l'enregistrement acoustique du 14 avril). Les structures acoustiques de surface de la SSL ne sont pas dessinées pour la clarté du schéma. Les flèches en haut du dessin indiquent les positions des stations 12, 22 et 24 milles (*voir* Fig. 8 *b*). PZ = Zone périphérique, FZ = Zone frontale, CZ = Zone centrale- MDSL = Couche diffusante profonde principale, ISL = Couche diffusante intermédiaire et CSS = Structure diffusante 'en chapeau'- IW = Eau intermédiaire. Les similarités des structures acoustiques observées dans la FZ et la CZ excluent l'idée selon laquelle il y aurait une influence directe des différences hydrologiques existant entre ces deux zones. Au contraire, les structures apparaissent couplées à la distribution de la biomasse chlorophyllienne matérialisée par l'isoplèthe 0,05.

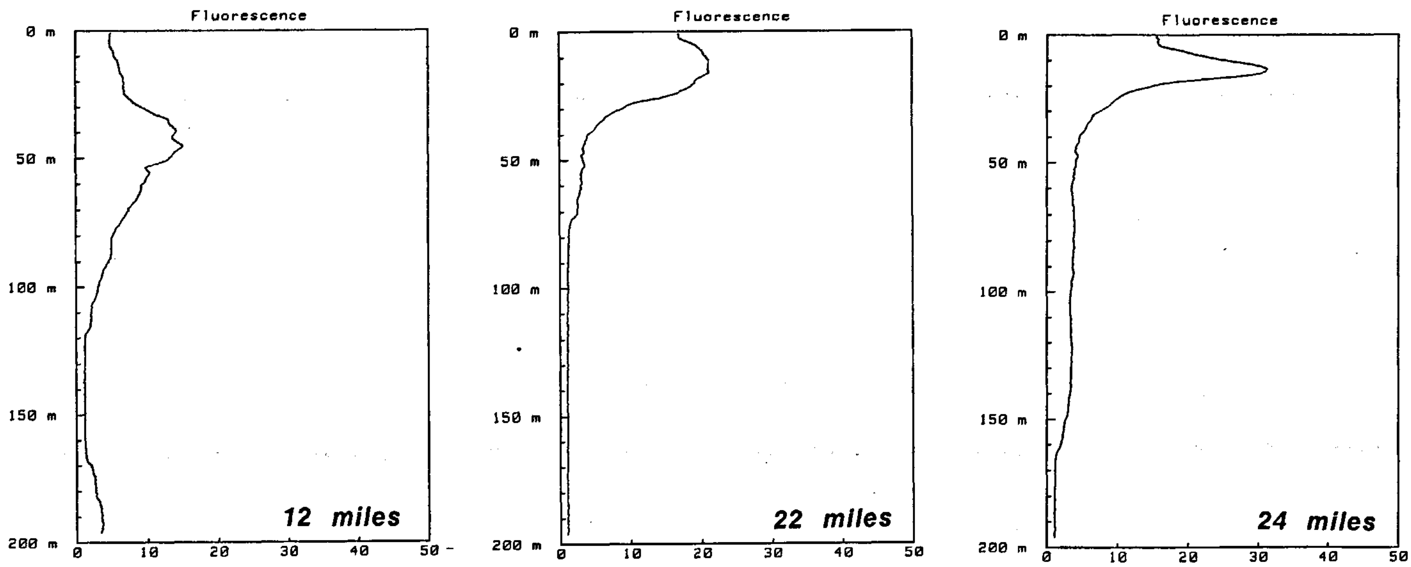


Figure 8 *b*

Vertical profiles of in vivo *fluorescence of chlorophyll* a *from 0 to 200 m at stations 12, 22 and 24 miles on 14 April, 1988.*

Profils verticaux 0-200 m de la fluorescence *in vivo* de la chlorophylle *a* aux stations 12, 22 et 24 milles le 14 avril 1988.

living microphytoplankton in the aphotic zone (Gorsky *et al.*, 1991) during April 1988 near the front could, for example, have concentrated copepods, attracting larger predators. Springtime diurnal acoustic patterns from the front and the central zone suggest locally high concentrations of scatterers, supporting observations of patchiness of plankton (Tranter *et al.*, 1983; Boucher, 1984) or fishes (Dufour and Stretta, 1973; Olson and Backus, 1985) that frequently occurs near fronts. Considering the frequency we used (50 kHz) during the survey, we assumed that the scatterers occurring in the scattering layers are large animals such as mesopelagic fishes, jellyfishes, crustaceans and siphonophores known to be numerous below 200 m in the Ligurian Sea (Palma, 1982; Laval and Carré, 1988; Laval *et al.*, 1989 *a*). Among these populations, the vertical distribution of numerous mesopelagic fishes such as *Cyclothone braueri* (Gonostomatidae) fits rather well the depth at which the MDSL is observed.

Only mesoscale acoustic patterns are reported in the present study and the interpretation of our acoustic images calls for more knowledge about the nature and the behaviour of the sound scatterers. However, the typical patterns of the surface acoustic structures detected on some of our images in the neighbourhood of the front are comparable to similar acoustic patterns found in Gulf Stream meanders (Nero and Magnuson, 1989; Arnone *et al.*, 1990) and in the Almeria-Oran front (Tintore *et al.*, 1988).

The conclusions drawn from our data are that, firstly acoustic imaging can provide considerable information on the physical and pelagic processes occurring in the Ligurian front. Secondly, seasonal differences exist in the acoustic patterns, reflecting the general seasonal variations of the ecosystem. Thirdly, the acoustic patterns described are linked to the frontal structure but similarities exist between patterns in the front and those of the central zone, which suggests that the scatterers are greatly influenced by the biological productivity occurring in these two areas.

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