1. Identification of Liguro provençal front Mediterranean Sea by remote sensing and fiel oceanographica data. Influence of front on the phytoplanctonic pigments distribution.

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Introduction

Pelagic production is the subject of several research programmes developed by belgian scientists, especially in coastal areas where the ecosystems are particularly complicated because they are constrained by many phenomena (marine, atmospheric and terrestrial) covering a wide range of time and space scales. These studies are led in the North Sea and since a few years in the Mediterranean Sea, off Corsica (Calvi, Station de Recherches Sous-Marines et Océanographiques). In Calvi, they are mainly directed towards the influence of the discontinuity zones, as fronts and thermocline, on the planktonic production. The fronts at the edge of continental shelves form a frontier between the general circulation and the shallow waters circulation, slackening thus the lateral diffusion. The vertical motions associated with frontal areas bring back to the surface waters rich in nutrients, involving a more important biological productivity.
The study of such problems is the aim of TROPHOS experiment which the field of investigations is the Ligurian Sea, off Calvi.

Since a few years, the use of remote sensing begin to be helpful to oceanographers. The satellite data permit, for instance, to identify unsuspected phenomena and to control better the evolution of the yet known phenomena.
The advantage of these data, namely the time repetitivity and the instantaneous survey of large areas, is useful to monitor the main features of the surface fronts in the Liguro-Provenç al basin.

General background

The Mediterranean Sea is a deep semi-enclosed sea, with depths exceeding four thousands meters. The tides have a very low range, less than ten centimeters, except for some shallows as the gulf of Gabes or the north Adriatic, and near Gibraltar strait where the Atlantic tides enter. So, the circulation is mainly determined by the exchanges with the atmosphere.

Due to the local climatology, the water balance is negative, the evaporation being more important than the precipitations and the rivers supply. In this concentration basin, the deficit is compensated for by an important water flux through the Gibraltar strait (Lacombe, 1973). After Bethoux (1980), the annual volume of surface Atlantic water crossing the strait is about 53.000 km^3; the outflow of Mediterranean water is nearly 50.500 km^3 per year.

The Atlantic surface layer goes eastwards along the North African coast, forming the African current (figure 1). In the Western part of the Mediterranean large cyclonic circulations are developed in the Thyrrhenian sea and in the Liguro-Provençal basin. After the crossing for the strait of Sicily, we observe in the Eastern part of the Mediterranean cyclonic gyres on the north and anticyclonic ones on the south of the African current. The winds generate transient circulations which can modify the general one.

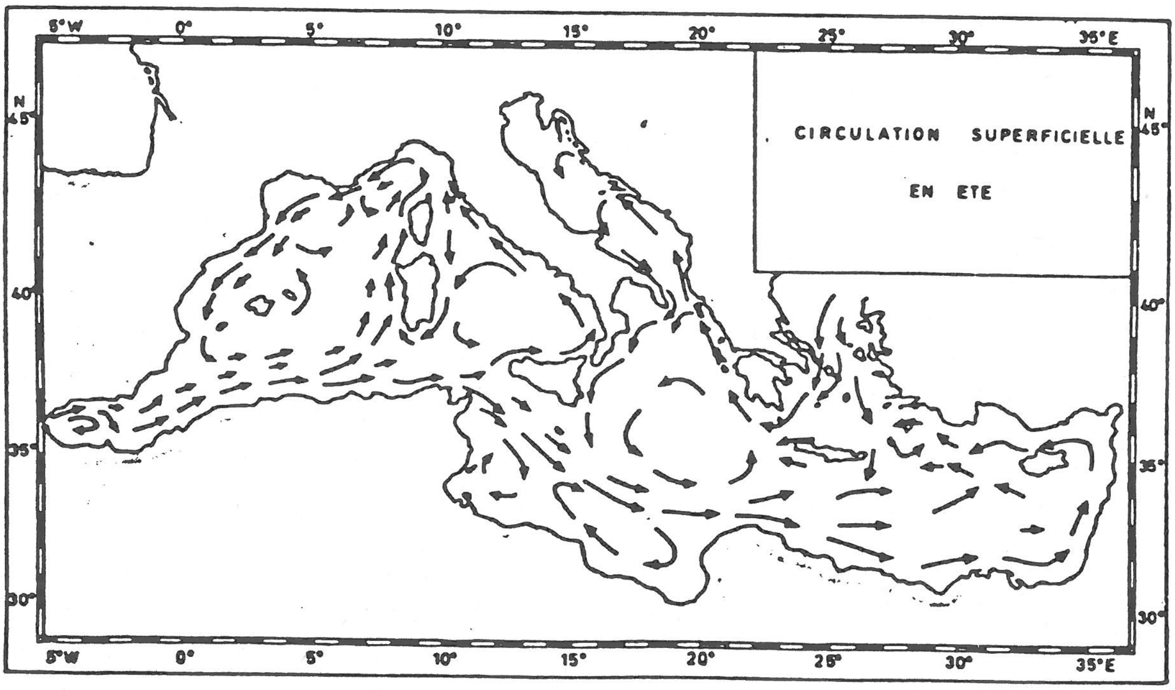

Figure 1. Surface circulation during summer

The summer heating of the surface layer lead to the formation of a seasonnal thermocline. During the winter, under the effect of dry and cold continental winds and of the difference of temperature between air and sea, the evaporation and heat transfer from the sea to the air become very important; hence the density of the surface layer increases, inducing an instability. The consequent mixing and convection give rise to deep waters. We observe this phenomenon of deep water formation in the North-West Mediterranean (Gascard, 1978), in the Levantin basin and in the Adriatic sea. The water formed during the winter in the Levantin basin crosses the Sicilian strait and spread in the Western basin, describing cyclonic circulations of a so called intermediate water.

The temperature-salinity diagramme coming from our measurements off Corsica during summer (figure 2) shows clearly three different masses of water : a surface layer of Atlantic water (0 to 100 m), an intermediate levantin layer (100 to 600 m) and a typically mediterranean deep layer (under 600 m).

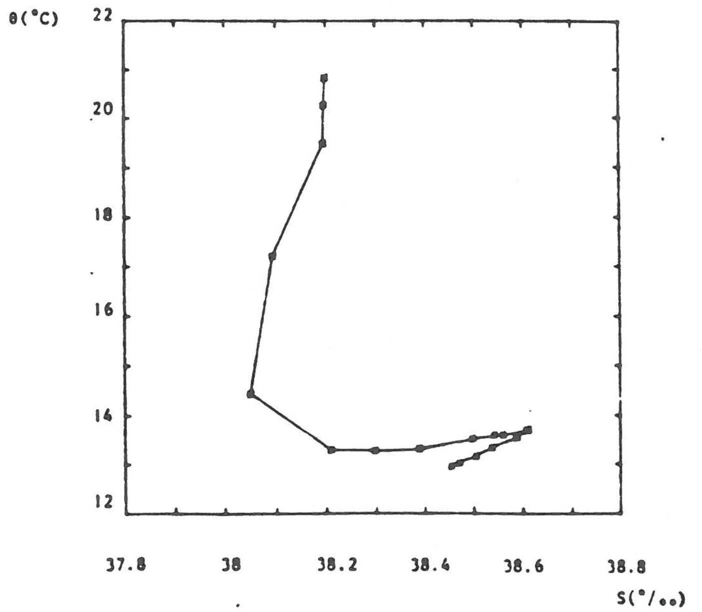

Figure 2. Temperature-salinity diagramme realised from measurements 15 N.miles off Calvi in July (Sounding : 1100 m, total depth : 2200 m).

From this general survey of the main features of the Mediterranean hydrology we emphasize the intense cyclonic gyre in the Liguro-Provençal basin carrying along the surface and sub-surface waters.

Examination of satellite data

The Centre de Météorologie Spatiale of Lannion (France) provides us with thermal limits charts weekly drawn from infrared thermographies obtained by TIROS N and NOAA satellites. These polar orbiting spacecrafts are equiped with an Advanced very High Resolution Radiometer measuring in the infrared (10.5-11.5 μm). The AVHRR scanner has a temperature sensitivity of less than 0.2°C and a horizontal resolution of 1.1 km (Philippe, 1982).

The charts of Lannion display the main fronts observed over each week and the associated structures, as described in the legend of these maps (figure 3). Since a few months, charts of absolute temperatures are available in addition of thermal gradients ones.
Naturally, it is not possible to examine here all the material provided by the CMS; we'll only consider some charts representative of each season, the seasonal changes being well marked for the thermal structures. The used data cover the period March 1982 - March 1983.

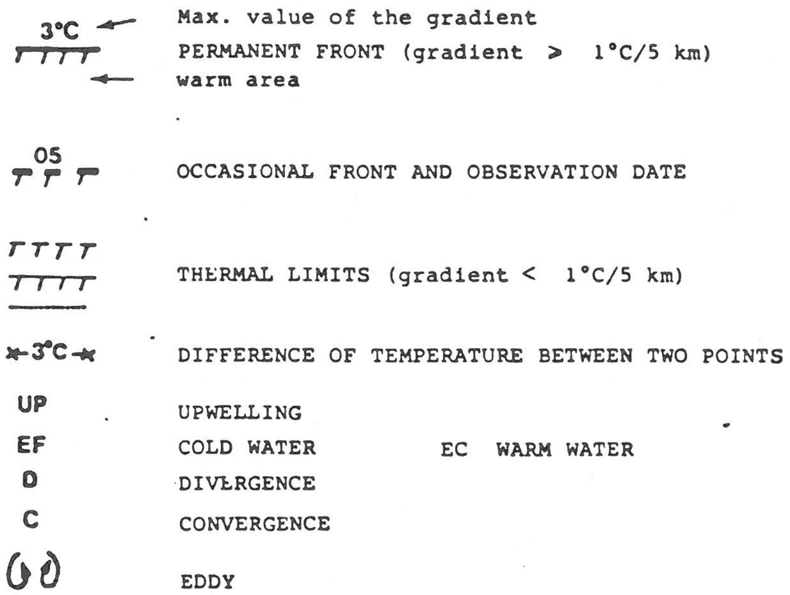

Figure 3. Legend of the CMS charts

The figure 4 represents a typical spring situation (here 30 April to 6 May) where we detect scarcely anything. Only very light thermal limits are observed in the north of the Balearic Isles and in the shallow gulf of Lion where the still cold water of Rhône river flows out. Another one going from cape Corse to the gulf of La Spezia (Italy) indicates the limits of the Ligurian and the Tyrrhenian seas. The weakness of the surface temperature gradients in this season is explained by the strong mixing of the surface layer by the cold winds during the winter. Spring images don't yield a lot of informations because the phenomena are masked, due to this absence of surface temperature signature.

The heating of the surface water during the late spring progressively establishes a vertical stratification; the consequent seasonnal thermocline is affected by the water motions which disturb it, giving rise to horizontal temperature gradients visible from satellites in the form of more of less marked fronts. It follows that the summer situation, as the one illustrated at the figure 5 (23-29 July), is rich in surface thermal structures, the most linked up with the major dynamic phenomena.

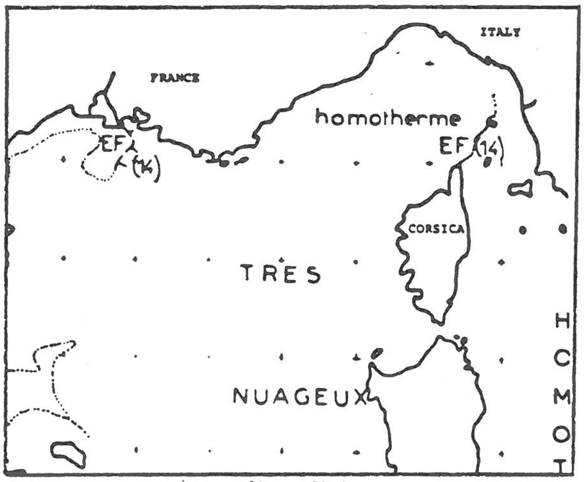

Figure 4. Spring chart (30 April to 6 May 1983)

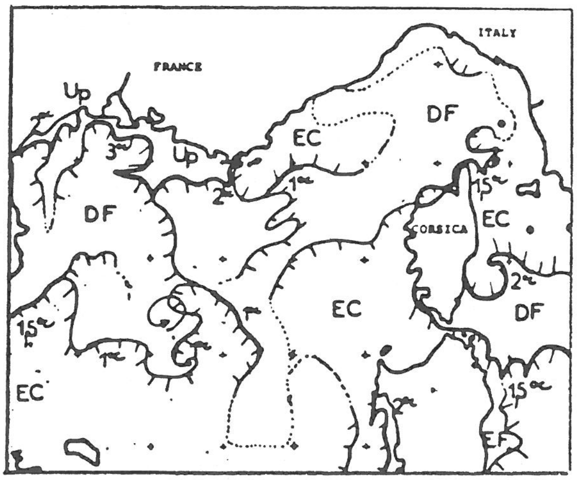

Figure 5. Summer chart (23 to 29 July)

A very well marked front, characterized by horizontal gradients exceeding 1°C/5 km, is apparent in the Liguro-Provençal basin, in relation with the cyclonic circulation present in this area. It separates dense water of the cold core from the warm water running around it. The width of the warm water strip is variable, the front being sometimes firmly situated in the coastal zone ; it is the case in the North of Corsica (figure 5) from Calvi to Cape Corse. In spite of its variability in space and in time, this cyclonic loop and its associated thermal front are persistent troughout the summer as clearly shown by the numerous satellite data.

Another active divergence area is visible east of the Bonifacio strait demarcated by a presistent front.

Fronts appear also at the periphery of upwelling areas. One can observe them mainly in the gulf of Lions where they are induced by transient North-West winds as the Tramontane and the Mistral (Millot, 1979) : the surface warm waters are drifted to the south-west where they are accumulated, when upwelling is appearing along the Languedoc and Provence coasts.

The examination of an autumn situation (figure 6, 19-25 November) shows that the most important summer structures, for instance the fronts associated with the Liguro-Provençal and Bonifacio divergences, still remain. However, they begin to weaken and to present instabilities, when thermal gradients are observed in some coastal zones where the river supply and the wind action are responsible of the cooling of shallow waters.

The winter meteorological forcing, especially the cold continental winds, removes the seasonnal thermocline and consequently the whole typical summer fronts. So, the winter images (figure 7, 18-24 February) display on the greater part of the Liguro-Provençal basin, a view without surface temperature gradients. One can notice, in the shallows of the gulf of Lion and along the Italian coast (south of La Spezia), the vey well marked coastal fronts already mentionned for the autumn season. They now are strengthened and persistent.

The winter and spring seasons thermographies don't suggest the cyclonic circulation of the L-P basin yet present in winter, as shown in figure 8 and as recently underlined by many authors.

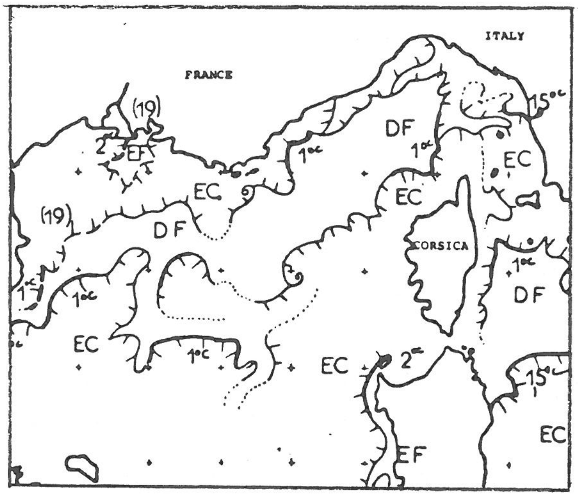

Figure 6. Autumn chart (19 to 25 November)

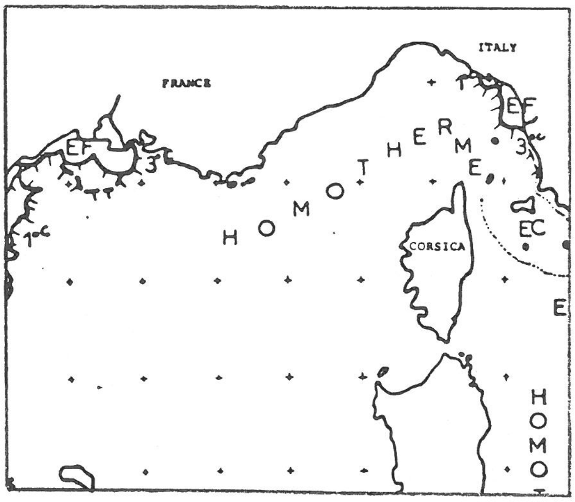

Figure 7. Winter chart (18 to 24 February)

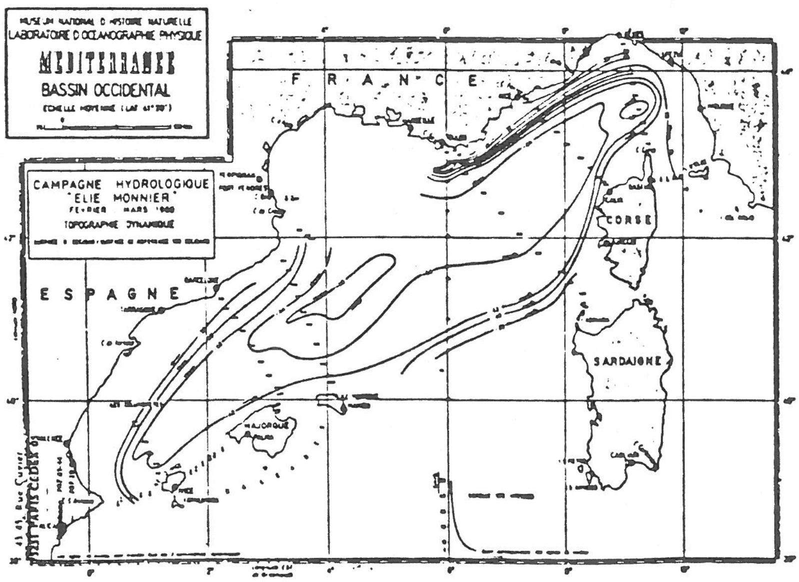

Figure 8.

Dynamic topography during winter in the Liguro-Provençal and Balearic basins (French experiment)

Examination of oceanographic data.

NOAA Satellite charts from Lannion provides us only thermic discontinuities distribution in the liguro-provençal area. From this point of view, during winter, liguro-provençal basin is generally homothermic; at least, thermic gradients are ephemeral and not well indicated.

Study of hydrological (Temperature, Salinity, Silicates) and biological (Chlorophyll a)data collected in March, May, July and October 1982, during oceanographic cruises across liguro-provençal front (Corsican area)provide us a more detailled picture of water masses distribution and seasonal fluctuations. These campaigns are carried out on board of "Recteur Dubuisson", oceanographic ship of the University of Liege at Calvi(Corsica) .Ten stations have been fixed on the Calvi-Nice axe, from Calvi(station n°1)to 30 nautic miles offshore(station n°10)-FIG.9-
At every station, conductivity and temperature are measured by means of bathysonde every ten meters from 0 to 70 meters. At these various depths, salinity(conductivimeter Beckman), silicate concentrations and chlorophyll a (Strickland and Parsons 1968)are measured on water sampled at these various depths.
Means of different parameters, integrated over 70 meters and standard deviations are presented on graphic as function of distance from the coast.

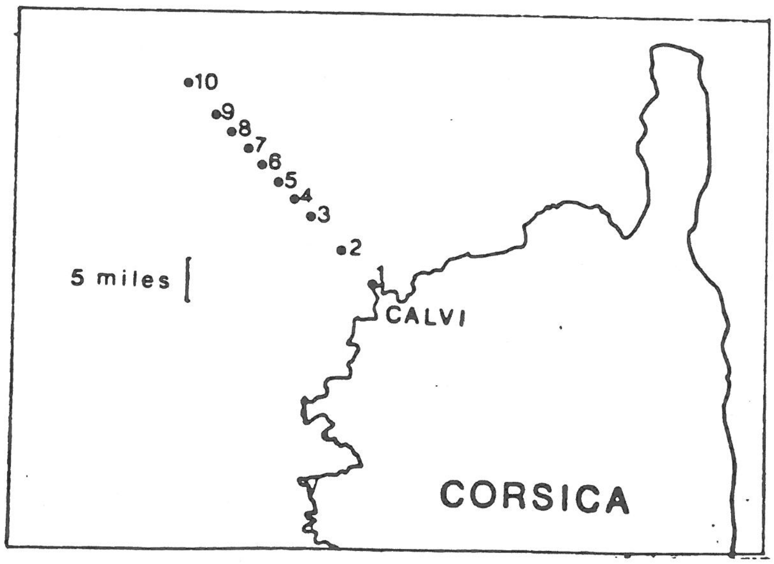

Fig 9.-Location map and position of sampling stations

During winter period, mean water temperature, integrated on the 70 surface meters don't present significative variations from the coast to offshore. Together, a salinity and silicate concentration horizontal discontinuity divides coastal from offshore waters (FIG.10). At this season, water column is homogeneous, at least to 200 meters; that explains little standard deviation values calculated for all parameters.

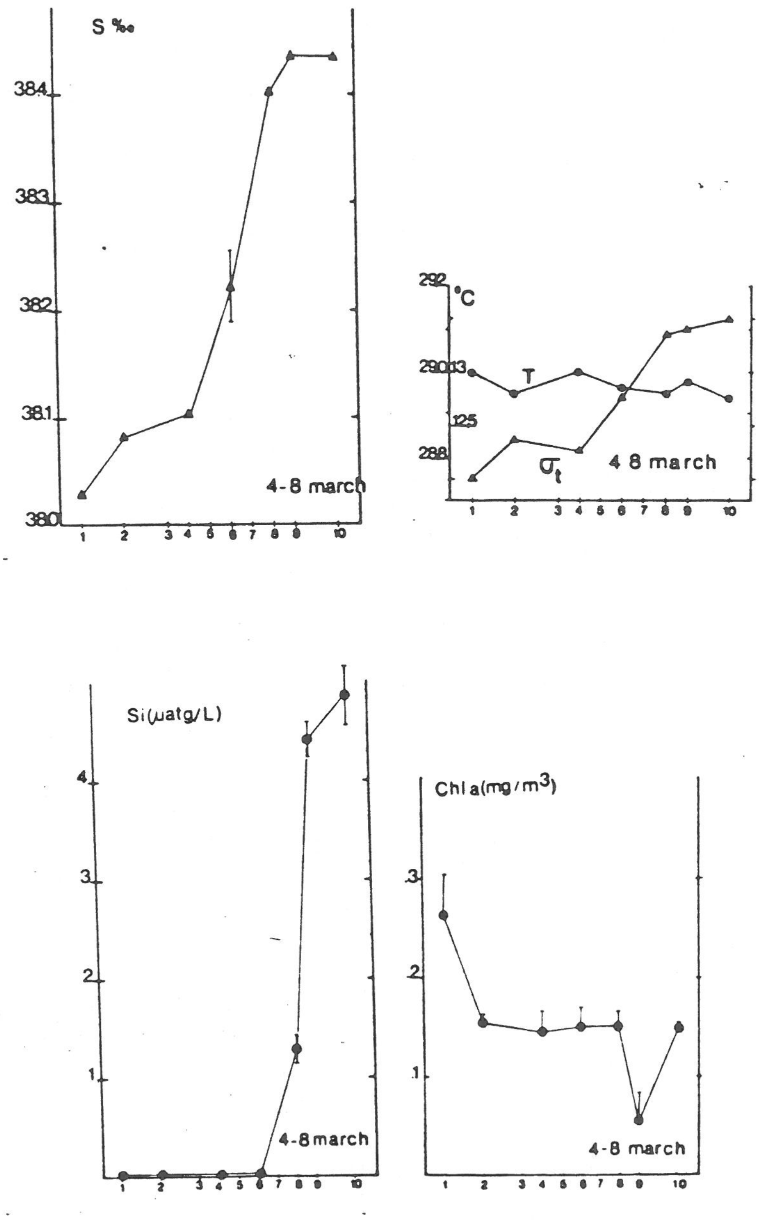

Fig. 10 .-Campaign 4-8 march 1982: Salinity, temperature, density, silicates and chlorophyll a distributions across front: Mean value calculated on 70 meters (each 10 m. data) from surface-standard deviation. (horizontal axes: numero of stations)

At the end of March,(FIG. 11),winter mixing reachs a maximum that explains high salinities,densities and silicate offshore values. Mixing inhibits primary production beginning and very low chlorophylle a concentrations are observed in the offshore area.
Near the coast,on the other hand,vertical mixing is weaker and phytoplancton concentrations reach the maximal annuel value (HECQ and al.1981)

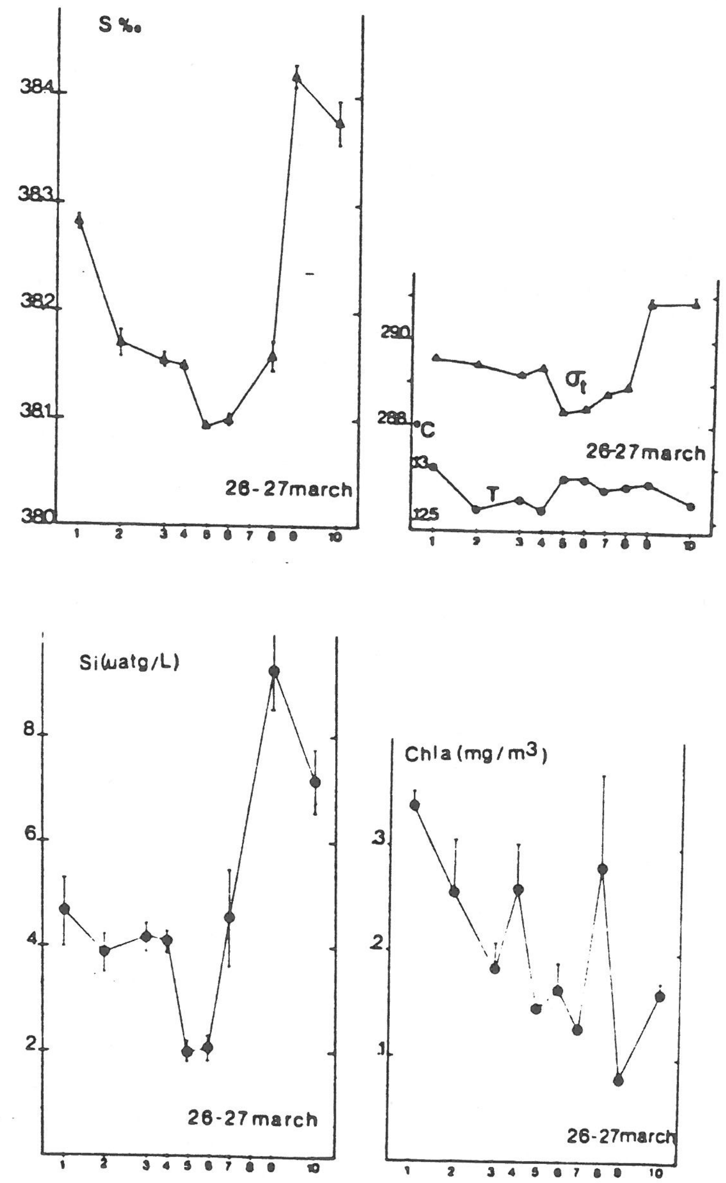

Fig.11 .-Campaign 26-27march 1982:Salinity,temperature,density, silicates and chlorophyll a distributions across front:Mean value calculated on 70 meters(each 10 m.data)from surface-standard deviation. (horizontal axes:numero of stations)

During spring,(FIG.12),densities,salinities and silicate mean values are lower and mean temperature higher than during winter. Standard deviation calculated for these parameters is increasing. These variations are related to water reheating which induces surface water density lowering,stratification and thermocline formation. Silicate concentrations are lowering in the prospected area:in one hand,silicates are biologically consumed by phytoplancton and in the other hand ,vertical density gradient prevents recycling in upper layers.

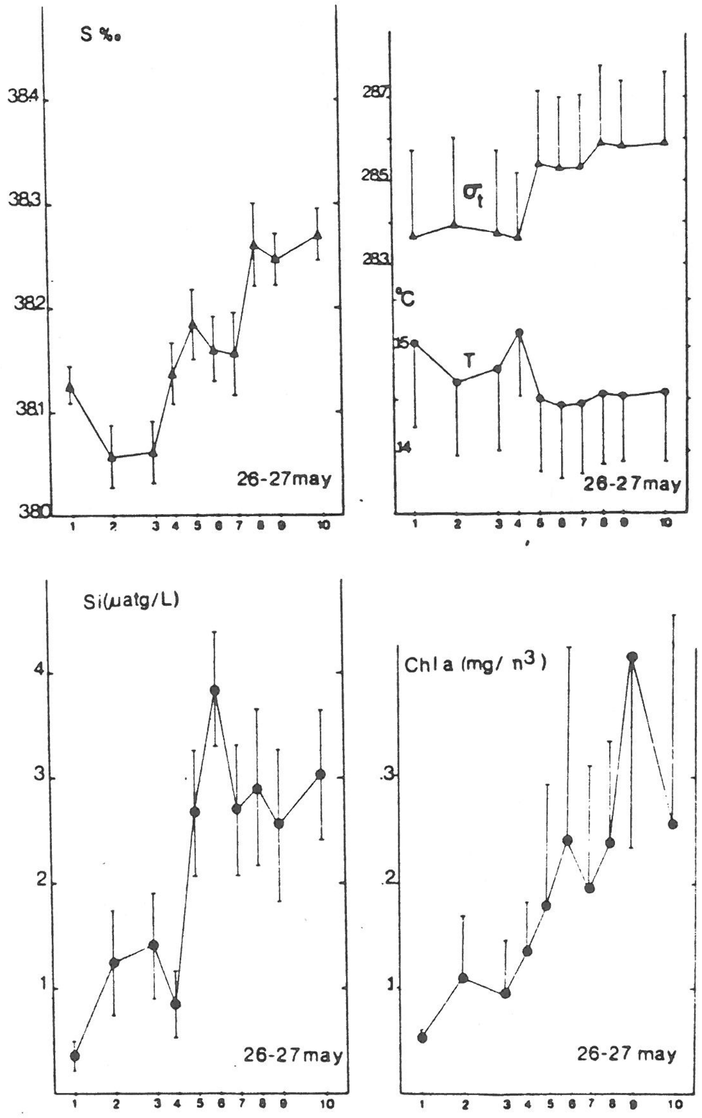

Fig.12 .-Campaign 26-27 may 1982:Salinity,temperature,density, silicates and chlorophyll a distributions across front:Mean value calculated on 70 meters(each 10 m.data)from surface-standard deviation. (horizontal axes:numero of stations).

Such spring stabilisation of water layers,resulting from stratification processes,have for consequence to inverse phytoplanctonic biomasses horizontal profiles.:indeed-At offshore stations,outside frontal area,phytoplanctonic biomasses reach a maximum value. Silicates are more abundant and stratification increased.

-At coastal stations,phytoplancton biomasses are weaker :nutrients are exhausted and stratification prevents their recuring.Phytoplanctonic organisms distribution is inegal in water column.A maximum chlorophyll peak appears around 40 meters above thermocline,where a compromise between ligth and nutrients provides to phytoplancton suitable conditions(HECQ end al. 1983).

During summer,hydrological and biological individualisation of different surface water masses induce mean temperature increasing and salinity,density and silicate contents decreasing (FIG.13).Water column reachs a maximum stratification degree.Standard deviations are the highest.

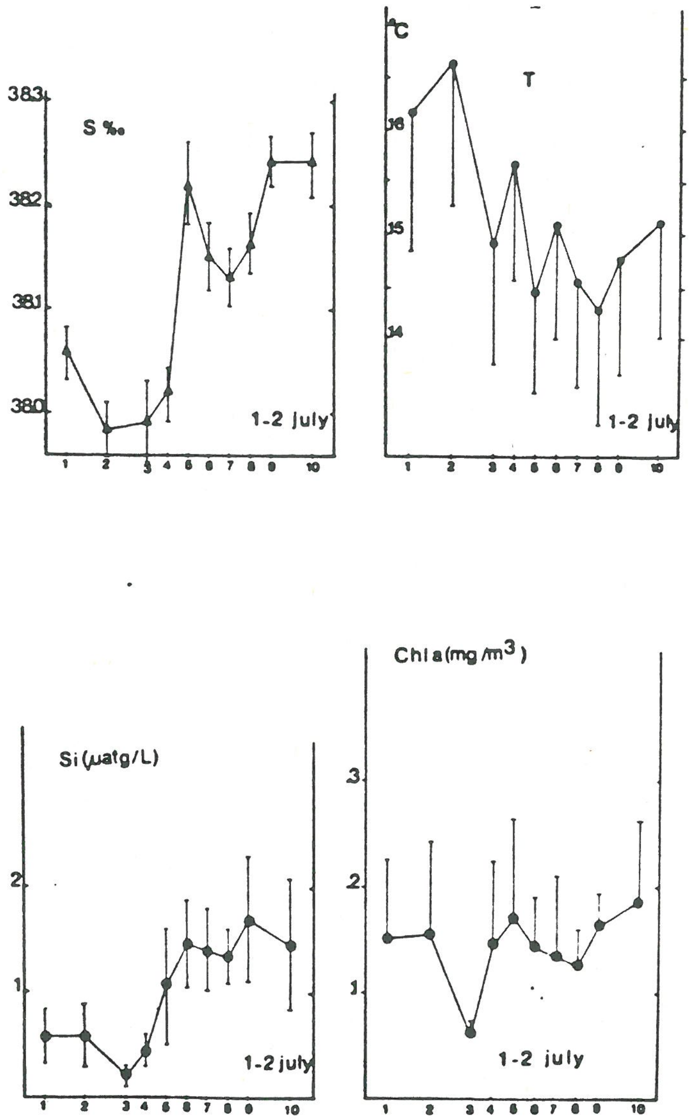

Fig13 .-Campaign 1-2 july 1982:Salinity,temperature,density, silicates and chlorophyll a distributions across front:Mean value calculated on 70 meters(each 10 m.data)from surface-standard deviation. (horizontal axes:numero of stations)

Phytoplanctonic biomasses are at a minimum and don't provide significant variations from a station to another. Phytoplancton is essentialy located between 40 and 60 meters ;elsenhere, biomasses are approximately zero.

During autumn, water retains hydrological characters obtained during summer (FIG.14). Statification limits all nutrient enrichment and/accordingly, surface waters are very poor in phytoplancto

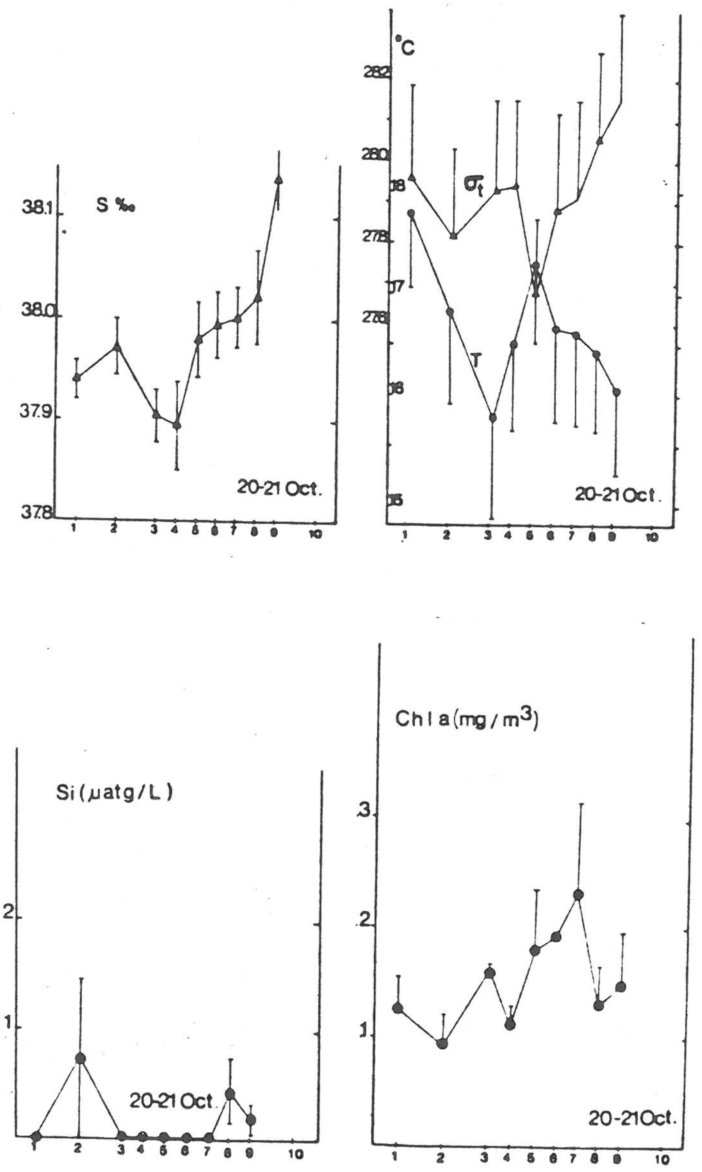

Fig. 14 Campaign 20-21 oct. 1982: Salinity, temperature, density, silicates and chlorophyll a distribution, across front: Mean value calculated on 70 meters (each 10 m. data) from surface-standard deviation. (horizontal axes: numero of stations).

Conclusion

The in situ measurements confirm fairly well the existence of different water masses as detected by remote sensing, at least during the seasons where infrared images give informations.

The water situated between the front and the Corsican coast has the characteristic of an atlantic water. The amount of silicates is very low, almost nought, showing a pronounced oligotrophy : the concentrations in phytoplankton hardly exceed 300 µg chl. α/m^3 ; however, these values remain lower than those measured in 1979 off Calvi (Hecq et al., 1981).

The water situated beyond the front has typically the characteristic of an intermediate levantin water. It reaches a maximum concentration in silicates at the end of the winter. This water remains rich in silicates throughout the year, what let to assume a permanent supply of deep water. Indeed this constituent, which the rate of remineralisation is reduced in the surface water (Walsh, 1971, Holme Hansen and al., 1977), could be considered as a tracer of deep water. In spite of its wealth in silicates, this water is relatively poor in phytoplankton throughout the year, when all the conditions for a high primary production seem to be present.