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Sess. Dynamics of Upwelling in the ICES Area.

UPWELLING DYNAMICS IN SPANISH AND PORTUGUESE COAST. A PILOT STUDY FROM NOAA-AVHRR IMAGES AND GEOSTROPHIC WINDS.

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ABSTRACT

Upwelling dynamics in East Atlantic has a very big influence in the economic structure of the Northwest of Spain and in the West of Portugal because this event regulates the sardine fisheries in our coast, and is the responsible of the appearance of red tides (toxic algae bloom) that have a direct effect in the growing of shellfish.

We have develop a system to study the upwelling comparing the theoretical evolution from geostrophic winds and the mass of water displacement. Geostrophic winds are estimated from isobaric maps in an interactive program and upwelling area is evaluated from NOAA-AVHRR images. We can estimate the increase or decrease of upwelling via cross correlation algorithms in pairs of consecutive images (with one or two days between both).

The first image is divided into squares of 32x32 pixels; the program computes the correlation factor between this square and all possible ones in a 64x64 template in the second image. The maximum correlation factor give us the displacement that our square has suffer in the second. As our images have been registered we know their the spatial resolution an we can measure an average velocity of movement.

1.-INTRODUCTION

The Iberian Peninsula, situated in the West of Europe, forms the last link in the so called African upwelling. Further North of the Finisterre Cape (fig 1), it is practically impossible to find this event, which is of vital importance for the economy of the fishing towns.

Studies carried out in Portugal (1) show that the behaviour of certain marine species is ruled by the presence or absence of this phenomenon, which provides the nutrients (phosphates and nitrates deposited on the sea bottom over the years) to set the food chain in action.

On the other hand, it presents singular importance on the West Coast of Galicia, as it is the mechanism that regulates the red tides that affect mussel production (2), which constitutes in itself the main source of income for the Galician coasts with respect to shellfish production.

This event has its origin in the persistence of winds with a North-South predominance, when they are parallel to the continental West Coasts in the Northern hemisphere. When the superficial layer of water is moved Southwards, its movement is modified towards the deep seas, and a vacuum appears near the coast which is filled with deep waters that are elevated when they hit the continental shelf. It is for this reason that the bathymetry of the zone plays an important role .We will be discussing this in chapter two.

In this paper we are presenting a study realized on the West Coast of the Iberian Peninsula, where we have monitored coastal upwelling with respect to three different parameters: a theoretical model based on the calculation of geostrophic winds from December to January foresees the existence of intensive upwelling (unusual at this time) during the month of February; The images obtained in the infrared range by the NOAA series of satellites provide us with the material for work so that, by means of statistic correlation methods we March evaluate the variability of the event day by day; Finally, the bathymetry of the zone under study explains certain key features of the phenomenon.

We have concluded our study with the discovery that the origin of the unusual upwelling studied was due to the entrance of a cold water mass from the deep sea towards the coast, which originated ascendent currents in the part of the continental shelf that was in contact with that mass of water.

From our study we also derive the importance of bathymetry over the movement of ocean water fronts, which is pointed out in chapter 4.

2.- ZONE OF STUDY

2.1- WEST COAST OF THE IBERIAN PENINSULA

The zone of study lies to the NW of the Iberian Peninsula and is located between 39 to 44 º North and 8 to 14 º West. It is swept by the Atlantic ocean in the East and the Cantabric in the North, and comprises Galicia (Spanish region in the North West of the Peninsula) and the West Coast of Portugal.

2.2.- DESCRIPTION OF THE IMAGES

The images we are going to work with come from the series of NOAA satellites and have been obtained through an AVHRR high resolution sensor. For their thermic study we are going to use channel 4, situated at the atmospheric window at 10.5 to 11.5 micra. We have chosen this range instead of that of the temperatures obtained through split-window methods because they offer a higher range of values, which improve results in the mathematic processes to which the images are subjected. The grey level scale that we are presenting in this visualization corresponds to the standard used in infrared, that is: light colors represent cold temperatures while dark ones stand for warm areas.

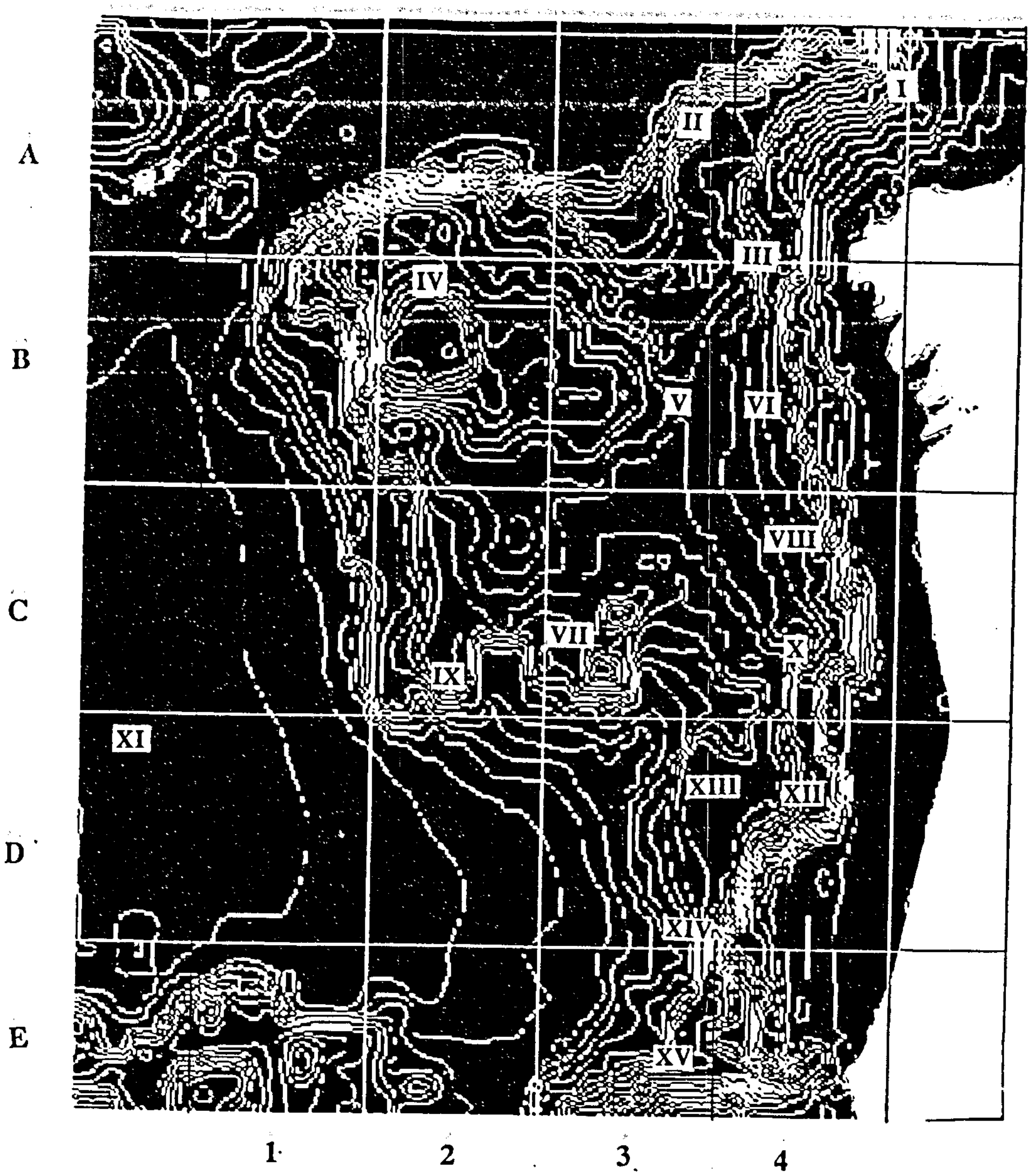
For a correct interpretation we have corrected each of them geometrically by using a rectangular projection so that the zone studied is the one presented in figure 1.

2.3.- BATHYMETRY OF THE ZONE

Along this coast, there exists a continental shelf which is 40 to 60 km wide and gives the zone an important role as an area of marine exploitation. On the Galician coast we find the so called "Rias" (zones of brine water where the sea enters the land), which have a high index of shellfish production.. Towards the West, this shelf falls abruptly form a depth of 200 to 3000 .in the canyons of La Coruña, Muxia, Arousa, Vigo, Oporto, Aveiro and Figueiroa. Then, towards the West we find the so called "Paso de Galicia" (Galician pathway) which is nothing other than a bathymetric depression from North to South at a depth of 300 m in front of the Galician coasts, bounded on the South by the submarine Mounts of Vigo and Vasco de Gama.

Further towards the North East is the "Banco de Galicia" (Bank of Galicia) situated at the South East of point 43N, 120W. This marine bank at a depth of 1000 is bounded on the West by the abyssal plain of Iberia at a depth of 5000m under the sea level.

The latter extends to the SE reaching the Nazaret canyon, to the South of the Mounts of Vasco de Gama mentioned above.



I -Coruña Canyon
II -Laxe Canyon
III -Muxia Canyon
IV -Galicia Shoal
V -Pass of Galicia
VI -Arousa Canyon
VII -Vigo Seamount
VIII -Vigo Canyon
IX -Vasco de Gamma Seamount
X -Oporto Canyon
XI -Abissal Plane of Iberian
XII -Aveiro Canyon
XIII -Oporto Seamount
XIV -Figueira Canyon
XV -Nazare Canyon

Figure 1.- Bathymetry of the zone of study

3.- METHODOLOGY

3.1.- INTRODUCTION

In the study of the evolution of upwelling on the Iberian Coast we have chosen a period of time beginning in the second half of February for two main reasons:

It is an unusual period because the traditional appearance of this event is as from March on, at the time of the maximum proximity of the anticyclone from the Azores to the Peninsula. It is worth studying, partly because there are doubts among scientists at present with respect to whether this phenomenon should be an instance of upwelling coming from the sea depths or simply the cooling of waters in the continental shelf, when they lose temperature and acquire the density of more salty waters on mixing with them.

It is an important opportunity to validate the monitoring system we have developed over a workstation and to correlate the appearance of cold waters on the coast with the persistence of North-South winds during the previous days.

For these two reasons, we will focus the study in two different ways:

The study of geostrophic winds obtained from isobaric maps will enable us to calculate the amount of upwelled water or Ekman's index, which is nothing other than a quantitative measure of the intensity of upwelling;

Correlation methods between pairs of successive images will give us an automatic method for the real estimation of the movement of waters with specific thermic characteristics . We will thus be able to know the qualitative evolution of the event, from its appearance to its disappearance.

From these two different points of view, we will be able to contrast the theory of the appearance of upwelling from the persistence of North winds with the real data given by the infrared images of the zone obtained from the NOAA polar satellites.

3.2.- THEORY OF THE CALCULATION OF EKMAN'S INDEX FROM GEOSTROPHIC WINDS

The calculation of geostrophic winds is realized with isobaric maps which are obtained daily during a period of time (one or two months) before the days we wish to study. Once we have them all, we generate pressure maps in all the points of the area of study by means of interpolation methods of finite differences between the isobaric lines.

Afterwards we calculate the geostrophic (5) daily winds for a previously chosen point according to the following equations.

$$V = \frac{g}{f}\frac{\partial z}{\partial x} = \frac{1}{\rho f}\frac{\delta P}{\delta x}\bigg|_z$$

$$U = \frac{-g}{f}\frac{\partial z}{\partial y} = \frac{-1}{\rho f}\frac{\delta P}{\delta y}\bigg|_z$$

$$f = 2\Omega\cos\phi$$

where U and V are the North and East components of the geostrophic wind, g is the gravity acceleration, f is the Coriolis parameter, ϕ is the latitude, P represents the pressure previously calculated and $\rho=1/\alpha$ where α is the specific volume of the air.

Then we correct the theoretic winds thus calculated to approximate them to the real ones by incorporating the friction term. We turn their direction 15 grades towards the low pressures and decrease their speed in a factor 0.7. From these, we calculate Ekman's indexes of upwelling (4), which give us the measure of the water displaced by the winds, which under upwelling conditions is simply the upwelled water. We have to calculate the deforming effort of the winds over the marine surface previously calculated (Tx,Ty)

$$T_x = \rho_a C_d \left(U^2 + V^2\right)^{\frac{1}{2}} * U$$

$$T_y = \rho_a C_d \left(U^2 + V^2\right)^{\frac{1}{2}} * V$$

where U and V are the components of the geostrophic wind chosen, Cd is the specific heat capacity of the air at a constant pressure and the density of the air.

This deforming effort generates a current towards the right of the movement of the Northern hemisphere, which in absence of pressure is regulated by the following equations.

$$\rho * \phi * V_E + \frac{\delta \tau_x}{\delta x} = 0$$

$$\rho * \phi * U_E + \frac{\delta \tau_y}{\delta y} = 0$$

τ_{xy} is the force exerted by the wind over the marine surface in the directions x and y respectively, Ue and Ve are the components of the Ekman speeds ($\rho * V * \delta z$) is the mass that flows in each direction through an area of a square meter on the XY plane so that the amount of displaced water by Ekman effect, E, is :

$$E = \frac{-\tau_y}{f * \rho} \qquad \text{en } m^3/\text{sec.}$$

3.3.- THEORY OF THE CALCULATION OF MOVEMENT BASED ON CROSS-CORRELATION METHODS

We have chosen 3 images with a cadence of 2 days (6 days of study) in order to show and to explain the movement of waters in them by means of cross-correlation methods.

This type of technique has been applied to the calculation of speeds of thermic drifts which are clearly differentiated in the images obtained by satellites or planes in the thermic infrared range of the electromagnetic spectrum, obtaining excellent results (6,7). The same type of technique has served even to monitor and evaluate the movement of huge icebergs quantitatively (8), because owing to their low temperature they are easily identifiable in thermic images.

The substantial difference we are going to introduce in this article on applying maximum cross-correlation algorithms to the study of upwelling lies on the fact that in our images there is no real movement of waters but rather an increase or a recession in the quantity of cold water raised from the depths to the surface .

For this reason only West-East movements in proximity to the continental shelf will be relevant for the evaluation of the intensity of upwelling.

We divide the first image in quadrants that we have chosen in a size of 32x32 considering the difference in days between the images (two days). With a center on the same point in the second image, we carry out a two dimensional sweep by calculating the correlation coefficient between the first quadrant and all the possible ones in an area of 64x64. The maximum found in the correlation coefficient gives us the displacement suffered by the quadrant with respect to the second image.

As Emery suggests (6) we have avoided the study of statistics decision rules, such as the Neyman-Pearson test, or the Fisher test (7), obviating correlation values inferior to 0.45.

In figure 5 we can observe the result obtained when correlating the two pairs of images. We present the movement by means of an arrow with its origin in the center of the window to be examined, and with its end in the center of the quadrant which has obtained the highest value of correlation.

4.-RESULTS

We have carried out the monitorization of the coast on a SUN Sparc-10 workstation, all the software being developed over a window X11 environment which makes the interaction with the user easier. In figures 2, 3 and 4 we can see how to represent the two images of the zone corresponding to the successive days in the screen, with the possibility of overlapping bathymetry and geographical localization. At the top of the figures we can observe the direction of the winds by calculating the isobaric maps some days before hand. On the right we can see the study of Ekman's Index obtained from the geostrophic winds mentioned above.

In figure 2 corresponding to February 15th we observe a cold water mass with SE direction situated to the East of point 40N, 11W which flows over the abyssal plain of Iberia (fig 1) up to the entrance of the Nazaré canyon, where we find that on the 17th it has disappeared owing to heating (at least at a superficial level).

Another cold water front in the same direction which is situated further North and is passing by the South of the Bank of Galicia reflects the relation existent between the movement of the columns of water and bathymetry. Thus, for example, when this column passes over the Mounts of Vigo (VIGO SEAMOUNT) turbulences appear which stick to the orography (fig 2).

In the area close to the coast, the presence of the continental shelf is revealed to us for the cold water mass follows the most abrupt line of that shelf closely. (figures 2 and 3)

It is of great interest to corroborate the action of the wind over the mass of water close to the coast, which is situated over the continental shelf. The wind exerts a particular deforming effort over the ocean surface, which originates a net current in a direction perpendicular to the wind and towards the right in the Northern hemisphere. This phenomenon only occurs in shallow waters close to the coast and if the winds are of a NS direction they produce upwelling. If they are of a SN direction, the opposite phenomenon known as downwelling takes place.

In the high seas, as we have observed, the incidence of winds over the displacement of the water mass is maximum, though this is not the case for the bathymetry which is reflected in the movements that these columns of water make.

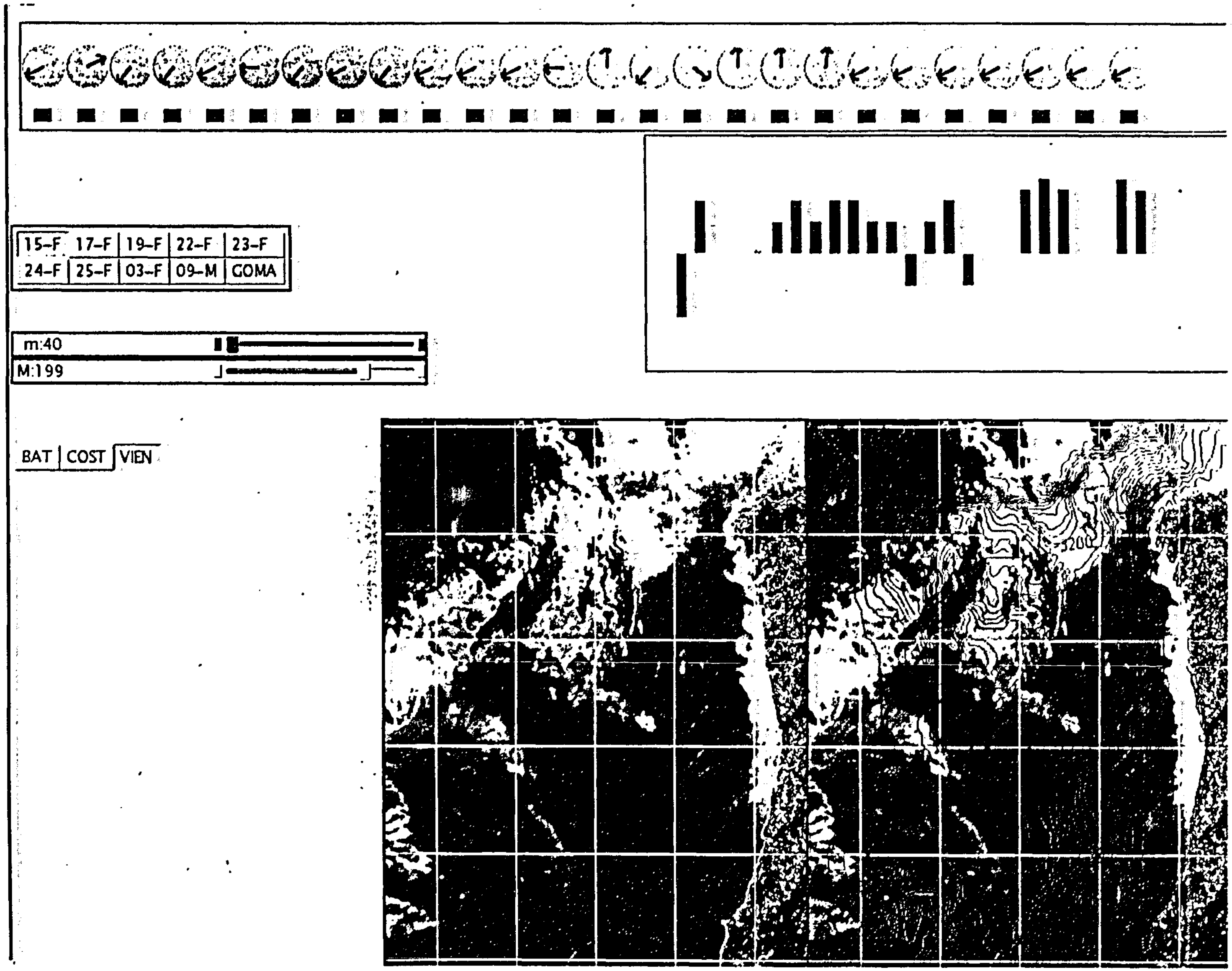


Figure 2.- Top: Monitoring of wind from January 27th to February 21th.
Top-Right: Monitoring of the Ekman's flux
Bottom: Image of February 15th, with and without bathymetry.

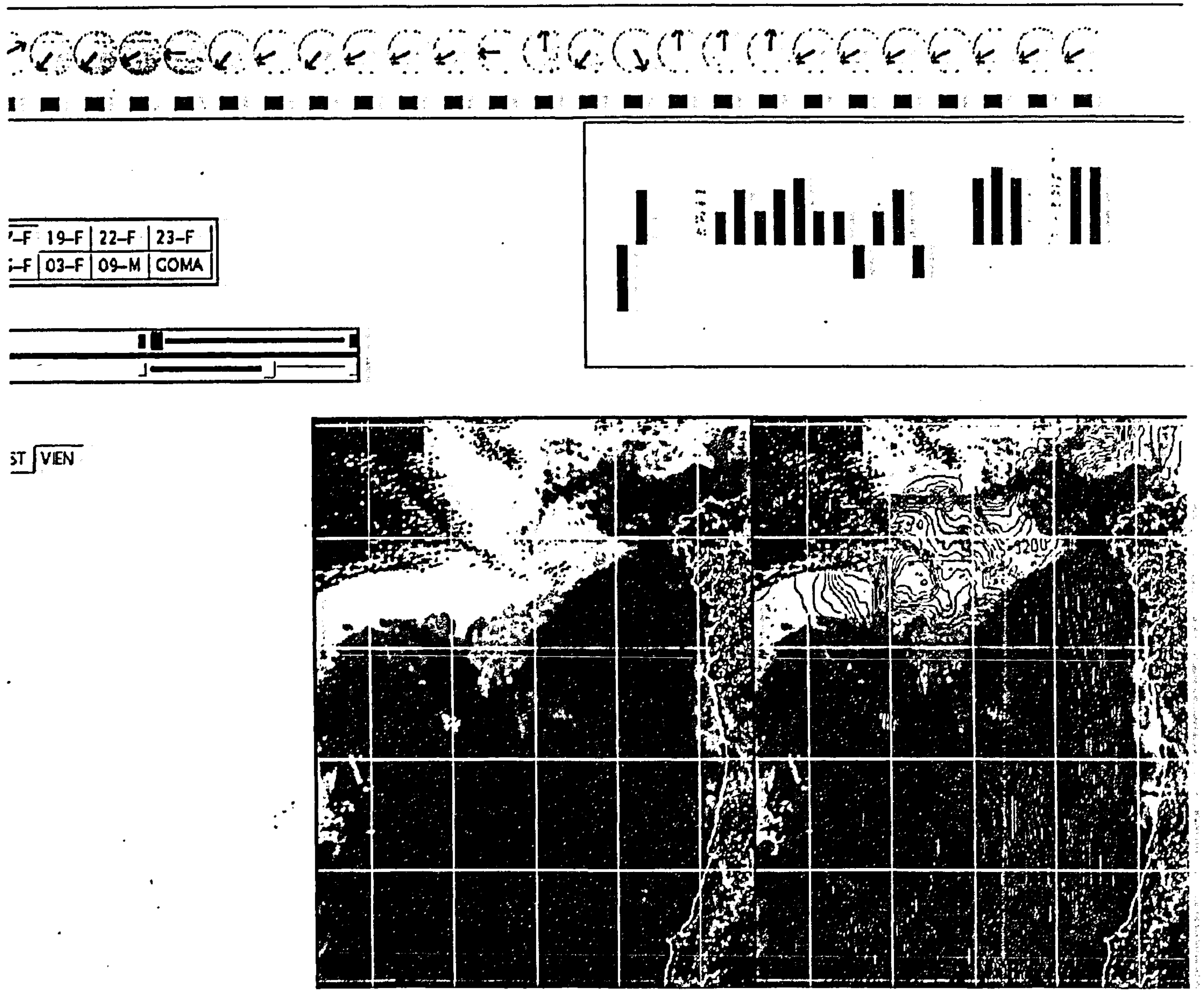


Figure 3.- Monitoring corresponding to February 17th

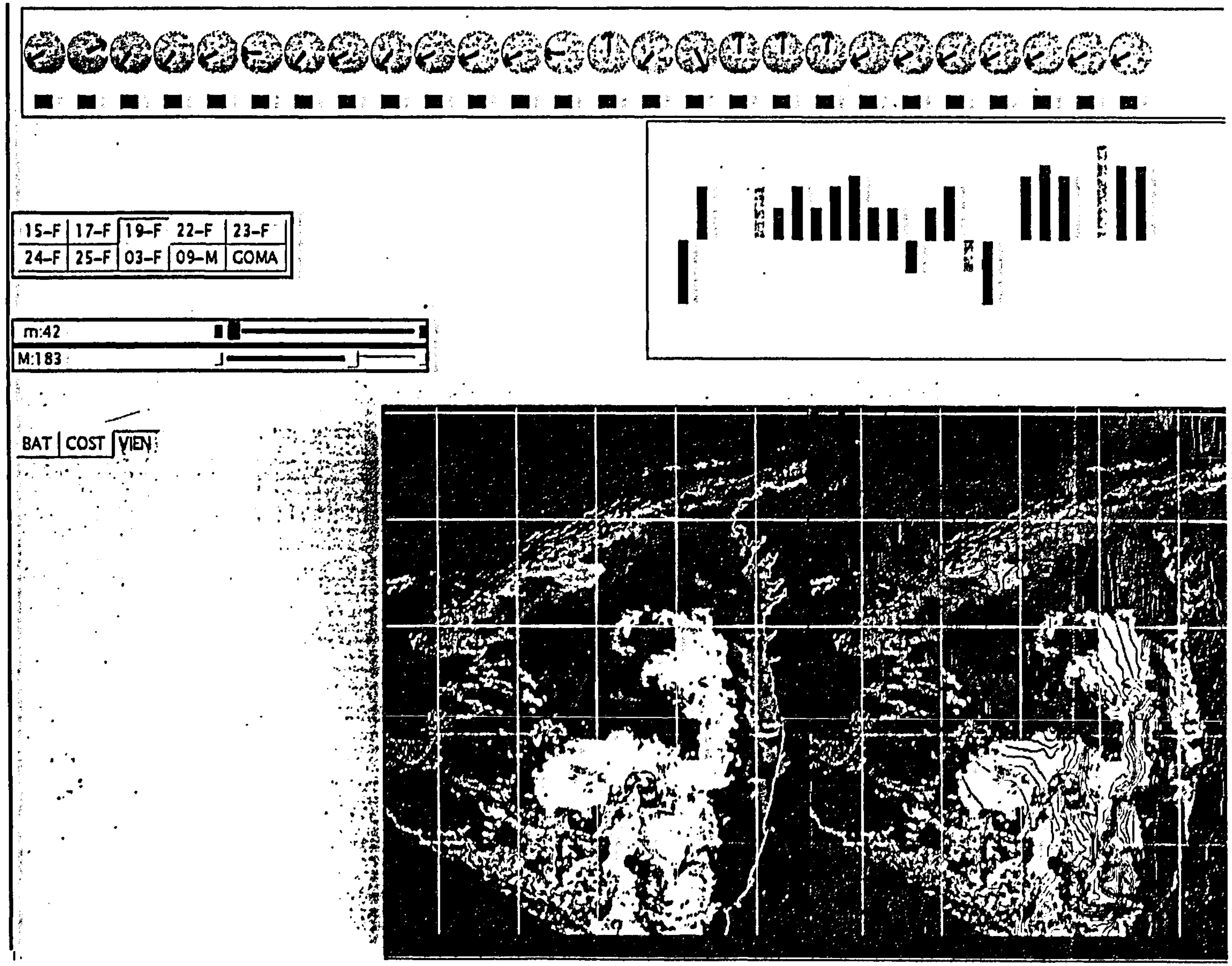


Figure 4.- Monitoring corresponding to February 19th.

Study of the movement of columns of water from February 15th to 17th

We have divided the zone into sectors for a better localization of the phenomenons we are going to describe. In the images of figures 2 and 3 corresponding to the 15th and 17th respectively we observe a displacement of a cold water mass in zones B2 and C2 corresponding to those images to the South of the Bank of Galicia. This reaches the North of the submarine mount of Vasco de Gama, then turning in a SW direction through the Submarine Mounts of Vigo in the zone C3 in both images.

Somewhat further North a displacement towards the West occurs in zone B3 in the images corresponding to figures 2 and 3.

The correlation study carried out over the images corresponding to the 15th and 17th appears in figure 5. We can observe the displacements already mentioned, while in the coastal zone we can see vectors representative of the movement suffered with an East direction in the zone of the Galician estuaries and in the South of the image. This would imply movements originated by unfavorable winds which would produce piling up currents which originate donwelling.

In the study of winds we find winds with a North direction from the 13th to 15th which would produce this effect and in the images corresponding to the 15th, 17th and 19th (Fig.2, 3 and 4 respectively) we can see a decrease in the cooling of coastal waters in zones B4 D4 and E4 of the given images.

In zone D3 in the images being studied, we observe the displacement along the zone which corresponds to the sea bed, between the submarine Mounts of Vigo and the Canyon of Figueira (see Fig 1), the submarine Mounts of Oporto being left just in the middle (Fig.8).

Study of the image corresponding to the 17th and 19th:

In zone D4 corresponding to the images of the Fig 3 and Fig.4 (days 19 and 19 respectively) there is a decrease of upwelling which is confirmed by the correlation image of those images (Fig 6), where we can see vectors with an East direction, which would correspond to the zone with a downwelling phenomenon. This is supported by the study of the winds prevailing the previous days, as it was explained in the paragraphs above.

On carrying out the correlation calculation (Fig. 6) we can see that in the zones A4 and B4 of the images in Fig. 3 and Fig 4 there is a displacement towards the East. In zone C3 of those images there is a concentration phenomenon around the suboceanic Mounts of Vigo and a displacement in the SW direction which is confirmed in the images of the study. In these images we can see several eddies on that zone, and we can appreciate the displacement mentioned above.

In zone B3 we can see in the images of study that a displacement has occurred towards the NW which also appears in the correlation study (Fig 6). Also in zone B4, in front of the Galician estuaries we can see that there exists an entering phenomenon in the mass of cold water on the coast. This reflects the existence of a lighter fall in the continental shelf in the zone.

Along the following days (see Fig.7), we observe the permanent entering of the mass of cold water from the North East towards the Canyon of Aveiro, with geostrophic winds which are unfavorable to upwelling. However, the shore to the South of parallel 42N and to the North of 40N maintains the cold upwelled waters during the whole of the second fortnight in February. This phenomenon does not appear either to the North or to the south of this area.

This unusual phenomenon of upwelling in this part of the year is due to the entrance of a cold water front that produces the sweeping of colder water over the continental shelf, which lasts while there is this entering mass of water (see Fig.8).

On March 3th, we observe the relaxation of the phenomenon up to its complete disappearance. On the 9th, the mass of entering water has completely disappeared.

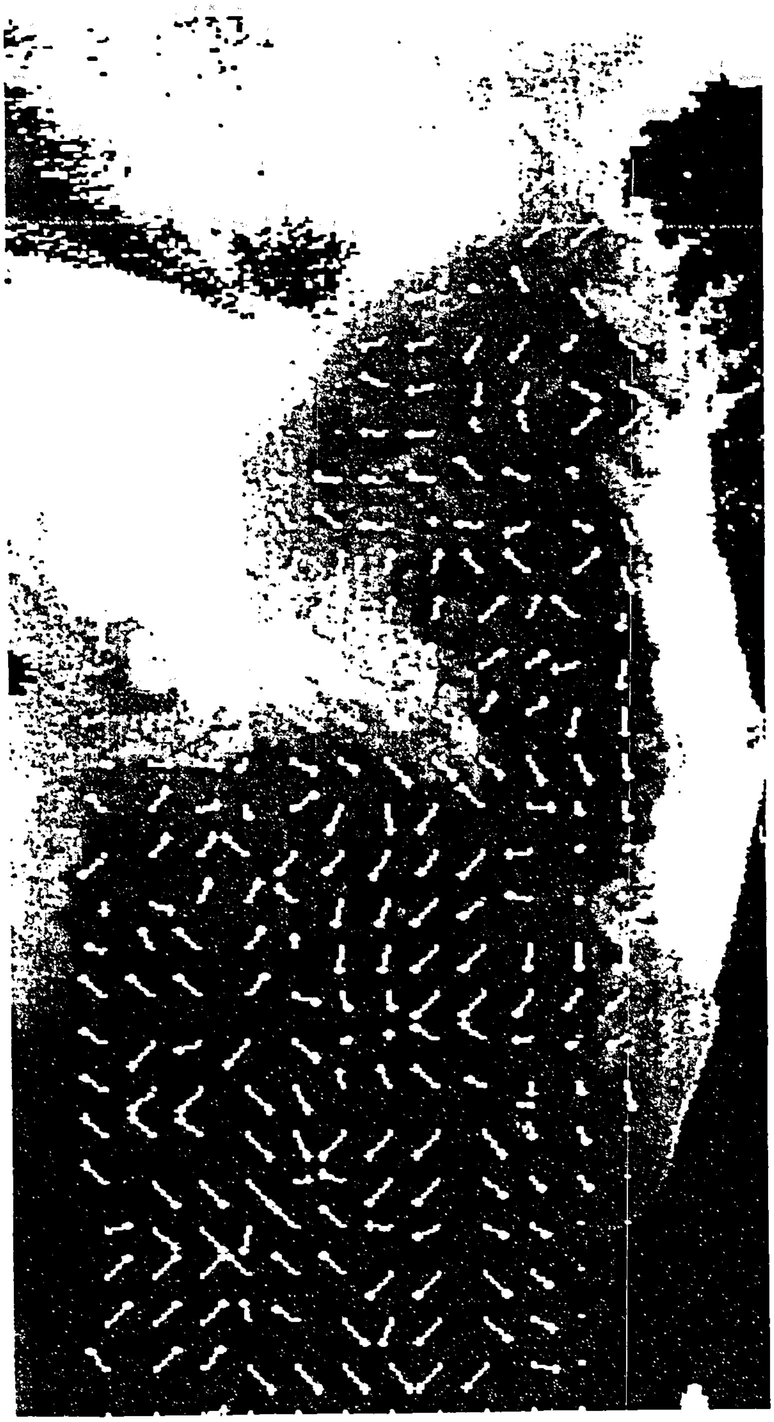


Figure 5.- Study of correlation corresponding from February 15th to February 17th

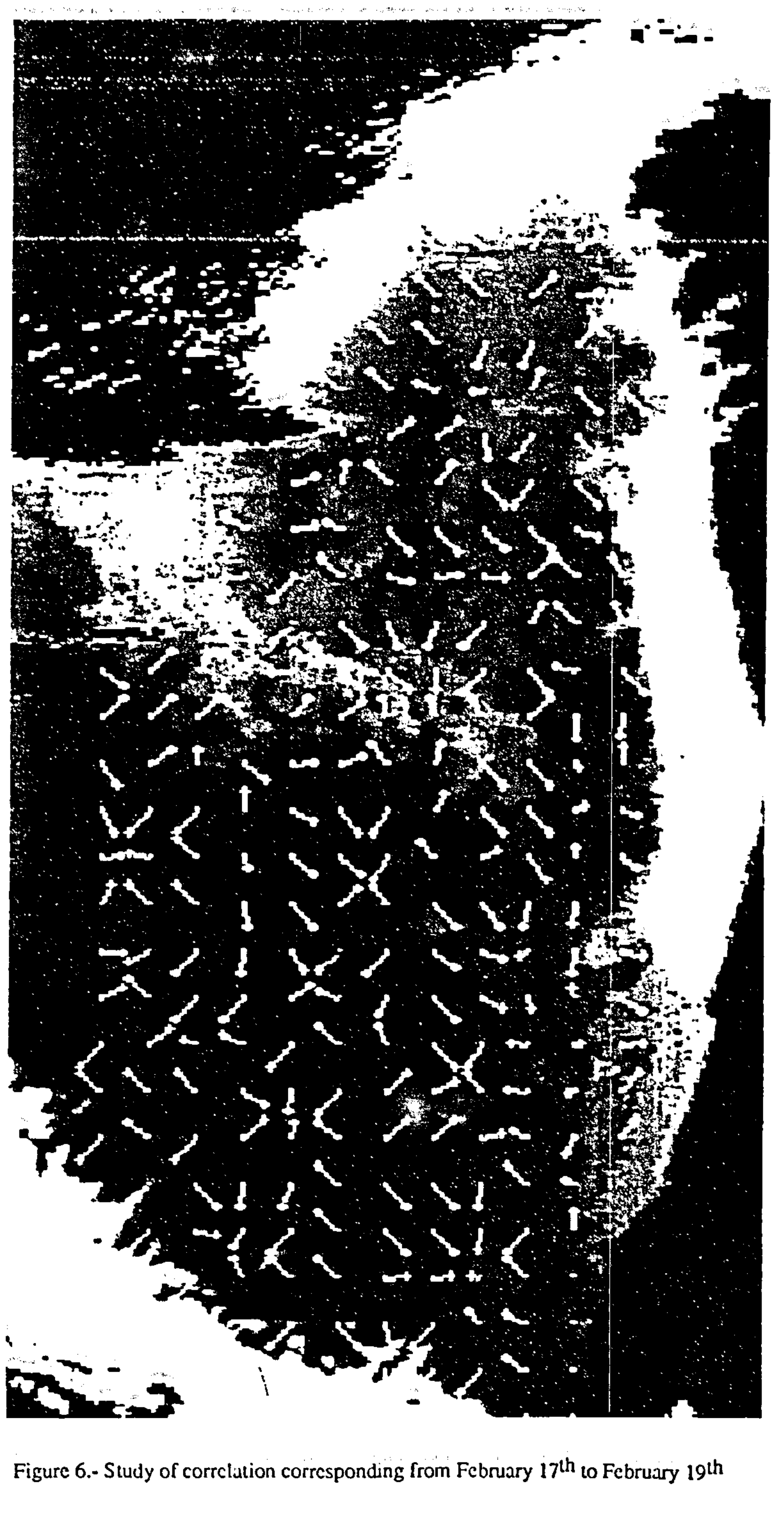


Figure 6.- Study of correlation corresponding from February 17^{th} to February 19^{th}

5.-CONCLUSIONS

On February 15th there is a mass of cold water along the whole coast, which at this time March be due to the general cooling effect of cold water when it is mixed with salt water, denser than it, owing to the fact that the winds calculated as from the end of January, do not reflect continuity and their contribution to upwelling is the same as would correspond to this part of the year (figs. 2, 3 and 4).

An entrance of cold water is produced which corresponds to the bathymetry of the zone and which when it reaches the zone of the shelf, it originates unusual upwelling with unfavorable winds between parallels 40 and 42 and which is maintained during the second fortnight of February, while this mass of entering water exists.

Winds favouring downwelling which blew from the 13th to the 15th did not have any effect on the area mentioned, which did however occur to the North and South of that zone.

6.- REFERENCES

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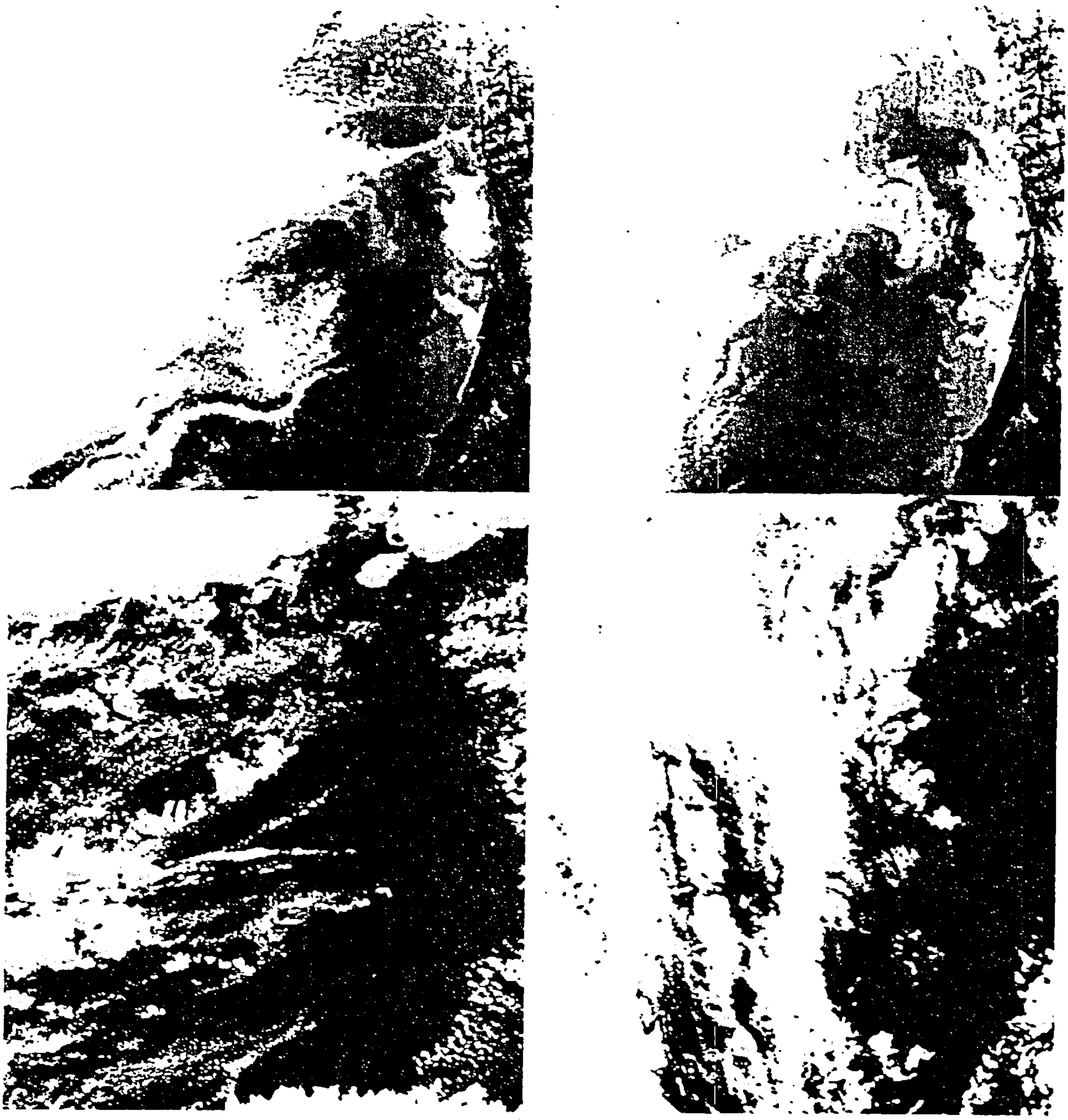

Figure 7.- Infrared images. Top-Left: February 23th, Top-Right: February 24th. Bottom-Left: March 3th, Bottom-Right: March 9th. We can observe the permanent entering of the mass of cold water from the North East towards the Canyon of Aveiro in the top of the image. On March 3th we observe the

Figure 8.- Flux of the water columns over bathymetry.