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OBSERVATIONS OF THE HUELVA COOL-WATER TONGUE

by

BRIAN WANNAMAKER

15 NOVEMBER 1981

NORTH ATLANTIC TREATY ORGANIZATION

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This memorandum has been prepared within the SACLANTCEN Underwater Research Division as part of Projects 01 and 04.

O.F. HASTRUP

Division Chief

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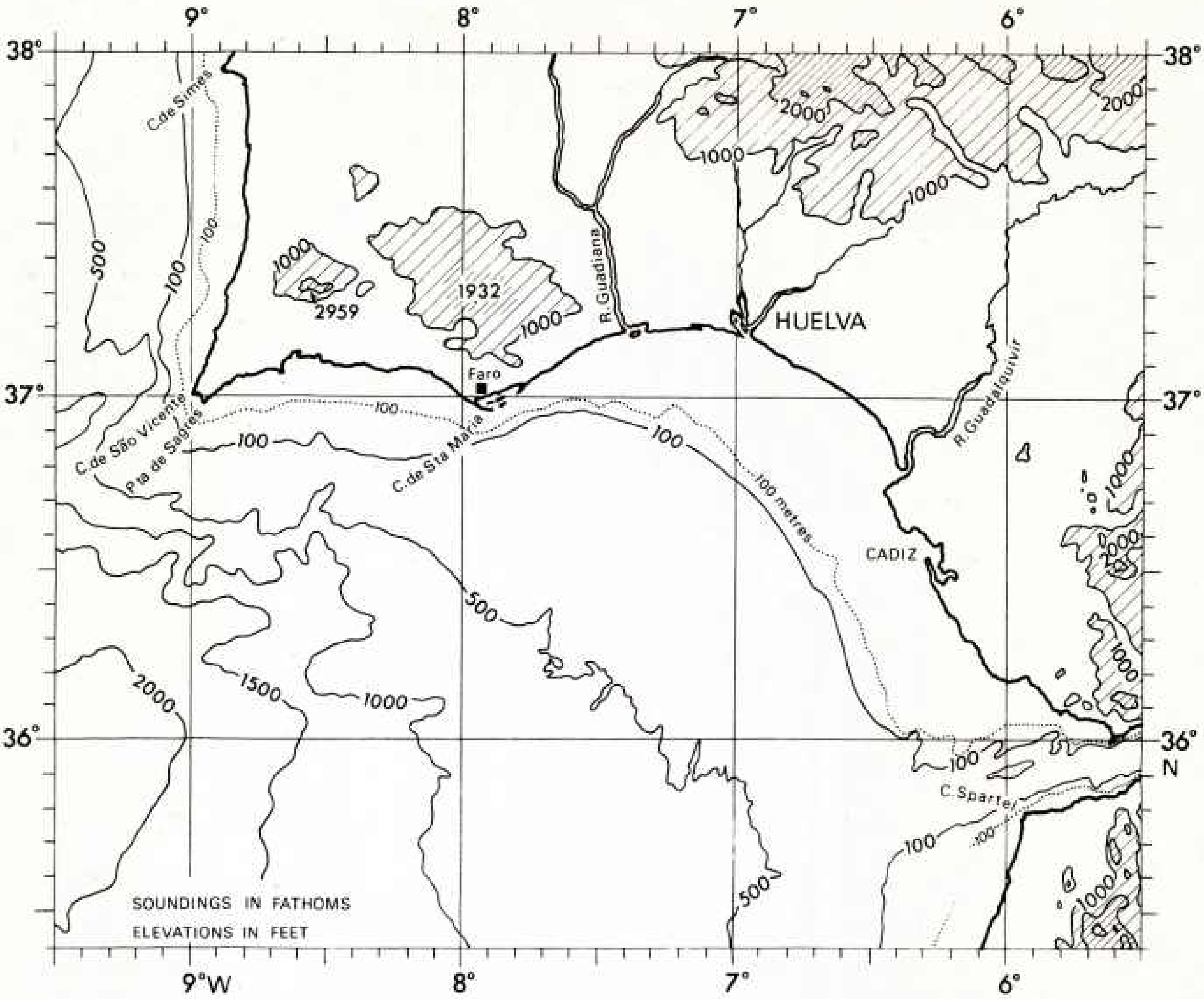

FIG. 1 THE GULF OF CADIZ AND ADJACENT WATERS

OBSERVATIONS OF THE HUELVA COOL-WATER TONGUE

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ABSTRACT

Data from near-polar-orbiting satellites and from ship cruises are used to describe the Huelva Cool-Water Tongue under summer conditions. This tongue extends southeasterly along the shelf break off the southwest coast of Spain and is formed as a result of the advection of water upwelled along the Portuguese coast near Faro or near Cabo St. Vicente. Estimates of the southeasterly speed of the flow are 16 to 18 cm/s from the satellite data and 18 to 28 cm/s from geostrophic calculations. A drop in sound speed of 9 m/s was measured across the tongue. Because of the variability of the tongue any environmental prediction of its occurrence should make use of high-resolution satellite data.

INTRODUCTION

The synoptic view of the ocean surface that has become available with the advent of reliable, precise remote-sensing has led to the observance and scientific study of a number of previously unknown features. One of these, the effects of which were first noted in visible images from the Skylab 2 mission in 1973 was named the "Huelva Front" and described by Stevenson in 1977 <1>. More observations from satellites and ships now allow a further description to be made, part of which is in disagreement with the earlier suggestions. The feature, more accurately described as a cool tongue, extends relatively southeasterly from an area off the mouth of the Guardiana River (the Portuguese-Spanish border) along the continental shelf break of the Spanish coast but has not been observed to extend to the Strait of Gibraltar. More recent, higher resolution, thermal images have revealed small-scale (10's of kilometres) features associated with the tongue.

The Gulf of Cadiz (Fig. 1) is bounded on the north by Portugal and on the east and north-east by Spain. Its continental shelf, which is generally smooth, is 30 to 40 km wide along the Spanish coast but narrows to about 8 km southeast of Faro. Beyond the shelf break a number of submarine canyons steer the Mediterranean outflow water into different branches <2>. Coriolis forces bend the general sweep of the southerly flowing Portuguese current around the right angle of Cabo St.Vicente into the western part of the region.

1 DATA SOURCES

1.1 Remote Sensing

Data from four near-polar-orbiting meteorological satellites (NOAA 5, DMSP, TIROS-N and NOAA 6) have been used to monitor the region in the summers of 1977 to 1979. Only photographic products of the first two have been used. The latter two are of the same series and have a sub-satellite point resolution of about 1.1 km in space and 0.12°C in temperature <3>. Digital data has been processed from computer-compatible tapes of the information received at the Centre de Météorologie Spatiale in France.

Figure 2* is an enhanced TIROS-N thermal infrared (10.5 to 12.5μ) image of the Gulf of Cadiz for 21 May 1979, when there was scant evidence of the Huelva Tongue. Figure 3, which is the same type of image for 16 August 1979, shows the tongue quite clearly with its axis some 40 to 50 km out from the coast. The warm-water inflow from the Guadalquivir River is also evident.

1.2 Ship Data

During the last week of June of both 1977 and 1978 SACLANTCEN's research vessel, MARIA PAOLINA G., completed seven XBT sections roughly perpendicular to the isobaths in the Gulf. Continuous temperature measurements were made at 5 to 10 cm and 4 m depth. STD stations were taken along two of the legs in 1978, using a Plessey model-9040 STD system sampling at 8 times per second. In both years the tongue was well developed, as shown by the surface isotherms in Fig. 4. The surface-temperature ranges measured were about 15° to 19°C in 1977 and 16° to 18°C in 1978.

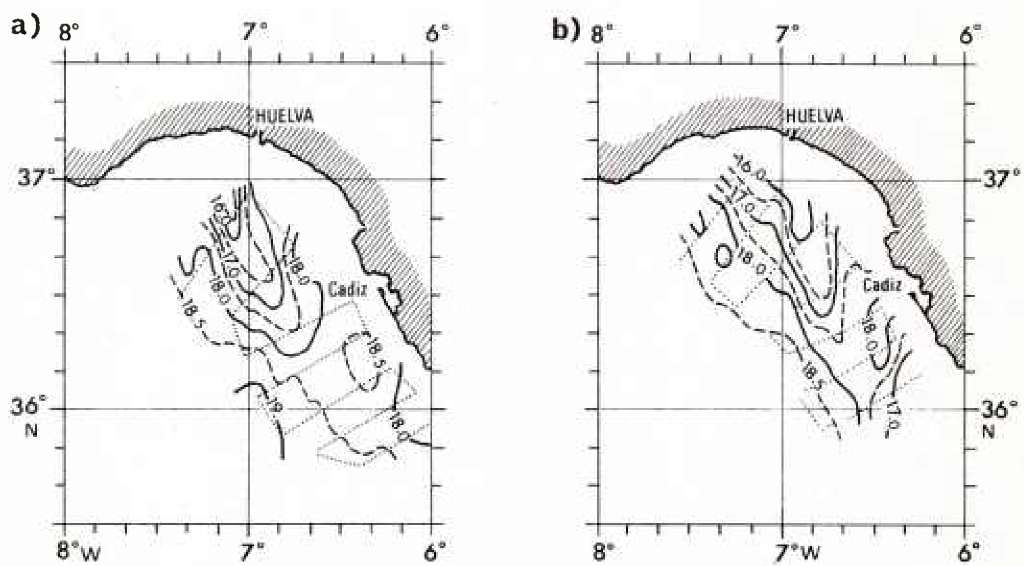

FIG. 4 COMPUTER CONTOURED SURFACE TEMPERATURE DATA
a) 25, 26 June 1977, b) 27, 28 June 1978

*Figures 2, 3, 6, 7, 8, and 12, showing satellite images, are at the end of the text on pp 11-21 respectively.

The northwestern part of the region has been the site of a number of physical and biological surveys (designated CAPEC I, II etc.) by the Portuguese Hydrographic Office. Each cruise occupied up to 185 stations along perpendiculars from the western and southern coasts of Portugal. Figure 5 shows the surface isotherms plotted from these data for August 1971, 1972 and 1973. Also shown are two-dimensional plots of the number of wind-speed observations for each wind direction, taken from the meteorological data collected on board ship during the entire cruise around the coast. There were gaps in the data series but the plots can be taken as indicative of conditions in the couple of weeks before and during the occupation of the stations in the Gulf. Only in 1971 were the data consistent with a cool tongue extending easterly out of the region of data coverage.

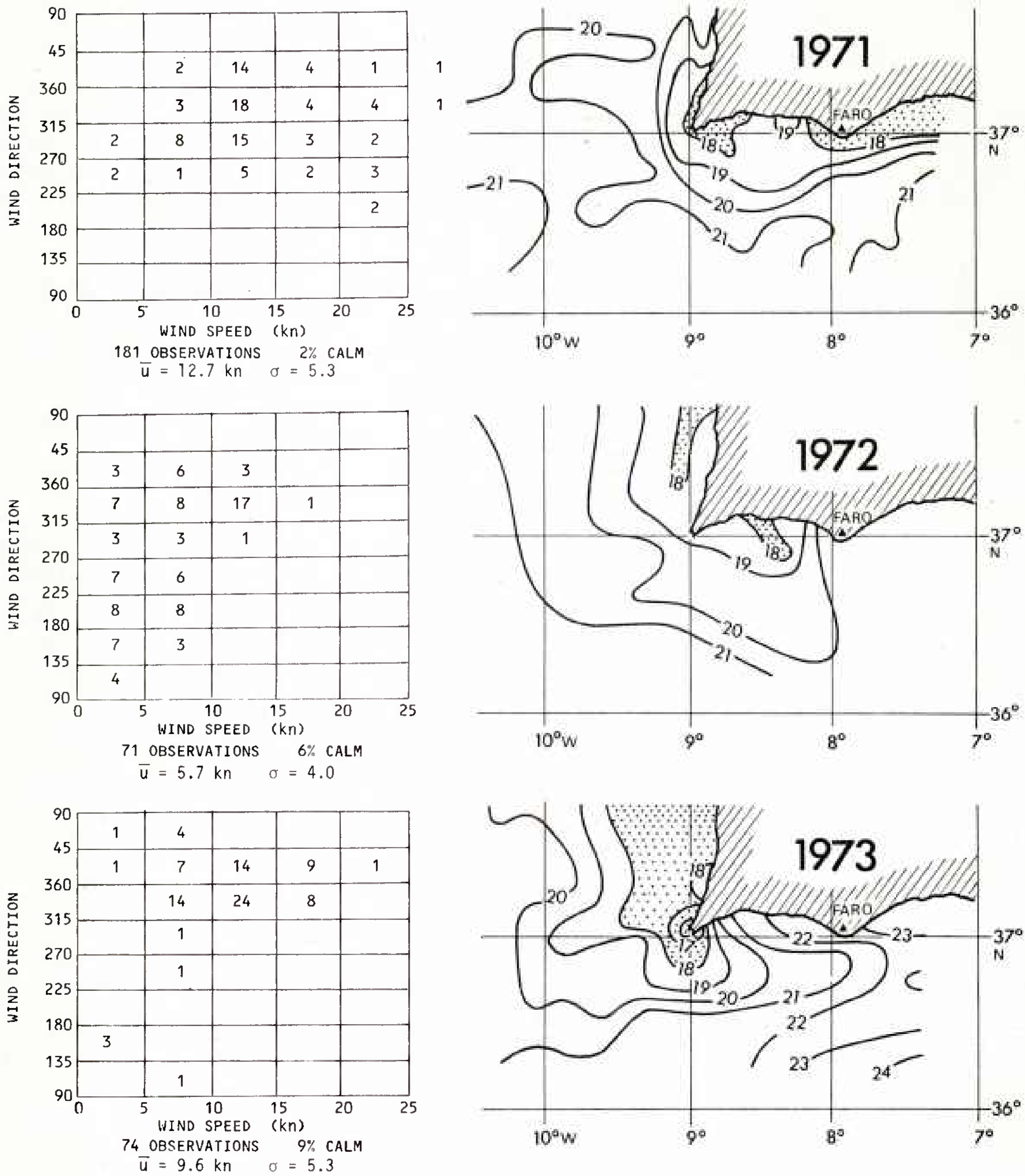

FIG. 5 SURFACE TEMPERATURE AND WIND SPEED HISTOGRAMS FROM CAPEC IV, VII, AND XI CRUISES IN AUGUST OF 1971, 1972, 1973

2 DISCUSSION

Consideration of the data reveals a number of details about the Huelva Tongue and allows some hypothesis to be made.

Figures 6, 7 and 8 are computer-processed infrared images of 3, 4 and 5 August 1979 respectively. The images in Figs. 6 and 7 are from TIROS-N and have been subjected to the same enhancement; the image in Fig. 8 is from NOAA6. At this degree of processing, the colour levels cannot be considered to represent exactly the same temperature if the atmospheric water vapour had changed from one day to the next. Water vapour has an attenuating effect on the infrared radiation, absorbing a fraction of the radiation emitted by the sea and radiating energy at a rate corresponding to the cooler water molecules. However, in this discussion only the patterns of temperature changes are considered.

The tongue was developing from one day to the next during these three days, with the source of the cooler water on the coast east of Faro and Capo Santa Maria. The continental shelf is narrowest here; the 100 fathom (183 m) line is within 4 n.mi of the coast. A cool patch of water along the coast between the mouth of the Guadiana river and Huelva grows somewhat from one day to the next but does not appear to supply much to the growing tongue.

Upwelling further along the Portuguese coast was well developed. A submarine canyon in the narrow shelf just north of Cabo St. Vicente is a likely source for the cold water. However, in each of these three images the regions of cooler water are separated by warmer water west of Faro.

In Fig. 6 (3 Aug) three cool-core eddy-like features (to the west of the arrows in the image) can be noted approximately along the eastern side of the position expected for the tongue. These can also be found in Figs. 7 and 8 (4 and 5 Aug), except that feature C was obscured by cloud in the latter, which was confirmed by images from the other infrared channel and the near-infrared channel. Since these features were visible for three consecutive days at known times, their displacement and drift speed could be estimated. The images were subject to different distortions due to satellite/earth geometry but the movement was virtually along a line from Cape Spartel to the mouth of the Guardiana river, a distance of 200 km. Distances were measured proportional to this. Table 1 shows the estimates.

TABLE 1

ESTIMATES OF SURFACE-CURRENT SPEED IN THE HUELVA FRONT
(August 1979)

Feature	Displacement (km)		Speed (cm/s)	
	3-4 Aug	4-5 Aug	3-4 Aug	4-5 Aug
A	14	10	16.3	16.3
B	16	12	18.7	19.5
C	14		16.3	

Orbit data: TIROS.N 4149 Ascending Node 1527 GMT, 3 Aug 79 at -3.86°E
TIROS.N 4163 Ascending Node 1516 GMT, 4 Aug 79 at -1.17°E
NOAA.6 550 Ascending Node 0759 GMT, 5 Aug 79 at 172.83°E

Images available from DSMP satellites (Defence Satellites for Military Purposes) after these dates showed that the cooler water continued to spread southeasterly until at least 20 August. Figure 3, from TIROS.N data on 16 August, indicated that it extended some 100 km from its 4 August position. This displacement was consistent with the flow of 16 to 19 cm/s estimated above.

The surface current in the area was also estimated from geostrophic calculations by using the 1978 STD data. Choosing a level of no motion is always difficult in geostrophic calculations; the justifications here are (a) that there is a known subsurface flow of high salinity in a north-westerly direction along the continental slope and (b) the following evidence provided by historical measurements.

A geostrophic current profile fitted at four depths to deep current meter records by Zenk at 36°22'N, 7°43'W indicated zero velocity at 500 m <4>. This may be approaching the western side of a large gyre that Stevenson has said exists in the area, based on displacement of a ship track and surface-temperature records. A jog in the ship track of the MARIA PAOLINA G's 1978 cruise similarly suggested the presence of shear about 8° west (see Fig. 3 of <5>. Other current-meter arrays in Zenk's experiment in the region southwest of the Huelva Tongue have also shown increasing speeds below 400 m in directions opposed to the expected surface flow. Nearer the Strait of Gibraltar the shallower southeasterly flow is confirmed by assymetrical sand waves on the shelf <6>.

With these considerations the salinity minimum at about 400 m was taken as the level of no motion and dynamic heights were calculated for each of the stations. For stations in a water depth less than the reference value, isolines of dynamic height were extrapolated inshore by using the slopes observed between the previous two stations. This method accomodates a non-zero shear at and near the bottom in the shallow water <7>. Using the geostrophic approximation, the current at the surface (actually at 5 m) was calculated between adjacent pairs of stations. Figure 9 illustrates the calculated velocities.

The cross isobath flow was low (<4 cm/s) except for the shallowest pair of stations. The flow through the more northerly cruise leg was also greatest (≅ 18 cm/s) at the coastal end. This was consistent with the pattern of surface temperature (Fig. 4b), which implied that the tongue entered the sampled region through its northeast corner. In the other STD section the current shear also occurred in the region of greatest horizontal temperature gradient. The estimated velocities (≅ 28 cm/s) were higher than the estimates from satellite data for the following year.

Figure 10 illustrates the horizontal temperature structure at 20 m and 50 m in 1978. Closed isotherms existed along the southeastern boundary of the tongue position at 20 m depth; this is consistent with the presence of eddies but the tongue itself did not show. At 50 m the temperature decreased toward the coast, showing no indication of the tongue or eddies.

Variability in the orientation of the tongue from one year to another can be observed in the image for 16 August (Fig. 3) and the surface isotherm plots (Fig. 4). Measurements of the orientations with respect to north gave values within 5° of 150°, 160° and 140° for 1977, 1978, 1979 respectively. The image of 16 August 1979 shows that the direction of the axis

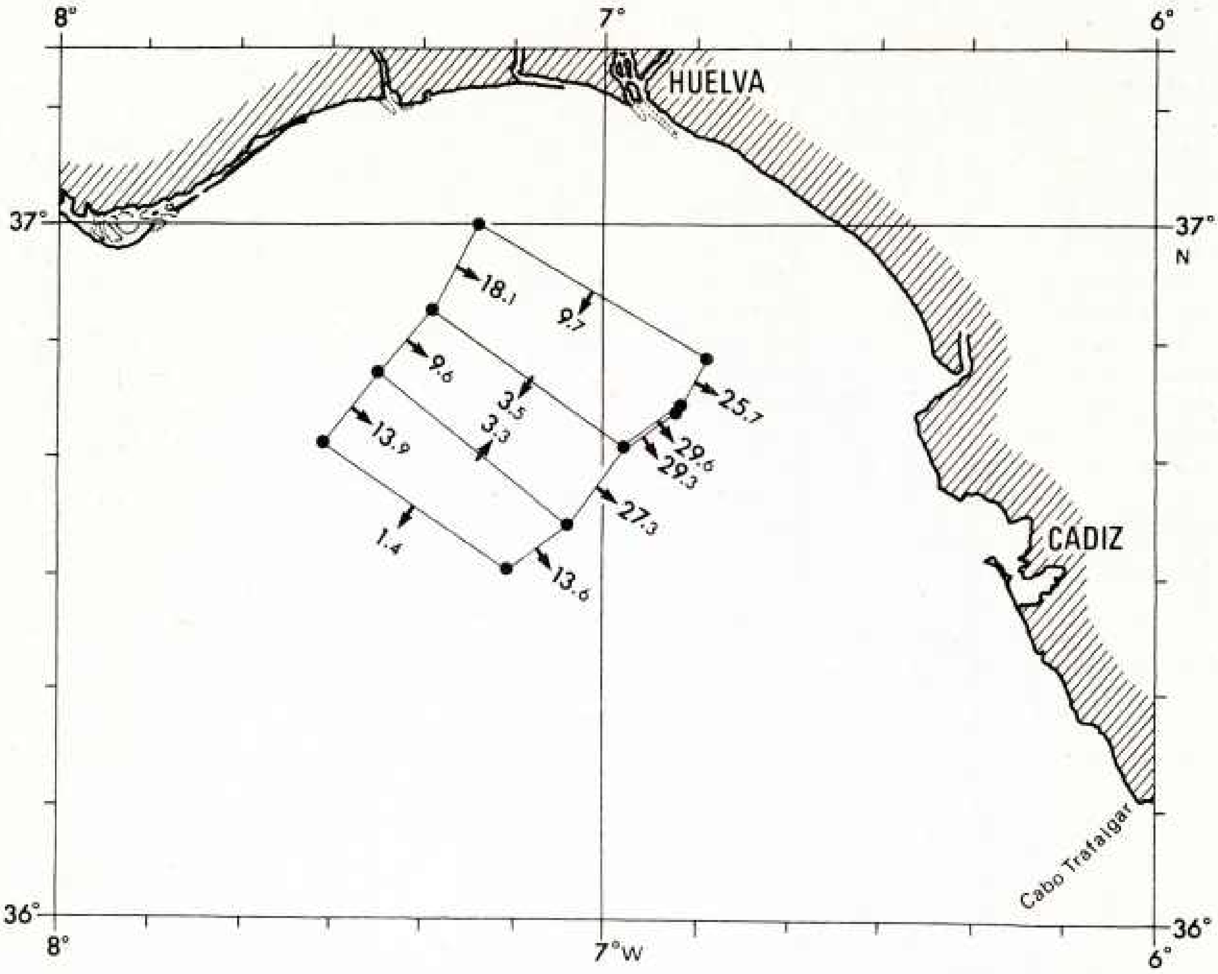

FIG. 9 CALCULATED GEOSTROPHIC FLOW FROM STD PROFILES IN JUNE 1978. Maximum estimated current was along the axis of the tongue

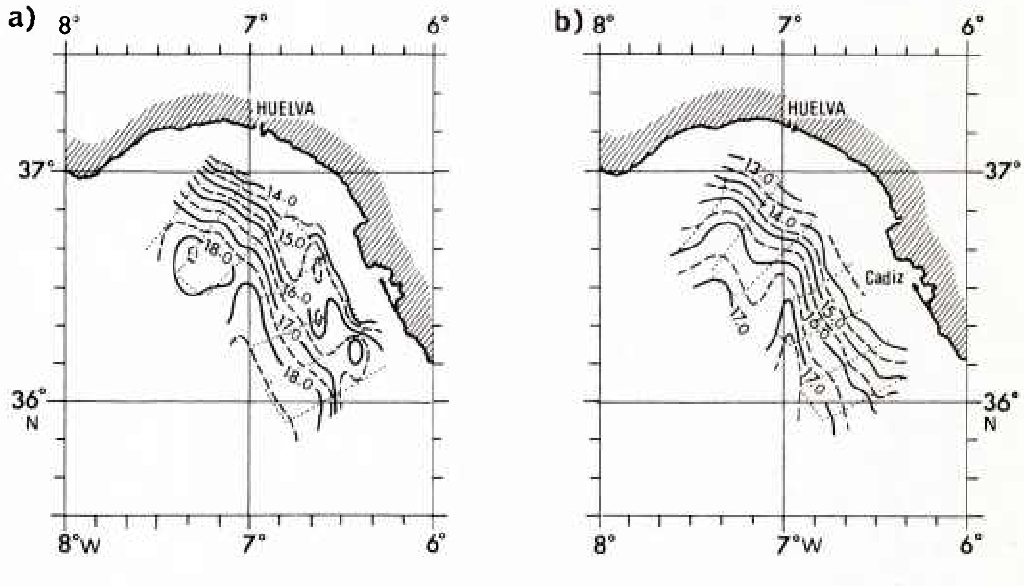

FIG. 10 COMPUTER-CONTOURED HORIZONTAL TEMPERATURE FIELD, JUNE 1978 a) at 20 m and b) at 50 m. The effect of the tongue has disappeared by 50 m

changed by 45° west of Cadiz, where it may have been interacting with what appeared to be a warm-water tongue extending outward from Gibraltar and curving northward.

A sound-speed section from STD data (Fig. 11) shows a charge of about 4 m/s in 5 km and a total decrease of 9 m/s across the tongue. It was also noted from the near-surface temperature record that temperature spikes of >1.4°C occurred especially near the edge and centre of the tongue; these were associated with surface slicks <8>. These would affect acoustic propagation in the surface duct.

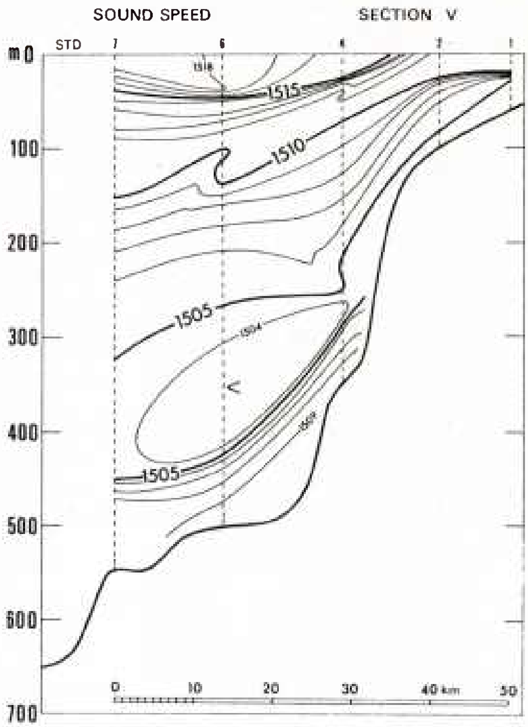

FIG. 11 SOUND-SPEED SECTION FROM THE MORE SOUTHERLY LEG OF STD MEASUREMENTS OF 1978

From the foregoing it can be hypothesized that the Huelva Tongue is caused by an upwelling and advection process associated with the same driving force as the upwelling off the west coast of Portugal – the Portuguese Trades. Climatologically, 28% of the winds on the west coast are northerly and another 22% northwesterly during July. These winds curve around Cabo St. Vicente and are funnelled down the valleys between the highlands of southern Portugal. This channelling of the winds was confirmed by a number of visible satellite images, for example Fig. 12. The direct solar reflection point was over central Portugal and a banded sun glint pattern should have extend north and south of this <9>. However, there were two anomalously dark areas fanning out from where the valleys open out onto the sea, which were the result of wind-roughening of the sea surface decreasing the area of specular solar reflection. The facts that the tongue is not always present and varies in strength, and that the major source of the cool water appears to be a small area near Faro, imply that a particular wind direction and a minimum strength may be required.

The upwelled water is advected in the general flow to the southeast at between 16 and 28 cm/s. When upwelling is intense or long-lasting at Cabo St. Vincente this may also supply cooler water to the Huelva Tongue (Fig. 3).

Support for these hypotheses comes from the Portuguese CAPEC data (Fig. 5). For 1972 the data showed no indication of upwelling east of Faro or the Huelva Tongue. The overall winds were 5.7 m/s, with the most uniform distribution of directions of any of the three summer periods <10>. In 1973, when winds were stronger (9.6 m/s) and mainly from the north and northwest, upwelling was evident and there was advection of this cooler water eastward. At that time upwelling had not occured further east. In 1971 upwelling was observed east of Faro as well as at Cabo St. Vincente, with warmer water between, similar to the 1979 satellite data. The wind was again stronger (12.7 m/s) and mainly from the northwest <12>. The upwelling was associated with stronger north and northwesterly winds.

The station data from the CAPEC cruises for positions east and south of Faro showed an initial decrease of salinity with depth. There was a salinity drop of 0.1‰ to 0.4‰ in the first 30 m, whereas the temperature drop was 5° to 6° over the same depth range. Thus upwelled water warmed at the surface would be in static equilibrium before reaching the same temperature as the surrounding surface water.

In 1979, from the beginning of the month until 10 August, the noon and midnight reports of wind at Sagres near Cabo St. Vincente were generally north to northwest at 10 to 15 knots. After two days of weak easterly winds or calm conditions the wind rose to 25 kn on 15 August and 20 kn on 16 August <13>. Because of the topography the winds at Sagres will not be equivalent to those at Faro and further study of upwelling in the area would require more wind-data points. The particular geometry of small sections of coastline relative to the wind are also important, as discussed by Millot in his work on upwelling in the Gulf of Lions <14>.

Southwesterly gales can set up currents of 2 kn along the coast <15> and this could be expected to cause disintegration of the tongue.

SUMMARY

The Huelva Tongue appears to be a shallow (<20 m) variable feature stretching along the continental shelf break of the northeastern Gulf of Cadiz. The temperature difference across the tongue can be about 3°C in the summer. The thermal front at its eastern edge is stronger than that at its western edge, being equivalent to a drop of about 4 m/s in sound speed in 5 km. The cool water in the tongue upwells from a quasi-point-source either east of Faro on Cabo Santa Maria or near Cabo St. Vincente and advects into the general circulation.

The flow in the tongue is southeasterly (not northwesterly as suggested in <1>) at a speed estimated as 16 to 18 cm/s from satellite data or as 18 to 28 cm/s from geostrophic calculations for earlier station data. The orientation may vary by 20° from one year to the next. Eddies sometimes form on the eastern edge of the tongue, probably due to the vorticity induced by current shear.

Because of its variable nature, study or prediction of the environmental effects of the tongue should include high-resolution satellite data: the locations and times of upwellings carrying nutrient-rich waters from below the thermocline are clearly delineated. To make acoustic models and predictions would require data on the vertical extent of the tongue at other times of the year. However, the horizontal changes in sound propagation across the tongue depend on temperature rather than on salinity. Thus the horizontal temperature gradient and location, and the extent and growth of the tongue, can all be measured from satellite information, while the depth of the tongue could be estimated from historical data and heat-budget calculations.

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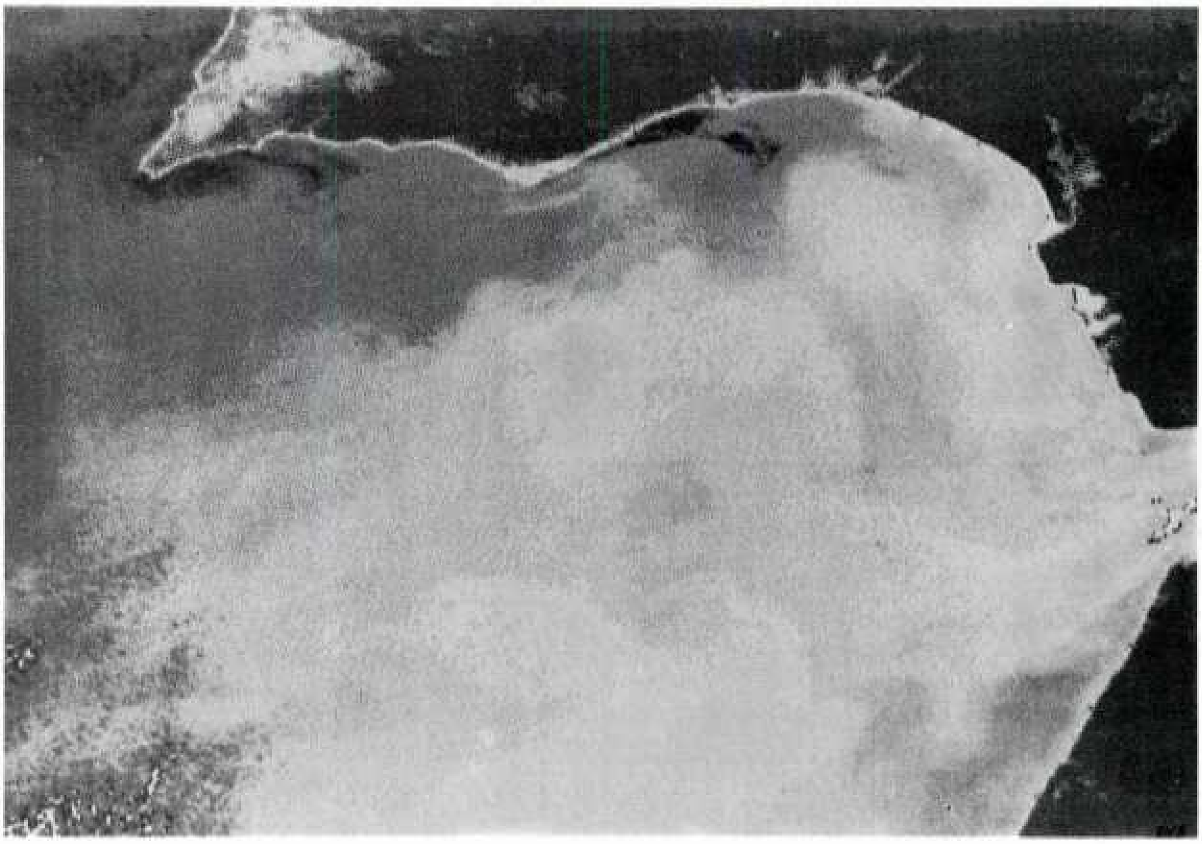

FIG. 2 TIROS.N THERMAL INFRARED IMAGE OF THE GULF OF CADIZ, 21 MAY 1979. The colour scale increases with temperature from white, through blue to red and white again. Land shows up in shades of grey.

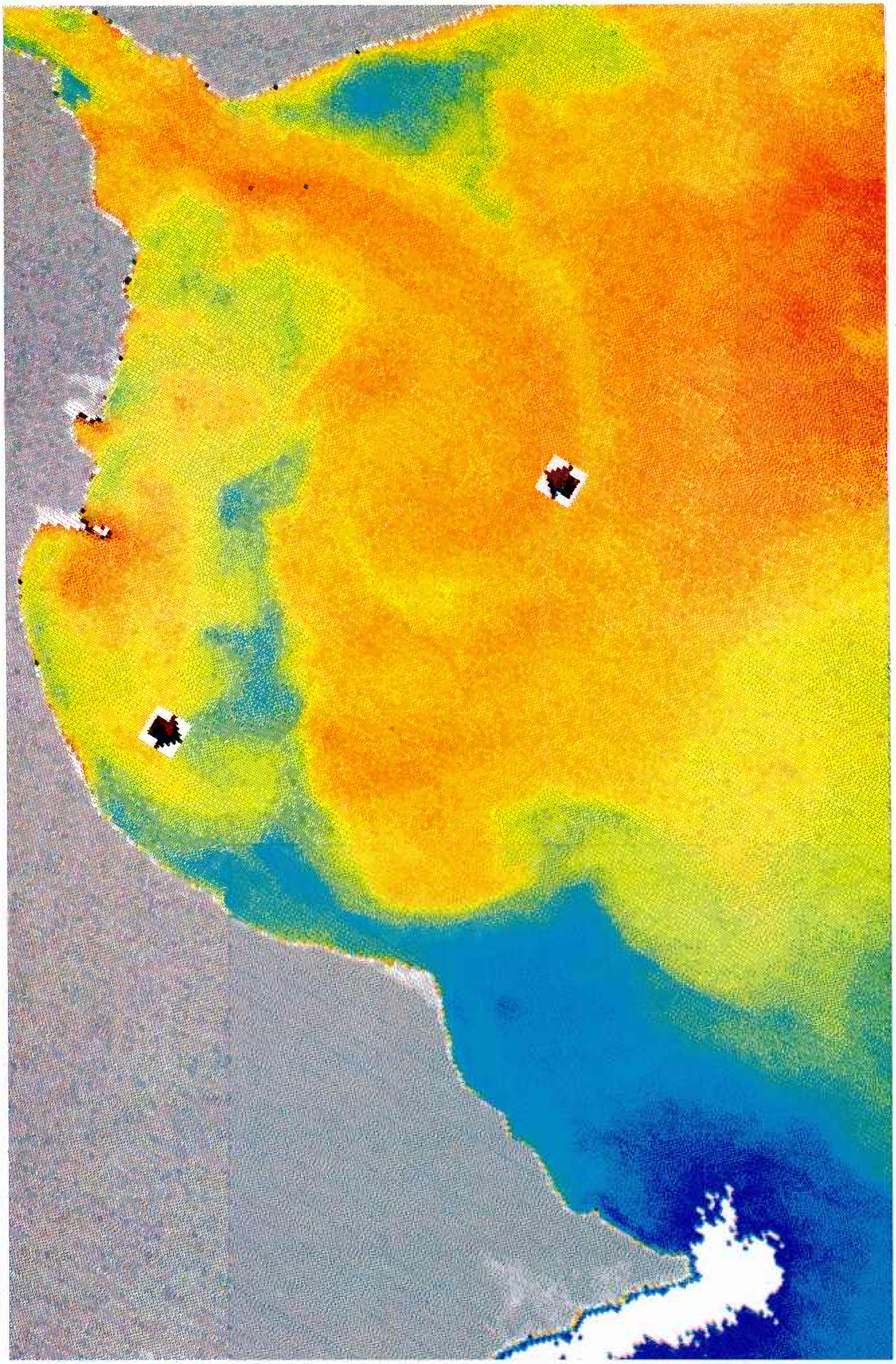

FIG. 3 TIROS.N THERMAL INFRARED IMAGE OF THE GULF OF CADIZ, 16 MAY 1979, SHOWING THE HUELVA TONGUE WELL DEVELOPED

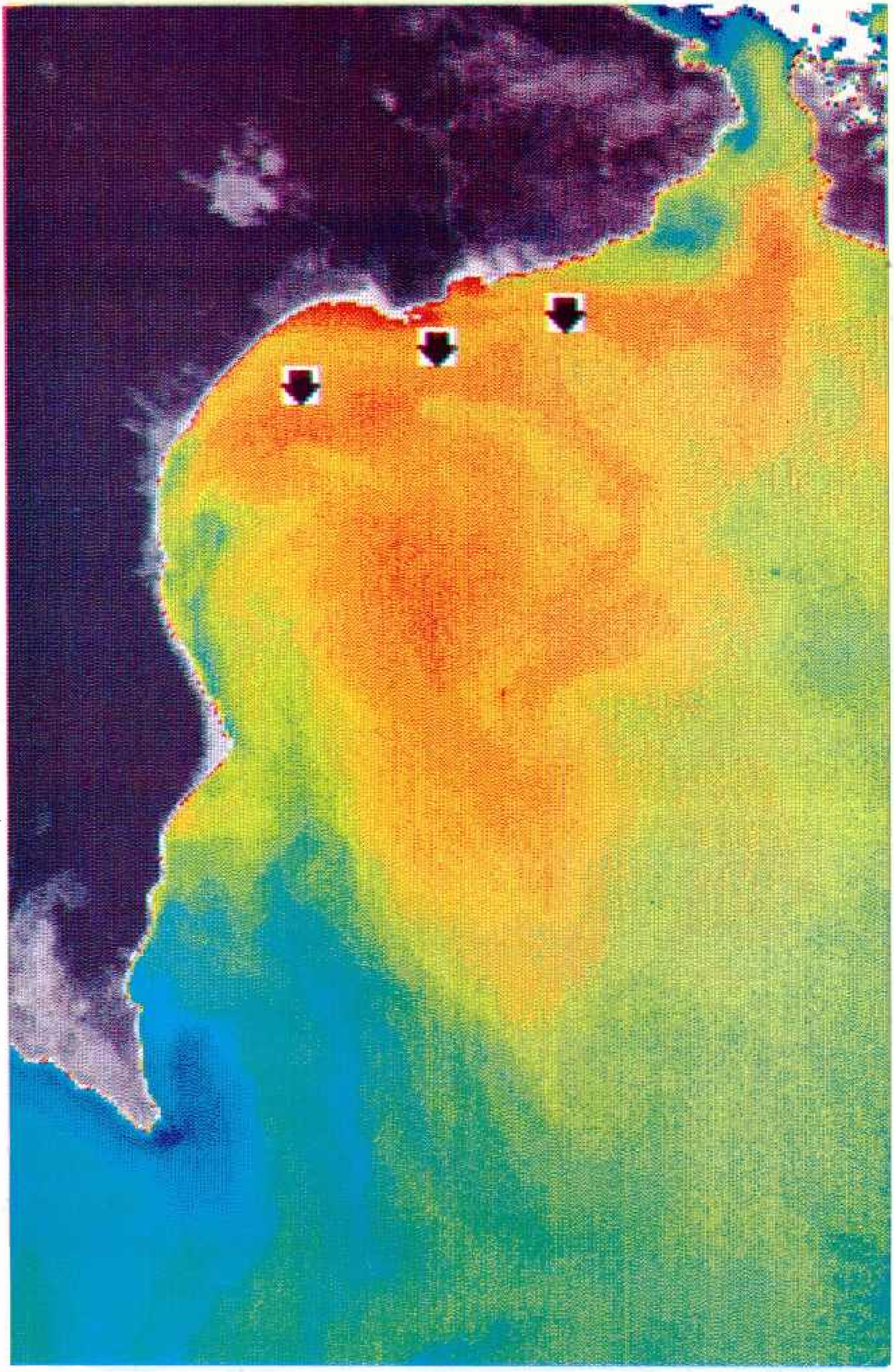

FIG. 6 TIROS.N THERMAL INFRARED IMAGE OF THE GULF OF CADIZ, 3 AUGUST 1979. Cool-core features lie to the left of the arrows

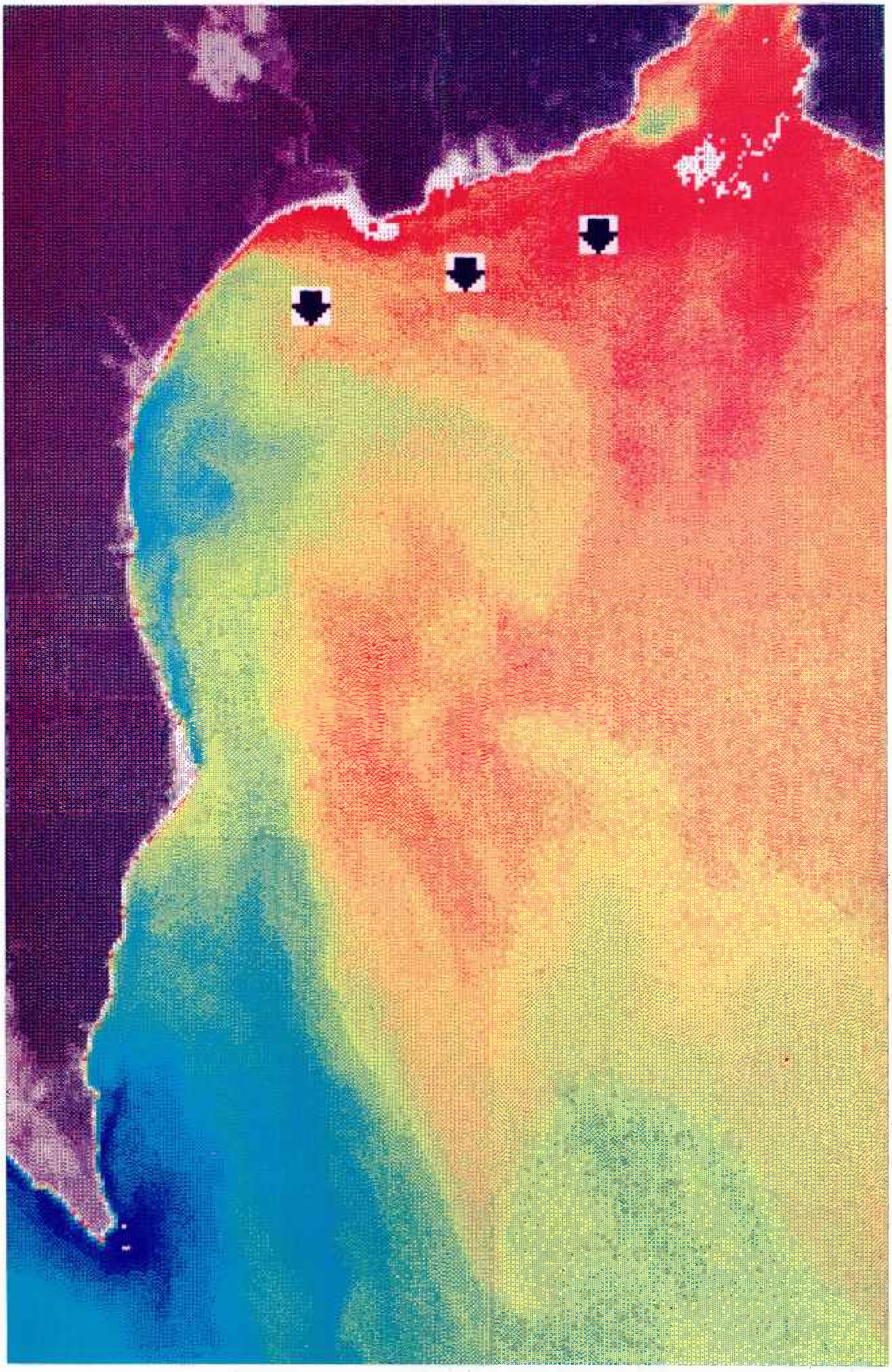

FIG. 7 TIROS.N THERMAL INFRARED IMAGE OF THE GULF OF CADIZ, 4 AUGUST 1979. Cool-core features lie to the left of the arrows

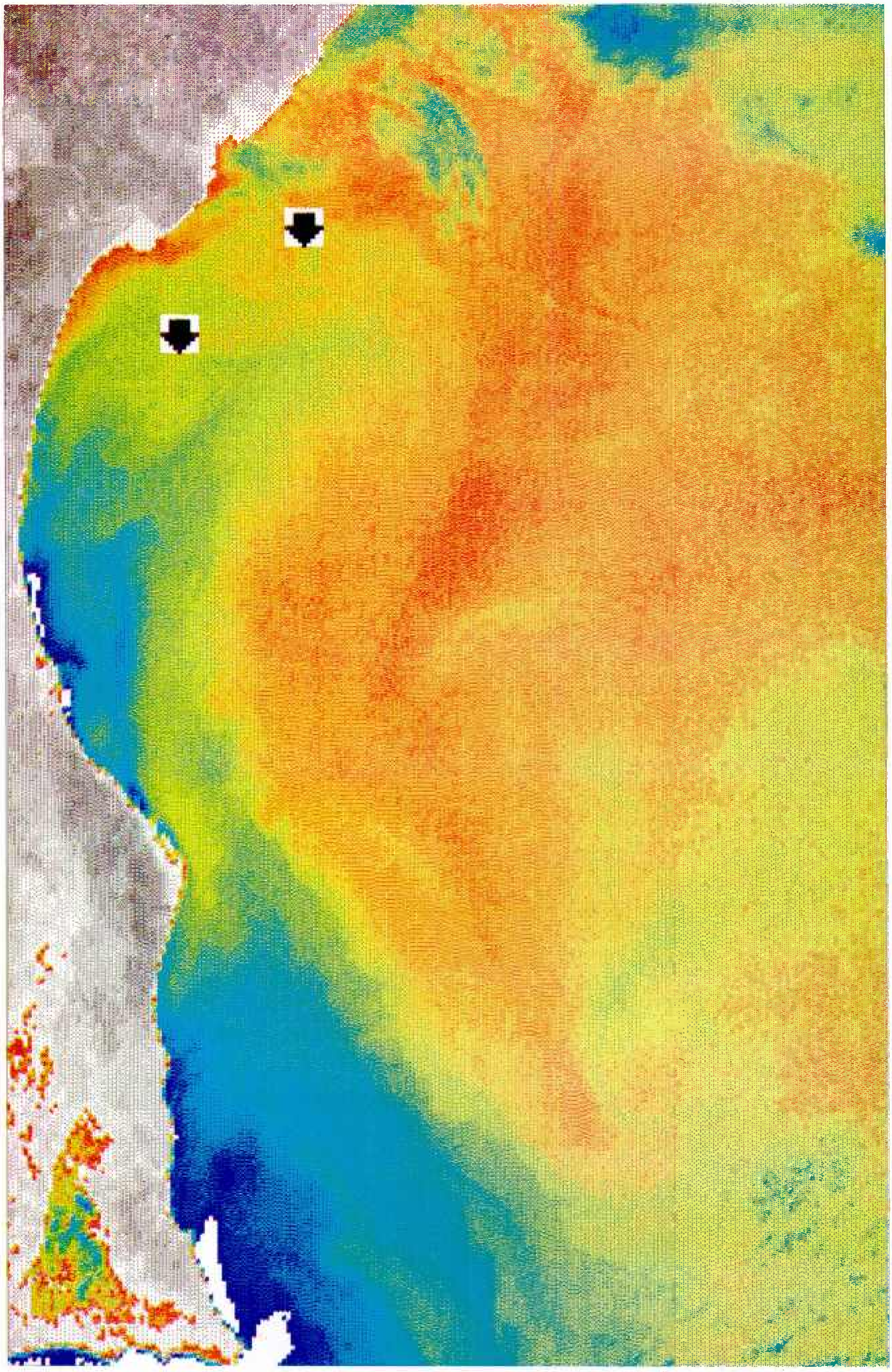

FIG. 8 NOAA6 THERMAL INFRARED IMAGE OF 5 AUGUST 1979. Fog or cloud obscures the cool-core feature in the lower part of the Gulf of Cadiz

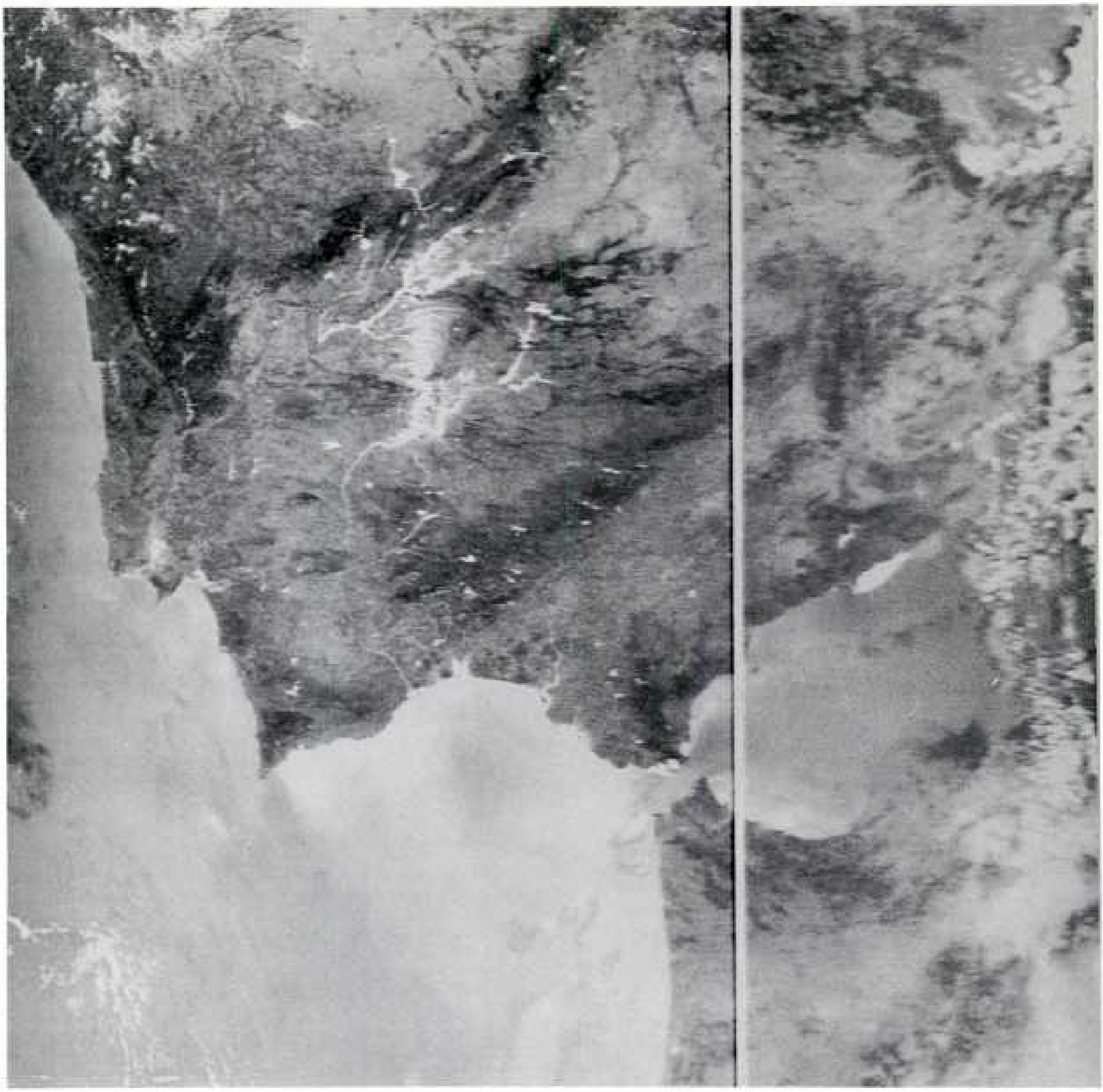

FIG. 12 NOAA.5 VISIBLE IMAGE OF GULF OF CADIZ. 12 JULY 1978. The sun glint pattern was disturbed by northerly winds

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