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Sea surface temperatures of the Aveiro region of the Atlantic coast of N. Portugal, using AVHRR data

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ABSTRACT: The Atlantic coast of Portugal, to the south of Porto, was formed during the Holocene (Rodrigues and Dias 1989) by the accumulation of sand deposits derived principally from the north. This created a linear coast aligned at an angle of 15º to the east of north. The main aim of this work was the study of the physical environment of the offshore system using AVHRR data to examine sea surface temperatures (SST) in the Aveiro region (Portugal), in order to identify, during 1999, the Portuguese coastal upwelling.

1 INTRODUCTION

The Atlantic coast of Portugal, to the south of Porto, was formed during the Holocene (Rodrigues and Dias 1989) by the accumulation of sand deposits derived principally from the north. This created a linear coast aligned at an angle of 15º to the east of north. Inland lies a coastal plain that was formerly the location of several lagoons. Once isolated from the ocean, these soon became infilled by sediments. Near Aveiro, however, the effect of a major river discharge slowed this process, permitting the formation of the Ria de Aveiro (Fig. 1) (40º 38´ N, 8º 44´ W), separated from the sea by a spit bar. Although it is designated as a "ria", the water body bears no resemblance to the Galician rias of north-west of Spain to the north, and a more accurate description is an "estuary-coastal lagoon" system..

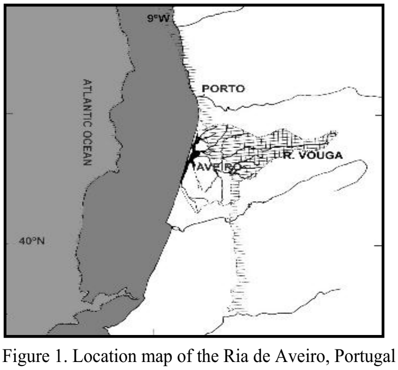

Figure 1. Location map of the Ria de Aveiro, Portugal

The objective of this work was to use, for the Aveiro region, sea surface thermal information from the AVHRR on the TIROS/NOAA series of polar-orbiting meteorological satellites for oceanographic applications in order to determine upwelling events and make an estimation of their frequency of occurrence during the year 1999. In addition, the role of bottom topography and the coast-line configuration in the generation of upwelling was studied. Description of the development of an upwelling in time to determine its main phases and the delay in time between the setting of a favourable wind and the moment of arrival of cold water at the surface was also estimated.

2 DATA USED

2.1 *AVHRR Data*

The data used were from AVHRR on the NOAA series of polar orbiting satellites and were provided by the Satellite Data Receiving Station at Dundee University.

A total of 21 cloud-free AVHRR images taken during the year 1999 were used for this work. Dates and times are shown in Table 1.

Table 1. List of AVHRR images acquired

MONTH	DAY	TIME
January	6 30	15:40 14:32
February	5 13	15:06 15:17
March	1 20	15:40 15:28
April	8 18	15:16 15:04
May	21	15:36
June	8 19	15:35 15:11
July	6	15:21
August	1 11	15:29 15:17
September	14 28	15:35 16:18
October	3	15:21
November	3 25	16:12 15:23
December	2 16	15:44 16:26

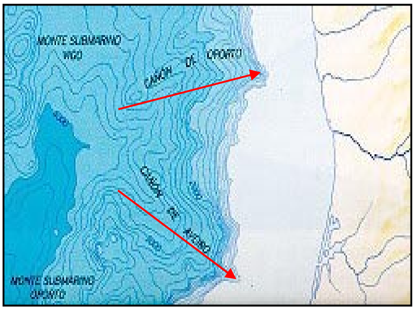

Figure 2. Bottom topography of the study area

2.2 *Sea Level Pressure Maps and associated winds*

Horizontal pressure gradients, which result from the uneven distribution of mass within fluids, are the main driving force of motions in the atmosphere and ocean. The pressure may suffer variations along a horizontal surface due to changes in the height or the density of the fluid above it.

The pattern of air masses over the ocean is not uniform and the mean pressure follows a seasonal cycle which forces another one on the sea surface. This cycle is partly generated by seasonal changes in the mean pressure over the oceans. In the summer season, the low pressure cell centered in Greenland loses intensity while the high pressure from the Azores moves to the central Atlantic, resulting in a pressure gradient which forces air flowing southward along the occidental coast of Iberia. In winter the high-pressure cell appears at the northwestern African coast and low pressures are located off the southeastern coast of Greenland. The relative location between these pressure systems leads to a pressure gradient, which results in an onshore wind with a strong northward component. Winds initiated by the Pressure Gradient Force (PGF) will be modified by secondary forces, the Coriolis Force (CF) being the most important one. The PGF is always perpendicular to the isobars and is directed towards lower pressures. The CF always acts at right angles to the wind, clockwise in the Northern Hemisphere, anticlockwise in the Southern Hemisphere.

Away from the ground, when both forces are of equal strengths and opposite directions, geostrophic balance is achieved, the wind speed being proportional to the gradient. Close to the surface, it is necessary to consider the frictional force. When friction is added to the force balance, wind is not considered to be in geostrophic balance any more and, since friction slows the air motion, it also causes the CF to be weaker. The PGF therefore becomes greater than the CF. From the condition of equilibrium of forces, this condition results in a deviation of wind direction with respect to the isobars.

2.3 *Coastal morphology and bottom topography*

Coastal dynamic processes are greatly influenced by capes and submarine ridges (Fig. 2) as well as temporal variations of wind stress. This close relation is important for studying coastal structures in order to get a useful tool for prediction studies. Typically, five or six fully developed upwelling filaments are observed off the Iberian Peninsula late in the upwelling season (Fiúza, 1982, 1983). Most of these are associated with major topographic features of the region, in particular the large capes which are common to the north and south of the peninsula.

3 METHODOLOGY

3.1 *Image selection*

A total of 21 full high resolution AVHRR NOAA images covering the year 1999 on a monthly basis have been selected by a meticulous consultation of the Dundee quick-look archive. The search was conducted in order to choose cloud free images that could be used in the SST calculation. Cloud free images are easier to find using the visible channels since thermal band data could be contaminated by low clouds nearly indistinguishable from the sea surface due to similar temperature and upwelling radiance. Each file contains data from all five channels for an image, and the corresponding calibration data.

3.2 *Geometric correction using GCPs*

Raw digital images usually contain geometric distortions so significant that they cannot be used as maps. The sources of these distortions range from variations in the altitude, attitude, and velocity of the sensor platform, to factors such as panoramic distortion, Earth curvature, atmospheric refraction, relief displacement, and non linearities in the sweep of a sensor´s IFOV. The aim of geometrical correction is to compensate for the distortions introduced by these factors so that the corrected image will have the geometric integrity of a map.

The geometrical correction process was made by the selection of a set of GCPs for the 21 NOAA images by identifying similar features on the raw satellite image and on a high accuracy digital map.

For each GCP there is a pair of geographical co-ordinates (easting, northing) with an associated pair of raw image co-ordinates (pixel, line). The distinctive western coastline of the Iberian Peninsula made it possible, except in the presence of clouds, to insert a large number of well-distributed GCPs on each raw satellite image.

3.3 *Land and cloud masking*

For oceanographers, the accuracy of satellite observations of SST is critically dependent upon the ability of satellite radiometers to view the sea surface unobstructed by cloud. Large areas of thick cloud can be identified very easily by visual inspection by an operator using an image display system; the contaminated area can be delineated with a cursor and then masked out. What are more difficult to handle are areas of very thin cloud (like high cirrus or low stratus) or haze or small clouds that are smaller than the size of the IFOV. These clouds are very much colder than the sea surface and can add large errors to the estimation of SST (Stewart 1985).

After masking land (in black colour) the histogram of brightness temperatures of the whole sea area was studied. This was expected to be bimodal with a clear separation between the digital numbers (DNs) for the colder clouds and the warmer sea surface. This method works in general satisfactorily. It will not work for clouds smaller than the IFOV, like trade wind cumulus or thin scattered clouds, because the pixel signal will be an average between cloud and sea temperatures.

3.4 *Sea Surface Temperature calculation and level slicing*

SST calculation has been carried out with the software "TEMPOS" developed under WINDOWS 95 in the University of Vigo. This software allows the user to choose the SST algorithm because it includes a database with information related to all the coefficients corresponding to each one of the algorithms available for the calculation.

The level slicing technique was applied to all the SST images. This is the technique whereby the DNs distributed along the *x* axis of an image histogram are divided into a series of intervals or "slices". All of the DNs falling within a given interval in the input image are then displayed at a single DN in the output image. Each level of temperature has been coloured according to a scale bar that ranges from 10ºC to 25ºC.

3.4.1 *Sea Surface Temperatures of the Ria de Aveiro*

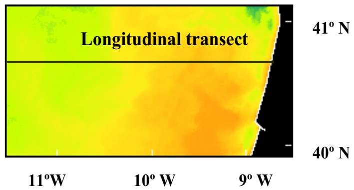

Figure 3. SST longitudinal transect. Values obtained along the line were plotted on a graph

A perpendicular transect to the coast line of Aveiro was traced using the *IDRISI* software in order to make the SST calculation.

Temperature values along this longitudinal line were extracted using the *POINTVEC* function for converting pixels into vector points and *CONVERT* function for converting the integer and binary output vector into an integer and ASCII file which has 3 columns: *X* value, *Y* value and *SST* value. Each ASCII file was imported with the import function of *Microsoft Excel*. Data were represented (Fig. 3) in bixial graphs: *X* longitude and *Y* SST (º C).

3.5 *Geostrophic wind calculation*

The strength of upwelling depends on wind characteristics such as speed, duration, and direction. Because of that, wind regime along the Portuguese coast was analysed using the geostrophic wind approximation.

Sea level pressure charts downloaded from the Internet were used in order to estimate geostrophic wind vectors. The wind calculation was made during:

-the 4 previous days in which SST estimation was obtained,

-and also on the same date of the SST estimation.

Wind vectors were obtained using the *Surfer* package. They are depicted with arrows showing the wind direction and speed (proportional to the size of the arrow) as shown below.

After applying the methodology explained above, SST and wind vectors were obtained in order to establish a correlation between the appearance of cold upwelled water appearance at the Aveiro coast and other parameters such as geostrophic winds and the typical bathymetry of the area.

4 RESULTS

Images and graphs presented in this section are the result of the SST and wind vector calculations obtained following the methodology described above.

The most representative of all were found at the following dates: 13th February (Figs 4-6); 21st May (Figs7-9); 6th July (Figs 10-12) and 14th September 1999 (Figs 13-15).

4.1 *13th February*

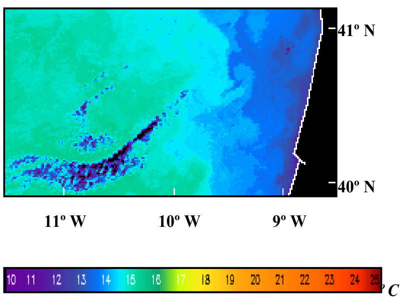

Figure 4. SST image (13th February, 1999)

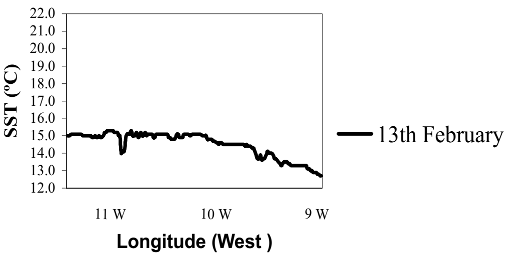

Figure 5. SST longitudinal variation (13th February, 1999)

Figure 6. Wind vectors corresponding to 9/2/99-13/2/99 period

The SST graph obtained for 13th Februaryis very similar to that of 5th February, i.e. SSTs showed a decreasing tendency towards the coast where the minimum value of 12.7º C was recorded.

Wind vectors showed a west component on the 9th February changing from westerly to northerly during the period between 10/2/99 and 13/2/99.

4.2 *21st May*

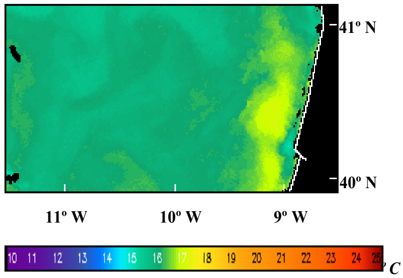

Figure 7. SST image (21st May, 1999)

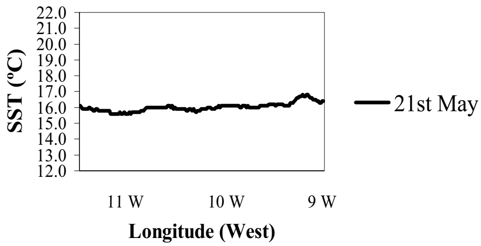

Figure 8. SST longitudinal variation (21st May, 1999)

Figure 9. Wind vectors corresponding to 17/5/99-21/5/99 period

On 21st May he SST reached its maximum value close to the shoreline (16.8º C). Far from the coast the temperatures oscillated between 16.3º C and 15.6º C. The average in the whole transect was 16º C. This was the first month of 1999 in which the temperature was higher close to the coast than in the open ocean. The period between 17th and 21st May was characterized by northerly and northwesterly winds.

4.3 *6th July*

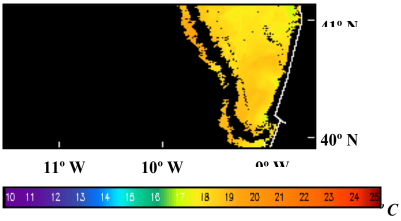

Figure 10. SST image (6th July, 1999)

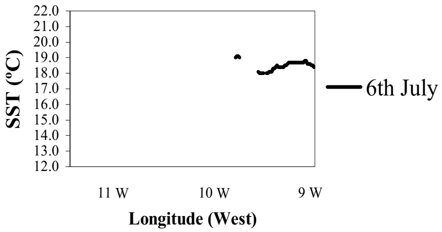

Figure 11. SST longitudinal variation (6th July, 1999)

Figure 12. Wind vectors corresponding to 2/7/99-6/7/99 period

The SST image for 6th July shows that the area of study was very contaminated by clouds, thus the graph shows very few points, which are located mainly close to the coastline. The maximum value observed was 19.1º C but it is not possible to ascertain the trend of the values within the gaps.

The wind regime was variable with a north-west component during 2nd July, a south-west component during 3rd, 4th and 5th July and again a north-west component on 6th July.

4.4 *14th September*

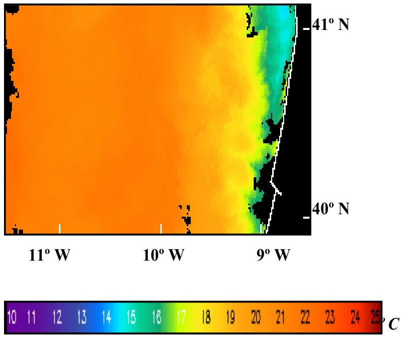

Figure 13. SST image (14th September 1999)

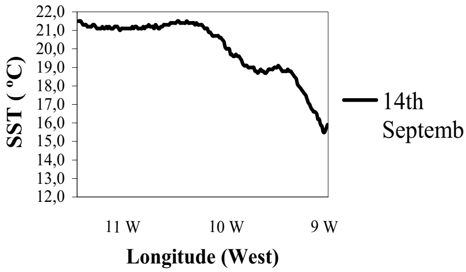

Figure 14. SST longitudinal variation (14th September, 1999)

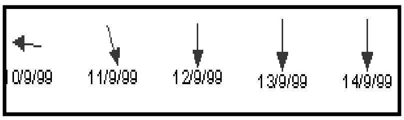

Figure 15. Wind vectors corresponding to 10/9/99-14/9/99 period

The SST graph for 14th September shows a decreasing trend towards the coast where the minimum value was reached (15.5º C). There was a significant temperature difference (6º C) between points near longitude 9º W and points in the open ocean where the maximum value was obtained (21.5º C).

Northerly winds were blowing during all days except 10th September, when they were blowing from the east.

5 CONCLUSIONS

From the analysis of all the data obtained in this work, it can be concluded that:

- The surface oceanographic features of the Aveiro region are primarily consequences of the dynamic balance between factors which promote upwelling activity versus those which suppress it. Given that upwelling causes surface cooling and that its suppression results in warming, many of these features can be identified according to patterns and gradients in the distribution of SSTs.
- IR satellite data have been demonstrated to be a useful tool (subject to cloud problems) that can provide information on the position and strength of the sea surface temperature gradient associated with upwelling. The main problem has been contamination by clouds.
- In a typical year off the northern Portuguese coast, upwelling starts in May or June (cold water bands appear close to the coast). The year 1999 shows a band of warm water close to the Aveiro coast during the months of May and June.
- 1999 was characterised by north winds along the Portuguese coast during winter and autumn. The selection of cloud free images was more difficult during summer months than winter months.
- SST graphs along the longitudinal transect show in most cases that, towards the coast, there is a diminution of the SST. This can be explained as a result of a vertical mixing process. The temperature values near the coast are, in most cases, lower than offshore.
- The bottom topography of the ocean floor can influence upwelling. Topographically induced upwelling occurs when an ocean current flows over a bottom projection that forces the current to rise and transport subsurface water to the surface.
- Upwelling is clearly detected on 14th September 1999. The SST image shows a cold band of upwelled water and the winds were favourable (northerly) for the development of the phenomenon. The location of the cold strip seems to be related to the bottom topography and not to the morphology of the coast line.
- The wind regime changed from north to south during the period between 14th and 28th September. This resulted in a noticeable increase of the water temperatures along the longitudinal transect.
- Results obtained during 1999 demonstrated that the upwelling phenomenon along the Aveiro coast is by no means as simple and predictable as other authors (e.g. Haynes *et al.* 1993) have found in the past. It is possible that 1999 year was an atypical year. More data from other years should be looked at in the same way and with the same methods in order to determine wether or not 1999 was atypical.

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