

Case Study 18

Characterization of Ecosystems in the Northern Canary Current System

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18.1 Introduction and Background

In the ecosystem-based approach for the study of the structure and functioning of marine pelagic ecosystems, the use of remotely-sensed satellite images is gaining appreciation among scientists and modellers. One of the most classic relationships in the study of marine ecosystems is that between the sea surface temperature (SST) and phytoplankton biomass (measured as chlorophyll-*a* concentration) because it represents the simplest link between environmental conditions and the lowest trophic level in marine food webs (Buttler et al., 1972; Chauhan et al., 2005; Demarcq, 2009; Irwin and Oliver, 2009).

Initially, the combination of ocean colour and SST imagery only provided synoptic maps of the current relationships between both parameters; however, the availability of long time-series of archived data has resulted in new research topics such the spatio-temporal evolution of marine productivity, or the study of regional phenology of marine eco-regions, i.e. the validation of the Cushing's match-mismatch hypothesis in fisheries science (Cushing, 1975; 1990; Platt et al., 2009). The main objective of this case study is to discuss the images used to examine these physical-biological interactions, how they are processed and what information can be extracted.

Satellite ocean-colour measurements have a relatively long history with over 30 years of data available from different missions. The first ocean colour sensor for the measurements of marine productivity was the Coastal Zone Color Scanner (CZCS) which was launched aboard the Nimbus-7 platform in June 1978, and operated until June 1986 (Feldman et al, 1989; Mitchell, 1994). During this period the CZCS provided 68,000 images of chlorophyll concentration with a resolution at nadir of 800 m. The possibility of having regular synoptic views of marine productivity opened a new world in marine biological research traditionally linked to expensive and regionally limited research cruises. Satellite imagery provided information for

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remote areas where previous knowledge was extremely limited, and gave us the first opportunity for a global approach of marine primary production.

After a gap of more than a decade in the availability of satellite ocean-colour data, the global temporal series was re-initiated with the launch of SeaWiFS (spatial resolution 1.1 km) in September 1997 which operated until February 2011. The family of ocean-colour sensors for marine research has been enriched with the MODIS sensor series launched by NASA in 1999 (Terra) and 2002 (Aqua), as well as ESA's MERIS sensor in 2002. The list of SST and ocean-colour sensors for the study of the structure and functioning of pelagic ecosystems has increased in recent years with the launch of a number of international and national space missions (e.g. India, China and Korea) helping to ensure the availability of a long time series of satellite data to investigate environmental and ecological conditions at regional to global scales. Further information about technical details of the various ocean-colour mission can be obtained from the website of the International Ocean Colour Coordination Group (IOCCG) at http://www.ioccg.org/sensors_ioccg.html.

The standard measurements of SST are performed at wavelengths between 11 and 12 μm , e.g. Advanced Very High Resolution Radiometer (AVHRR); however, at these wavelengths there is notable water vapour absorption making the atmospheric correction difficult in humid regions such as the tropics. On the other hand, the 4 μm band is much less sensitive to the influence of water vapour and has been integrated in the design of the newer sensors (e.g. MODIS-Aqua). Furthermore, the ocean "skin" is heated by sunlight during the daytime causing an overestimation in the SST values in relation to the values a few centimeters deeper. This variation between the first few millimeters and the lower layers is greatest in regions with high solar irradiance. For this reason we have chosen to use nighttime images collected with the 4 μm band for our case study.

The combination of SST (NOAA-AVHRR) and ocean-colour images has been used for the identification of potential fishing zones in several countries (Morales et al., 2009), however for many years the main limitation in the operational use of this application was the time elapsed between the input of both sources of data in the analysis system. This limitation has been resolved with the integration of SST and ocean-colour sensors in the same payload e.g. Envisat mission and MODIS-Aqua. For this reason we will use SST and ocean-colour data collected by MODIS-Aqua for our case study.

18.2 Data and Methods

For this case study we will work with image data collected by MODIS-Aqua in 2003. The images were downloaded from NASA's Giovanni web site (<http://daac.gsfc.nasa.gov/giovanni/>). Image data are available in three formats: HDF, netCDF and ASCII. We have selected the netCDF format because it is a format most widely

accepted by public domain packages (see www.unidata.ucar.edu/software/netcdf/ for further information). The selected area for this case study corresponds to the coordinates: 11°W to 1°E and 30°N to 47°N. This region includes most of the Canary Current System (CCS), one of the four major Eastern Boundary Upwelling Systems (EBUS), and consequently an important fishing area. From a biogeochemical point of view the study area includes two relevant upwelling areas: the Sahara upwelling region off the west coast of Africa and the Iberian upwelling system off the west coast of Portugal/Spain. Other important features include the Gulf of Cadiz (SW Spain), a large discontinuity within the CCS, and two important aquaculture centers in the north near Galicia (NW Spain) and the Bay of Arcachon (SW France), outside of the CCS.

Image data were processed using NOAA's public domain package Ferret (<http://ferret.wrc.noaa.gov/Ferret/>), which has mathematical flexibility for information treatment despite its apparent syntax complexity. Furthermore there is an active Ferret user community involved in the development of this tool. Alternatively, if your interest is limited to more simple operations, such as rapid image visualization, the ncview (http://meteora.ucsd.edu/~pierce/ncview_home_page.html) software is a good option.

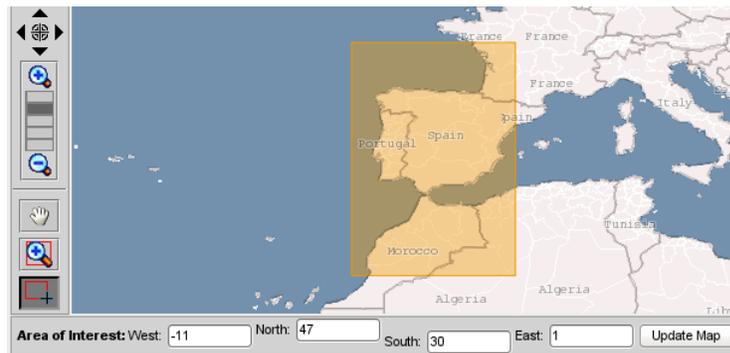


Figure 18.1 Giovanni area selection window.

18.3 Demonstration: Image Analysis

Chlorophyll and SST image data can be downloaded from NASA's Giovanni (see above) using the following steps:

1. Select the option "Ocean Color Radiometry", then under Area of Interest (new window) enter the geographical coordinates of the study area, in our case -11°W to 1° E; and 47°N to 30°S (Figure 18.1)
2. Select the sensor and variable to analyze: MODIS-Aqua/chlorophyll and Sea Surface Temperature (4 μ m, night).
3. Select the month or time period. In our case "April 2003".

4. Select visualization (lat/lon map, time-averaged).
5. After the image has been generated, click on the "Download Data" option.
6. At the Two Dimensional Map Plot screen select the "Download Files" option and click on the NCD (netCDF) window as type of download file. This will download the single data file for April 2003 and the selected area.

Before the final processing with Ferret, the variables in the downloaded file(s) must be renamed, and provided with temporal and depth dimensions. For this operation we will use the following netCDF Operators (NCO), which are a suite of stand-alone, command-line programs (see <http://nco.sourceforge.net/>):

1. Re-name the April 2003 chlorophyll file (A20030912003120.L3mxxxxxx.nc) to clor-ap2003.nc
2. Type: `nccat -u depth clor-ap.nc clor-ap2003.nc`
3. Type: `nccat -u time clor-ap2003.nc clor-ap2003.nc` (when the system asks if you want to overwrite the file, answer yes).
4. We will rename the dimensions of the file clor-jan2003.nc with the command `ncrename` to permit its visualization. In our example, we will use `G3fakeDim1` for the longitude and `G3fakeDim0` for the latitude (use the "`ncdump -h your-file.nc`" command line to see the true dimensions's names). Type the following commands: `ncrename -d G3fakeDim1,longitude -v G3fakeDim1,longitude clor-ap2003.nc`
5. `ncrename -d G3fakeDim0,latitude -v G3fakeDim0,latitude clor-ap2003.nc`

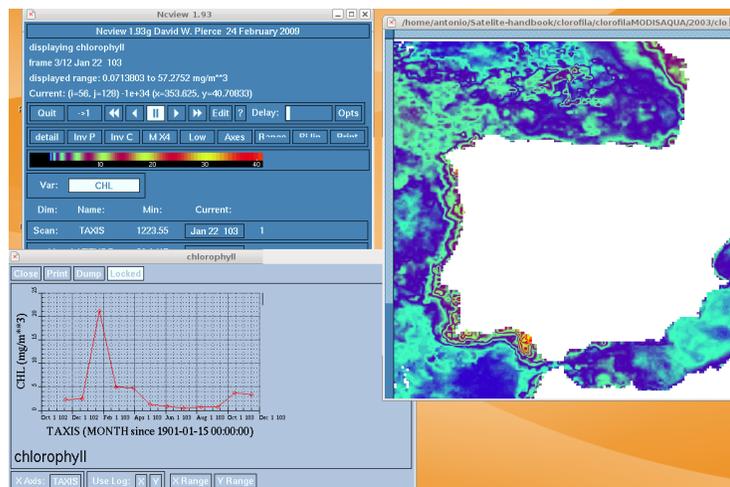


Figure 18.2 2003 Chlorophyll data visualized with nview (http://meteora.ucsd.edu/~pierce/ncview_home_page.html)

6. To change the name and title of the default variable (e.g. chlorophyll) L3M_DATA (as it is downloaded from Giovanni), type the following:
`ncrename -v L3M_DATA,chlorophyll clor-ap2003.nc`
7. `ncatted -o -a long_name,chlorophyll,o,c,chlorophyll clor-ap2003.nc`

This process must be repeated for each image that you need to analyze. Additionally, if you want to create a single file which includes, for instance, all data from one year, you must use the NCO tool called *ncrcat*. The command to concentrate the twelve monthly files is as follows:

```
user@server:~$ ncrcat jan.nc feb.nc mar.nc...nov.nc dec.nc year2003.nc
```

Using *ncview* we can view the file *c1orap2003.nc* (Figure 18.2).

18.3.1 Image processing with Ferret

1. Run the software using the reference directory where the file *c1or-ap2003.nc* is located.

```
yes? use c1or-ap2003.nc
yes? show data/variables
currently SET data sets:
l> ./c1or-ap2003.nc (default)
name      title      I      J      K      L
chlorophyll chlorophyll 1:145  1:204  1:1    1:1
mg/m**3 on grid GPS1 with 65535 for missing data
X=11.1W(348.9):1E(361) Y=30N:47N Z=0.5:1.5
time range: 1
```

2. Visualize the data using the "shade/trim" and "fill/over" commands to get a graph with solid contours and reference scale. Using the "go land detail" command we will get a detailed coastline profile:

```
yes? shade/trim chlorophyll;fill/over chlorophyll;go land_detail
```

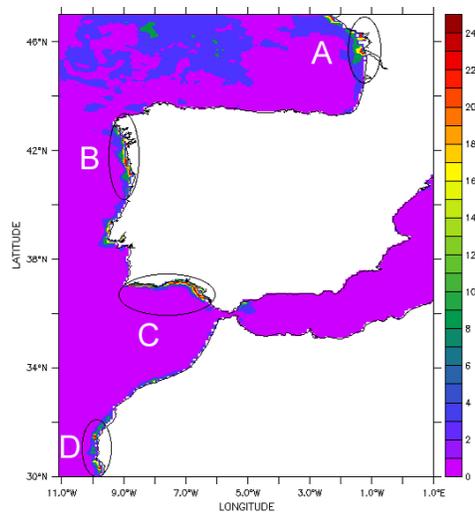


Figure 18.3 April 2003 Chlorophyll (mg m^{-3}) showing the four main areas of interest: Arcachon Bay (A), Northwestern Iberian coast (B), Gulf of Cadiz (C) and Western Sahara coast (D).

Looking at the image (Figure 18.3) we can see that most of the ocean has a chlorophyll concentration near zero, and only near the coast is the chlorophyll concentration $2\text{--}3 \text{ mg m}^{-3}$. In a more detailed observation, four zones with higher chlorophyll can be identified (A, B, C, D); however, we cannot clearly see where

potential phytoplankton blooms relevant for local fisheries are located. Moreover, the coastline looks gridded with many white squares, caused by the low spatial resolution (4 km) of the image data resulting in a coastline that is not well defined. In addition to the constraints of the spatial resolution of the data, we must also take cloud coverage into account, which may hide specific areas, especially during autumn and winter.

18.3.2 Seasonal patterns of chlorophyll and SST

For this exercise we will compare and interpret the SST and chlorophyll images from spring (Figure 18.4). Along the Portuguese and Sahara coasts there is an inverse relationship between SST and chlorophyll concentration with colder waters having higher concentrations of chlorophyll-*a*. On the other hand, near the mouth of the Guadalquivir River (SW Spain, near the Portuguese border) a large algal bloom can be observed, and the temperature is warmer than in the neighboring upwelling area. To analyze this situation in more detail, latitudinal transects can be drawn to compare both variables, beginning at longitude 6.5°W and extending from 36°N to 37°N latitude (Figure 18.5 a,b). The same operation can be performed on the Sahara coast, but in this case the transect will be longitudinal, located at latitude 30.3°N and going from 9.7°W to 10.5°W longitude (Figure 18.5 c,d).

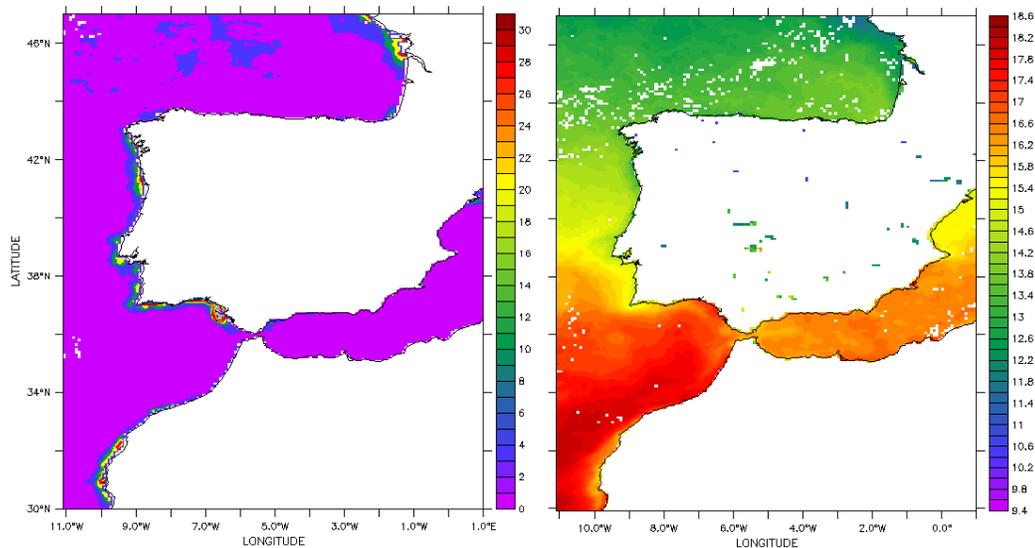


Figure 18.4 Mean 2003 spring Chlorophyll (mg m^{-3}) (left) and SST data ($^{\circ}\text{C}$) (right) for the whole study area.

In Figure 18.5 a,b both variables have a direct correlation, while in the Sahara transect (Figure 18.5 c,d) the correlation is inverse. In the latter case, the intensity of the upwelling process and the flux of nutrients into the surface waters causes a rapid increase in phytoplankton biomass, while in the case of the Guadalquivir

River mouth the increase in the chlorophyll concentration is probably related to the discharge of nutrients by the river combined with warm coastal waters.

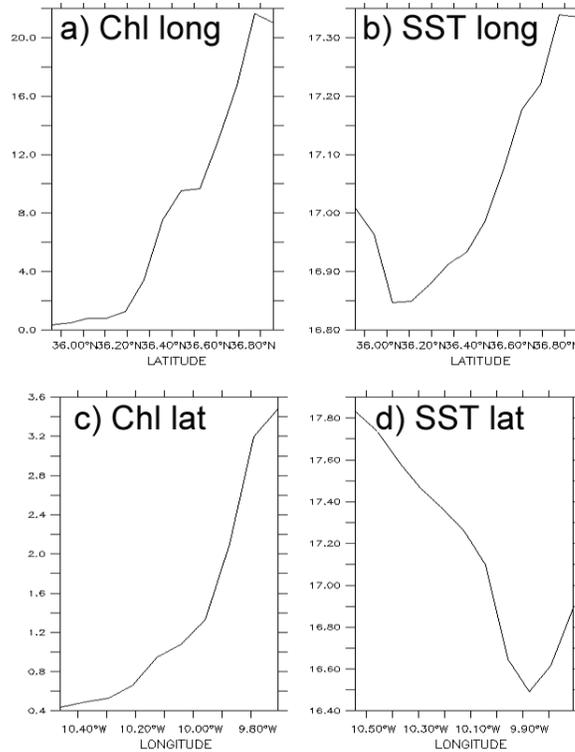


Figure 18.5 Longitudinal transects (6.5°W) from 36°N to 37°N showing the mean 2003 Chlorophyll (a) and SST (b), and latitudinal transects (30.3°N) from 10.5°W to 9.7°W showing the mean 2003 Chlorophyll (c) and SST (d).

18.3.3 Local biogeochemical analysis

We will now consider a more detailed analysis of a specific region, and for that we will use the chlorophyll image of April 2003. The following commands can be used to select a region for a more detailed study (e.g. Gulf of Cadiz, Figure 18.6):

```
yes?set region/x=-10:-6/y=35:38
yes? shade/trim chlorophyll; fill/overlay chlorophyll; go land_detail
```

An intense gradient of chlorophyll concentration can be observed in this region, with the highest concentrations (~15 mg m⁻³) being found along the Portuguese coast (37°N, 8-9°W) and the mouth of the Guadalquivir River (around 36.8°N, 6.5°W). The nutrient input could be derived from the coastal upwelling in the case of the Portuguese coast, and river discharge in the case of the Guadalquivir River. To confirm these hypotheses, we require further information e.g. SST (to examine whether colder waters are present near the coast, which could explain coastal upwelling), or rainfall records (to evaluate the river discharge). Another oceanographic feature clearly identifiable in this image is the shelf margin front. The geostrophic current

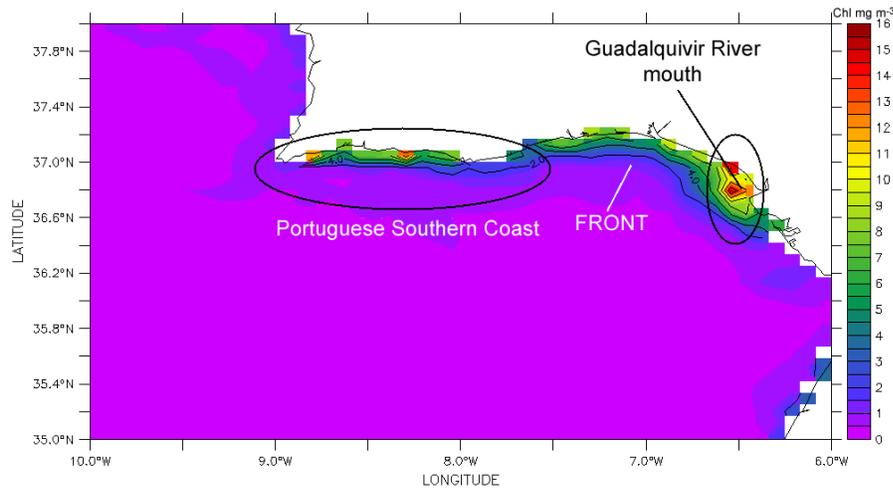


Figure 18.6 April 2003 Chlorophyll (mg m^{-3}) for the Gulf of Cadiz

flows eastward from southern Portugal to the Gibraltar Strait.

A similar procedure can be followed to extract the SST image for the same region and period (Figure 18.7) using the following Ferret commands:

```
yes?use sst-ap2003
yes?shade/trim sst; fill/overlay sst; go land_detail
```

The cold water observed along the southern Portuguese coast is most likely nutrient-enriched water resulting from the intense upwelling centers located along the southern coast of Portugal. In the center of this region is a colder mass of water (dark green in Figure 18.7) which could be the result of a local upwelling induced by the westerly winds, but these are generally short duration events. The cold water observed around the mouth of the Guadalquivir River is likely a result of the river discharge of cold inland water. In both cases, the input of nutrients can explain the presence of the high phytoplankton biomass observed in Figure 18.6. If we look

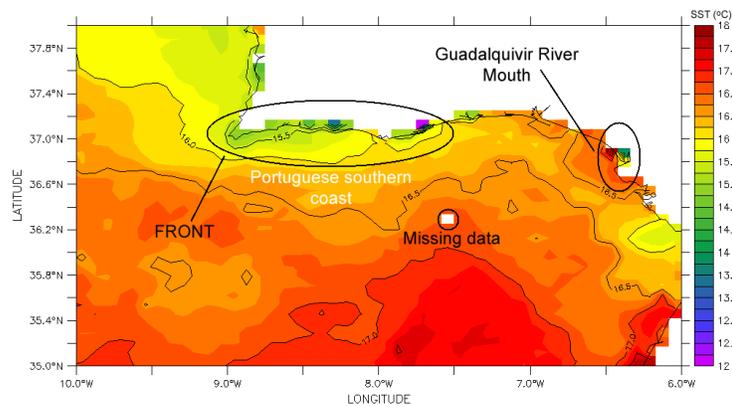


Figure 18.7 April 2003 SST ($^{\circ}\text{C}$) for the Gulf of Cadiz

at the SST image of the whole study area (Figure 18.8) we can observe some other interesting features. There is a clear north-south latitudinal temperature gradient, with colder waters to the north and northeast, and warmer waters to the south and southwest. A similar pattern can be observed in the Mediterranean area. The white patches above 44°N latitude and around 36°N (Canary Islands, Madeira and Azores Islands) are caused by cloud coverage in those regions.

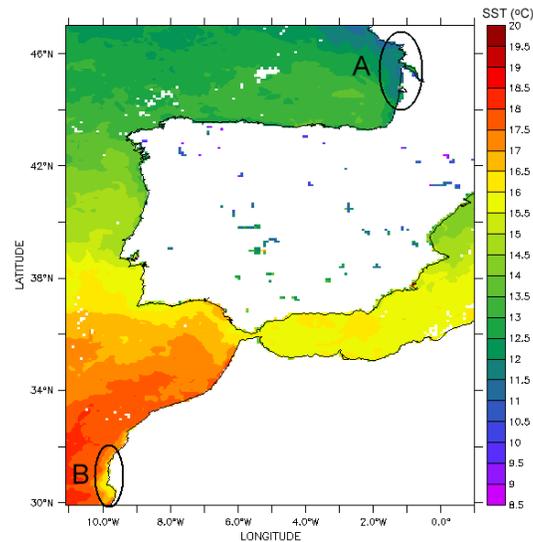


Figure 18.8 April 2003 SST (°C) for the Arcachon Bay (A) and Western Sahara coast (B).

18.4 Questions

Q 1: Looking at Figure 18.9 (chlorophyll-*a*), describe geographically (lat/lon) the areas with the highest chlorophyll concentrations. What can you interpret from this regional chlorophyll distribution pattern?

Q 2: Looking at Figure 18.10 (SST), describe geographically (lat/lon) the areas with colder and warmer waters. What is the meaning of the compressed isothermal lines?

Q 3: What are the most interesting features and processes observed in the regions 37 - 44°N/10 - 8.5°W and 36 - 41°N/1°W - 1°E.

Q 4: What are the thermal differences in the water masses on both sides of the Gibraltar Strait (36°N/5.30°W).

Q 5: Looking at Figure 18.11 (chlorophyll and SST), what can you observe by comparing both images and what is your preliminary interpretation about the

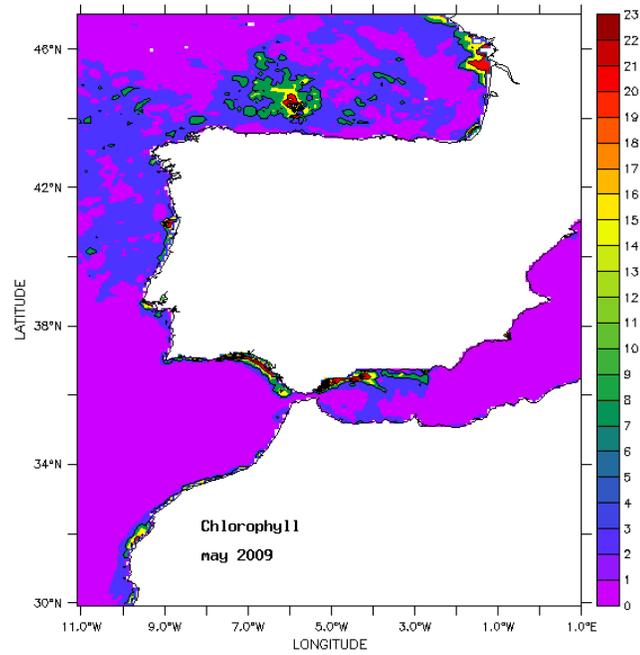


Figure 18.9 May 2009 Chlorophyll (mg m^{-3})

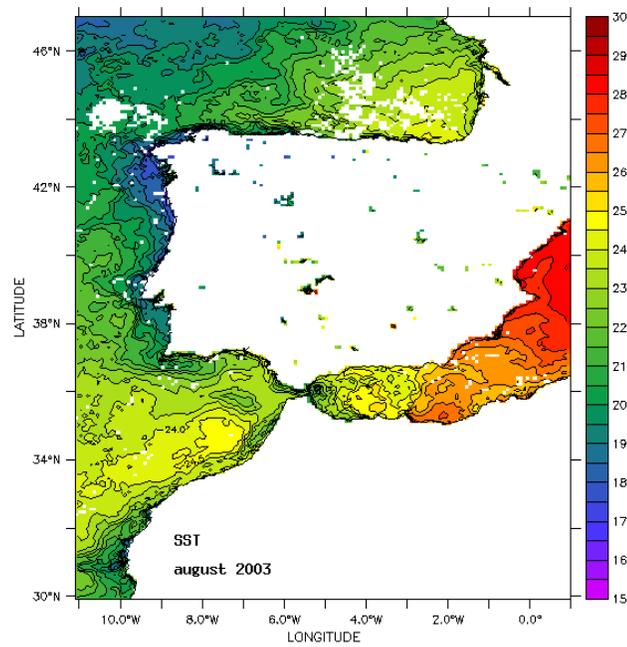


Figure 18.10 August 2003 SST ($^{\circ}\text{C}$)

regional oceanography and productivity in that region?

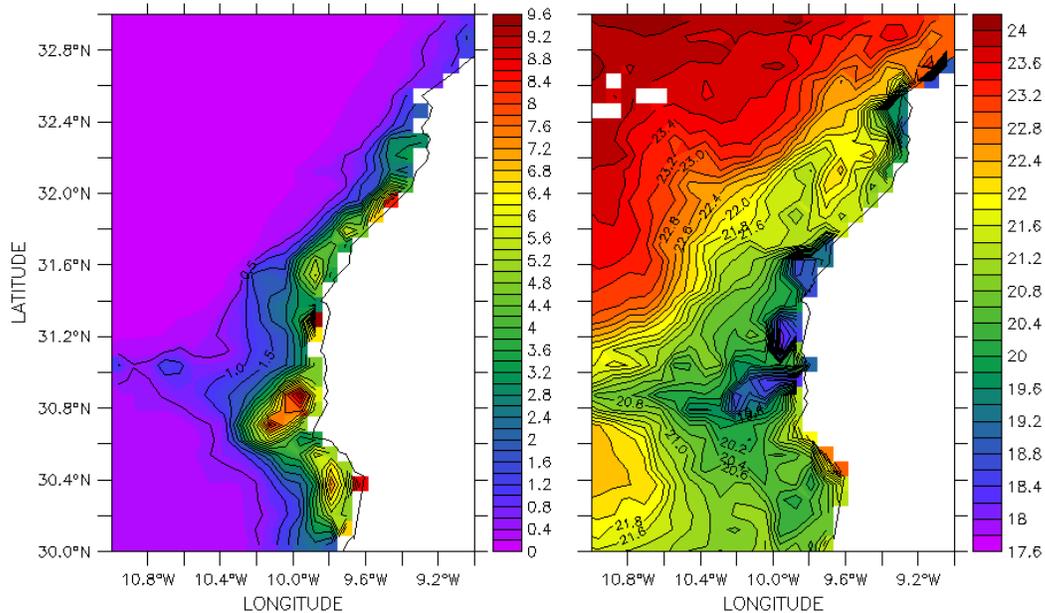


Figure 18.11 August 2003 Western Sahara coast. Left: Chlorophyll (mg m^{-3}), right: SST ($^{\circ}\text{C}$).

18.5 Answers

A 1: High phytoplankton biomass areas can be identified in four main regions:

- ❖ Along the Sahara coast from 31.5 to 32.5°N latitude and 9.5 to 10°W longitude.
- ❖ At both sides of the Strait of Gibraltar from 4 to 8°W longitude (36°N)
- ❖ In and around the Arcachon Bay (France). A square of 1° x 1° around 46°N and 1.5°W.
- ❖ A big patch over the northern Iberian coast, a square of 3° x 3° with center at 45°N and 6°W.

The chlorophyll concentrations range from 9-23 mg m^{-3} , with the higher values for Arcachon Bay and the patch off the northern Iberian coast. The high chlorophyll values observed along the Sahara coast are produced by the strong upwelling processes in this area.

A 2: The lowest SST is located in the following regions: the Iberian Peninsula, from 37 to 43° N and 9 to 10° W; The Sahara region from 30 to 32°N and 9.5 to 10.5°W. Sea surface temperature in both cases is around 17°C, while the surrounding waters are 4 to 5°C warmer. In most cases, a dramatic drop in SST within a narrow region along the coast is a good indicator of a coastal upwelling.

A 3: The marked differences in sea surface temperature between the colder Atlantic and the warmer Mediterranean water masses are especially relevant. There is a

general tendency to warming from offshore to the coastal regions, with the exception of the intense upwelling areas located along the Sahara and Iberian coasts. The point of interest is the possibility of using the images to gain a better understanding of the dominant process in a particular region; the cold water observed near the coast in the Sahara region indicates that coastal upwelling is the main nutrient enrichment process in this area. Looking at the Arcachon Bay area, the SST is not as cold as expected in an upwelling area, consequently the nutrient enrichment required for the development of high chlorophyll values shown in Figure 18.11 is probably the result of river discharge.

A 4: The Gulf of Cadiz is a relatively warm zone in between two cold water areas: the Iberian upwelling region (northern Canary Current System) and the Sahara upwelling region. This discontinuity in the whole Canary Current System is also the transition zone of the warmer Mediterranean water coming into the Atlantic Ocean.

A 5: It is easy to observe the close relationship between the cold waters observed in the SST image as a result of coastal upwelling and the high chlorophyll concentrations. In this image the spatial coverage of the process is restricted to an area of less than 1° wide, with the signal of the bloom decaying a few miles away from the location of the main bloom.

18.6 References

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