Remote Sensing in OMEX II-II

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Abstract

The highlight of remote sensing activities this year was the successful launch in August of NASA's long-awaited SeaWiFS ocean colour sensor. The automated processing system was extended to convert these new images into calibrated ocean colour products and chlorophyll maps. Ocean colour and temperature data for the OMEX region were routinely processed on the same day as reception, and disseminated over the World-Wide-Web; and four OMEX cruises this year were supported with near-real time imagery. A five-year sequence of weekly and monthly sea-surface temperature maps was compiled to provide a physical description of the Galician region. Statistical information on upwelling and filaments was provided and progress was made on the automated detection and analysis of these features. All deliverables for the first year have been met and future deliverables are on target.

Introduction

This paper describes the activities carried out by the PML Remote Sensing Group during the first year of the OMEX II-II project on Work Packages I and II. The primary roles of remote sensing within OMEX are: to support cruises by providing real-time information on the location of fronts, upwelling, filaments, and eddies; to calculate statistics on the distribution and attributes of such features; to assemble a regional archive of SST and ocean colour data for comparison with *in situ* measurements and model results; and to research ocean colour and temperature algorithms for deriving surface maps of biological parameters, including phytoplankton pigments, primary production, and nutrients.

Methods

Sea-surface temperature

During the first two years of OMEX I, the Panorama system was developed to satisfy the satellite data-processing requirements of the project. Since then, this system has been used to process over 15,000 AVHRR satellite passes accurately and efficiently into SST maps for several OMEX regions of interest. A brief overview of the Panorama methodology is given here, as the details have recently been described (Miller *et al.* 1997, Miller *et al*. 1998). Up to nine AVHRR passes are received every day by the Dundee Satellite Receiving Station, and are immediately relayed to Plymouth Marine Laboratory via a fast Internet link. Each incoming pass is detected by Panorama, and then automatically calibrated and converted into SST values, cloud-masked, and geo-referenced. A database stores details of regions of interest, which are automatically extracted from the satellite pass and annotated with coastline, bathymetry, and a co-ordinate grid. Coloured versions are immediately disseminated to the OMEX community on the remote sensing web site (http://www.npm.ac.uk/rsdas/omex/). On average these data are available only 90 minutes after the satellite transmission.

In order to obtain synoptic SST maps for frequently cloudy European seas, composite images are also routinely generated. These comprise all cloud-free data for a week, month, or arbitrary period, and show the median SST at each location. This methodology has been applied within the OMEX II-II project to provide a long-term physical description of the sea-surface in this region.

Ocean colour

NASA's Sea-viewing Wide Field-of-view Sensor (SeaWiFS) was finally launched on 1st August 1997, and began operational acquisition on 19th September 1997. SeaWiFS is an optical scanner with 6 channels in the visible spectrum (412, 443, 490, 510, 555, and 670 nm) designed to provide optimal discrimination of phytoplankton, sediments, and coloured dissolved organic matter. It operates in a sun-synchronous orbit, with all data captured at local noon. The swath is 2800 km wide, and the resolution is 1.1 km at the sub-satellite point. One or two passes over NW Europe are received every day by Dundee Satellite Receiving Station, and are then immediately transferred to Plymouth via the Internet.

Modules have been added to the Panorama system to process SeaWiFS data for the OMEX region of interest, using dimensions and map projection identical to AVHRR (Lavender and Groom 1998). These modules are based on NASA SeaDAS routines (NASA 1997). Many ocean colour products are derived for each region, including chlorophyll concentration, water-leaving radiance, and diffuse attenuation coefficient. Also a colour composite image is produced by combining the 555, 510, and 443 nm channels for viewing coloured dissolved or particulate material. All products are made available on the web site within two hours of the satellite over-pass, although access is subject to registration with NASA. There is normally a two-week embargo on SeaWiFS data, but this restriction is relaxed during and one week prior to OMEX cruises.

As suitable OMEX II-II cruise data become available at BODC, these will be used in conjunction with SeaWiFS ocean colour data to investigate algorithms for retrieval of phytoplankton primary production, new production (using regional SST/nitrate relationships (Joint *et al.* 1997)), suspended particulates and coloured dissolved organic material.

Remote sensing cruise support

AVHRR (and post launch, SeaWiFS) satellite imagery have been processed continuously prior to and during OMEX II-II cruises, to provide the latest surface locations of fronts, upwelling, filaments, and phytoplankton blooms. All data have been made available immediately via the web site, and during the cruise via Inmarsat connections, to enable the sampling strategy to be optimised, and put *in situ* measurements into context. Remote sensing support will be of crucial importance to the success of several forthcoming cruises during the 1998 upwelling season that aim to study the exchange generated by dynamic and transient upwelling filaments. In particular the Work Package I cruise on Charles Darwin (CD114) during August will use satellite data and drifting buoys to track the change in physical and biological processes associated with the flow within a filament. Synthetic aperture radar (SAR) data will also be supplied during this cruise to locate the tracks of internal waves for investigation and comparison with measurements using the FLY turbulence probe.

Statistical information on physical features

Panorama automatically generates large data-sets of high-quality and high-resolution satellite ocean temperature and colour maps. This raises practical problems for oceanographers in interpreting potentially huge quantities of data, involving laborious visual browsing and analysis to locate and characterise features of interest. A technique has been implemented to automatically locate oceanic fronts using an adaptive statistical edge-detection and contour-following algorithm (Cayula and Cornillon 1992, 1995). The front detection algorithm immediately simplifies the information contained in a SST image to just the location and magnitude of significant gradients. Front maps from a time-series of SST images can be composited together to indicate persistent features, and animated sequences of individual or composite front maps clearly describe the characteristics of dynamic processes such as upwelling, filaments and eddy rotation. Further research is being undertaken to analyse the shape, gradient, orientation and position of frontal segments in order to detect these processes automatically. This will enable the thousands of satellite images of the OMEX region to be objectively analysed to gather statistics on all physical processes, which can then be used to calibrate the parameters of the OMEX hydrographic model.

This research is due to be completed after several cruises that could benefit from the planned results, so certain statistics were compiled by manually analysing all of the weekly SST composite images of the Galicia area, from June 1993 to April 1998. These statistics were the start and end of each period of upwelling (defined here to be significantly colder surface water extending offshore of the 200 m isobath) and filaments for each of two sections of the coastline: in the vicinity of Cape Finisterre (42.5 – 43.5 N) and Vigo (41.0 – 42.5 N).

Remote sensing web site

A web site dedicated to remote sensing within OMEX has been developed to provide rapid dissemination of data and imagery to the community (http://www.npm.ac.uk/rsdas/omex/). New browsing and searching tools allow users to quickly find clear individual SST or ocean colour images between a specified range of dates. Series of small 'thumbnail' versions of weekly and monthly composite images show the seasonal and inter-annual variations in SST distribution. The site also contains monthly chlorophyll data for the Galician region between 1978 and 1986 from the Coastal Zone Color Scanner (CZCS), and various selected images to illustrate eddies, upwelling and filaments. As of May 1998, 36 OMEX scientists had registered for access to the remote sensing web site.

Results

I.1 Weekly SST maps from 1993 to 1997 have been visually analysed to determine the times during the year when upwelling and filaments occurred within the OMEX II-II region (Figure 2). Each coloured horizontal line in this figure represents the dates and duration of one such period, in the Finisterre or Vigo region. This graph summarises the inter-annual variability of the Galician upwelling season during the last five years. The dates of two forthcoming OMEX research cruises are indicated by vertical dashed lines. Data from previous years may be used with caution to estimate the likelihood of observing upwelling or filaments during certain months, which may assist in planning the times, locations and activities of future cruises.

II.1.1 At the start of the OMEX II-II project all AVHRR images covering the Galician Sea region were processed into weekly and monthly SST maps. Figure 1 shows the results of this long-term analysis; each map depicting the median SST for one month, where colours from blue to red represent increasing temperature and black indicates cloud or land. This figure summarises the 15,000 satellite images that have been processed since the start of OMEX I. The seasonal temperature distribution is well represented, with wind-induced upwelling beginning in June or July producing a zone of cooler surface water along the western coast. Upwelling often peaks in September when cold filaments may extend more than 200 km from the coast. Outside the upwelling season a warm band of water - the pole-ward-flowing 'Navidad' current - can often be seen along the shelf break (e.g. January 1996). Large inter-annual variations are also seen especially in the timing and strength of upwelling.

II.1.6 An algorithm for detecting oceanic fronts on SST maps has been applied to OMEX II-II data for 1997. Weekly composite front maps have been found to provide a good basis for statistical analysis of fronts, eddies and filaments. Figure 3 presents a sequence of four consecutive weekly front maps from 6th July to 2nd August 1997. The transition from the first to second week, from a well-defined upwelling front to a situation with several established filaments, is particularly striking. Filaments are believed to be important in the generation of exchange across the shelf-break.

II.12.1 Individual AVHRR SST and thermal infrared images and SeaWiFS ocean colour images, are being continuously processed in near-real time and disseminated to OMEX scientists via the web site and Inmarsat transmissions. Table 1 lists those cruises supported with near-real time data this year.

Charles Darwin	CD105	29/05/1997 to 22/06/1997
Belgica	BG9714	18/06/1997 to 07/07/1997
Charles Darwin	CD110	23/12/1997 to 19/01/1998
Poseidon	PS237-1	26/02/1998 to 16/03/1998

Table 1. OMEX II-II cruises supported with near-real time remote sensing.

Figures 4a and 4b show example images from 21st January 1998 just after CD110, the first OMEX cruise to be supported by ocean colour images in addition to SST. The warm Navidad current is clearly seen on the SST image whereas the true-colour image shows increased concentrations of suspended particulate material, possibly from river runoff as a result of the severe storms experienced during the cruise. Figures 4c and 4d show SST and chlorophyll from 15th March 1998 during the Poseidon cruise. Increased chlorophyll concentration is seen near the coast, a possible indicator of the start of a Spring bloom.

Figure 5 shows an SST and chlorophyll map from 30th September 1997, just 11 days after SeaWiFS became operational, and indicates the potential of this new instrument for studying upwelling within the OMEX project. High chlorophyll concentrations are seen within the upwelling zone (which appear green on the inset true-colour image), confirming that this region remains productive late into the summer. The filaments extending in the NW direction from Cape Finisterre are being shaped and split by the eddy near 44 N 10 W. Unfortunately there were no OMEX cruises during this period, but in 1998 there will be at least three cruises during the upwelling season.

Discussion

This has been a productive period of remote sensing development within OMEX, with the addition of high-quality ocean colour data to complement the existing SST imagery. During the coming year, cruise measurements will be used in conjunction with SeaWiFS data to investigate algorithms for retrieval of surface biological parameters within the OMEX region. All deliverables for the first year have been met and future deliverables are on target.

References

Joint, I., Wollast, R., Chou, L., *et al.*, 1997, Pelagic production at the Celtic Sea shelf break – the OMEX I project. *Deep Sea Research* (in press).

Lavender, S.J. and Groom, S.B., 1998, The SeaWiFS Automatic Data Processing System (SeaAPS). *International Journal of Remote Sensing*, (submitted).

Miller, P., Groom, S., McManus, A., Selley, J., and Mironnet, N., 1997, PANORAMA: a semi-automated AVHRR and CZCS system for observation of coastal and ocean processes. *RSS97: Observations and Interactions, Proceedings of the Remote Sensing Society*, pp 539-544, Reading, September 1997.

Miller, P., Groom, S., McManus, A., Selley, J., Mironnet, N., and Lavender, S., 1998, Panorama: an automated AVHRR, CZCS and SeaWiFS system for monitoring oceanic processes. *International Journal of Remote Sensing*, (submitted).

NASA, 1997, The SeaDAS web site is: http://shark.gsfc.nasa.gov/~http/SeaDAS.html

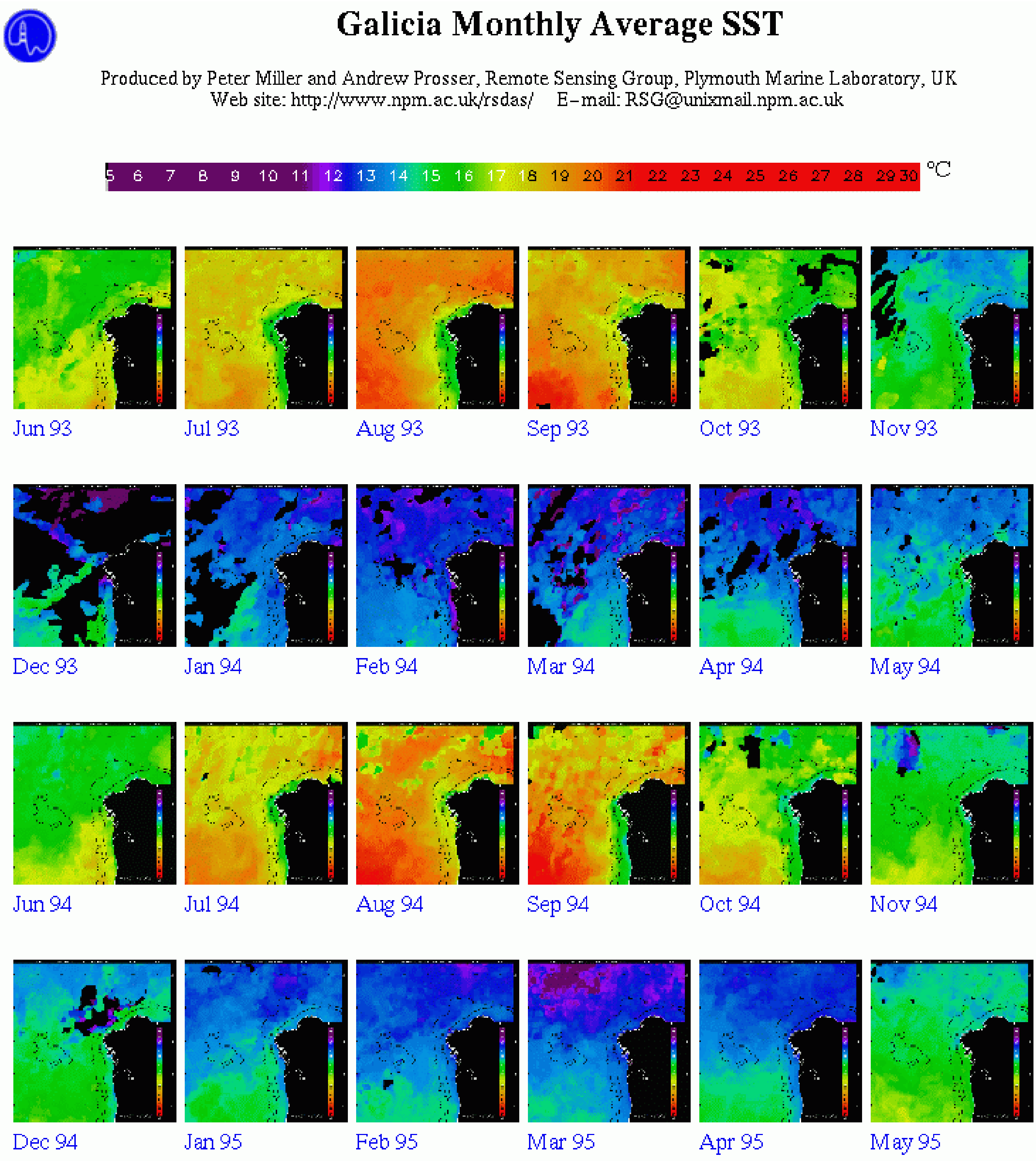
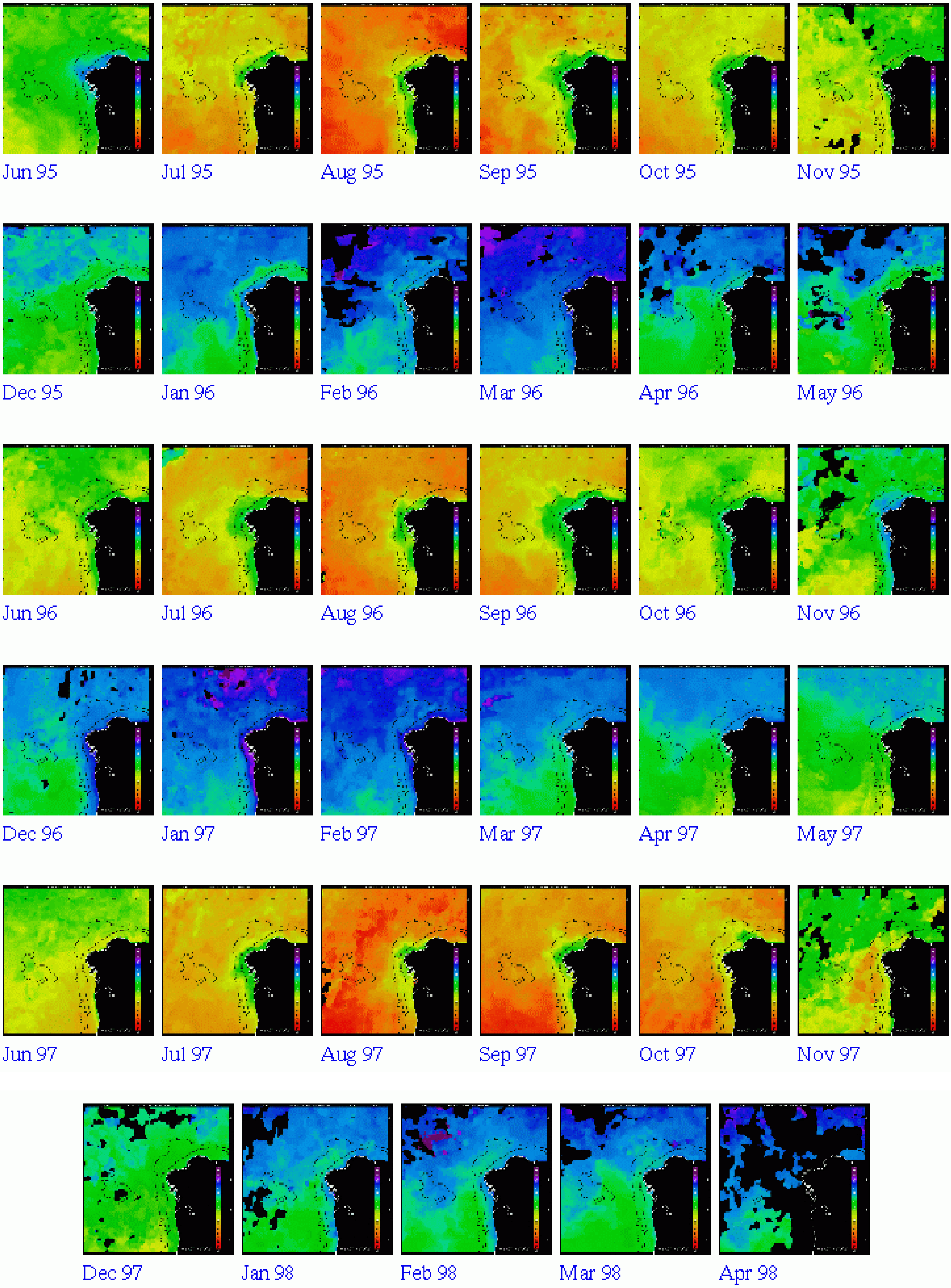


Figure 1. Sea-surface temperature distribution (SST) in the Galician Sea area containing the OMEX II-II study box. Each map depicts the median SST for one month between June 1993 and April 1998, where colours from blue to red represent increasing temperature, and black indicates cloud or land. Black dotted lines mark the 200 and 2000m bathymetry contours. (Continued overleaf.)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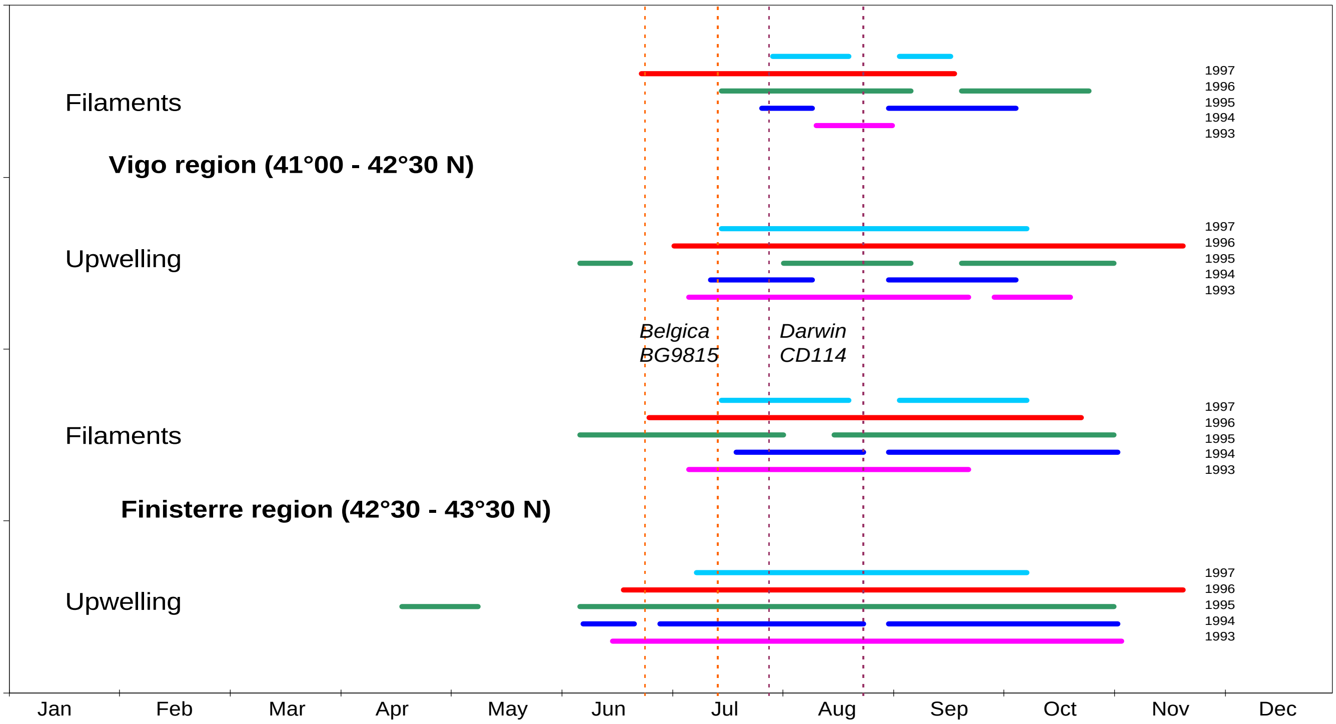


Figure 2. Duration of upwelling and filaments in OMEX II-II box observed using weekly satellite SST data. Each coloured horizontal line represents the dates and duration of one period of upwelling or filaments, in the Finisterre or Vigo region, for the years 1993-1997. The dates of two forthcoming cruises are indicated by vertical dashed lines.

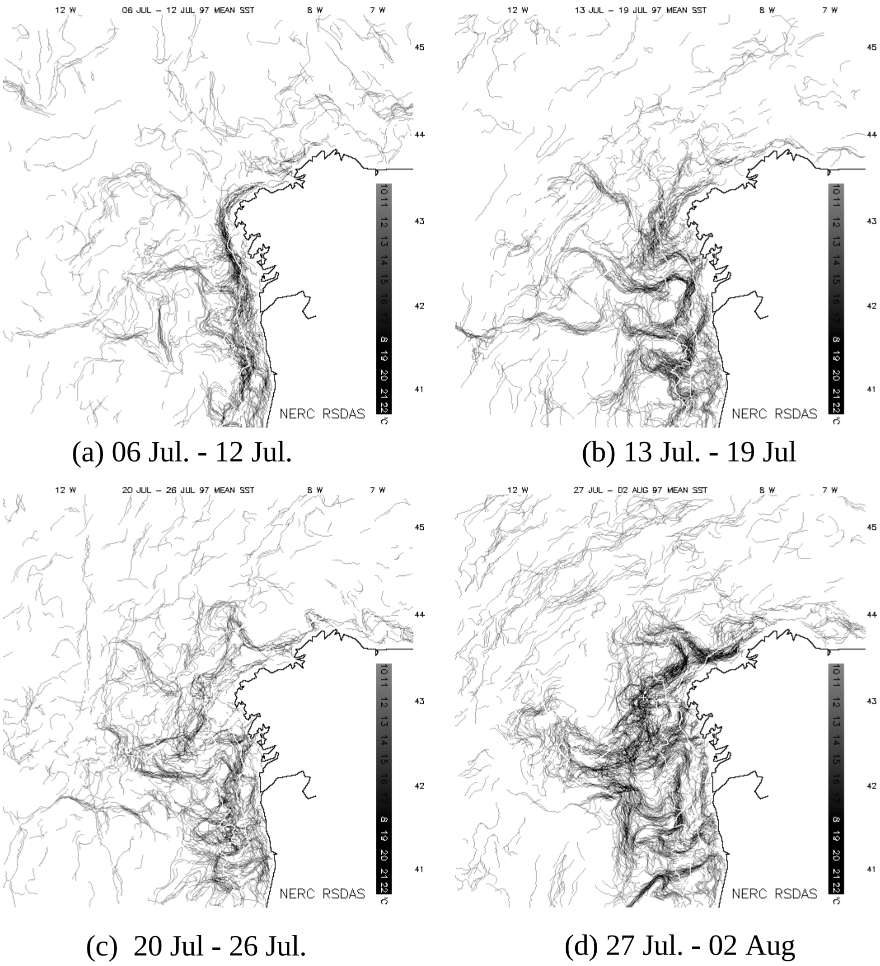
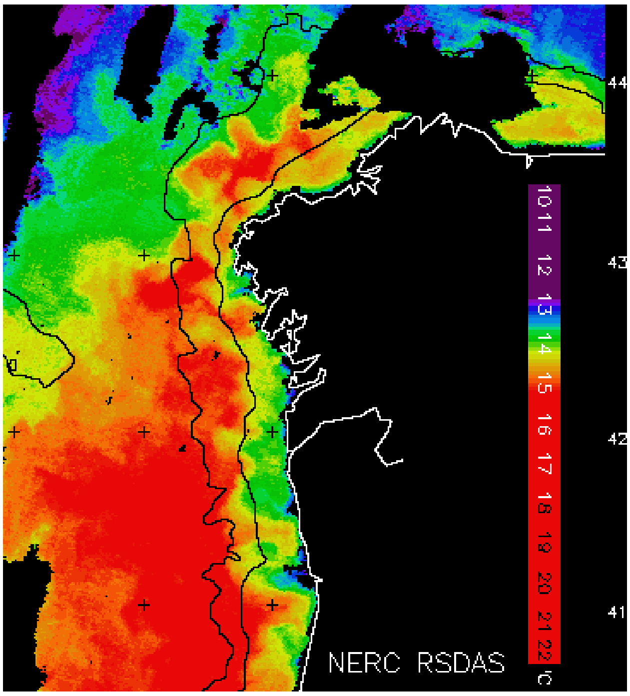
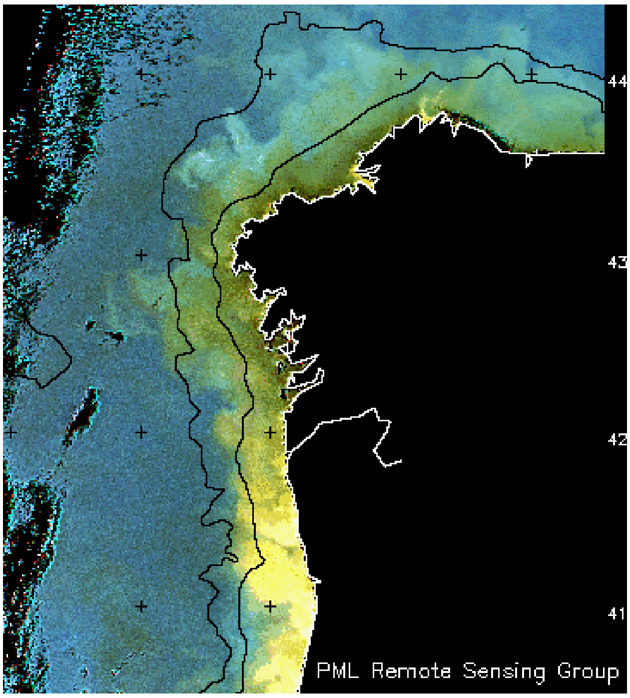


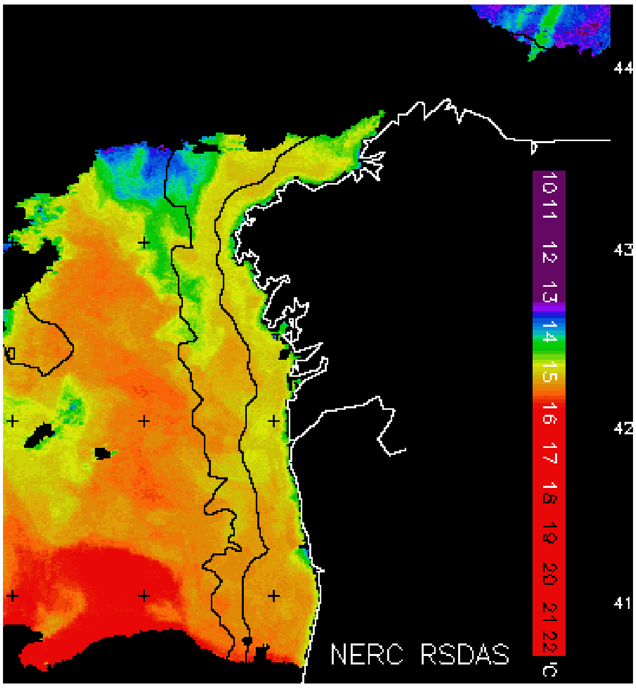
Figure 3. Sequence of four consecutive weekly front maps, from 6th July to 2nd August 1997, which covers the transition from a well-defined upwelling front to the formation of several established filaments.



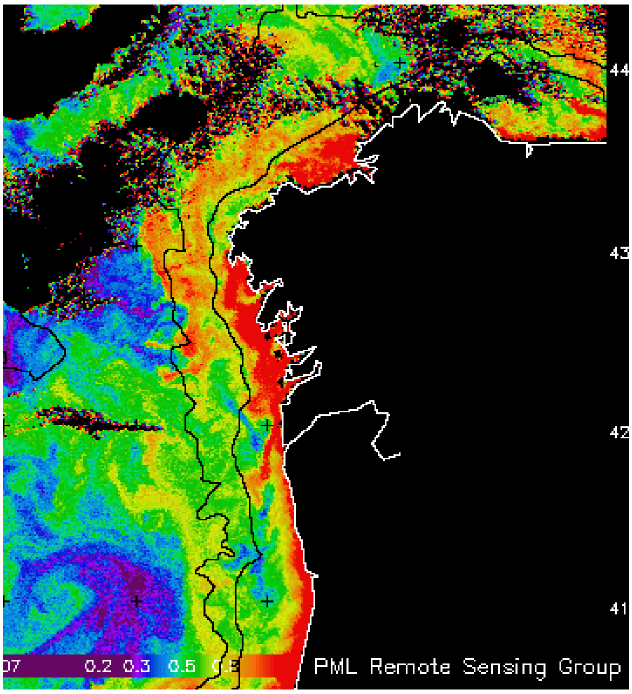
(a) 21 January 1998



(b) 21 January 1998 Colour

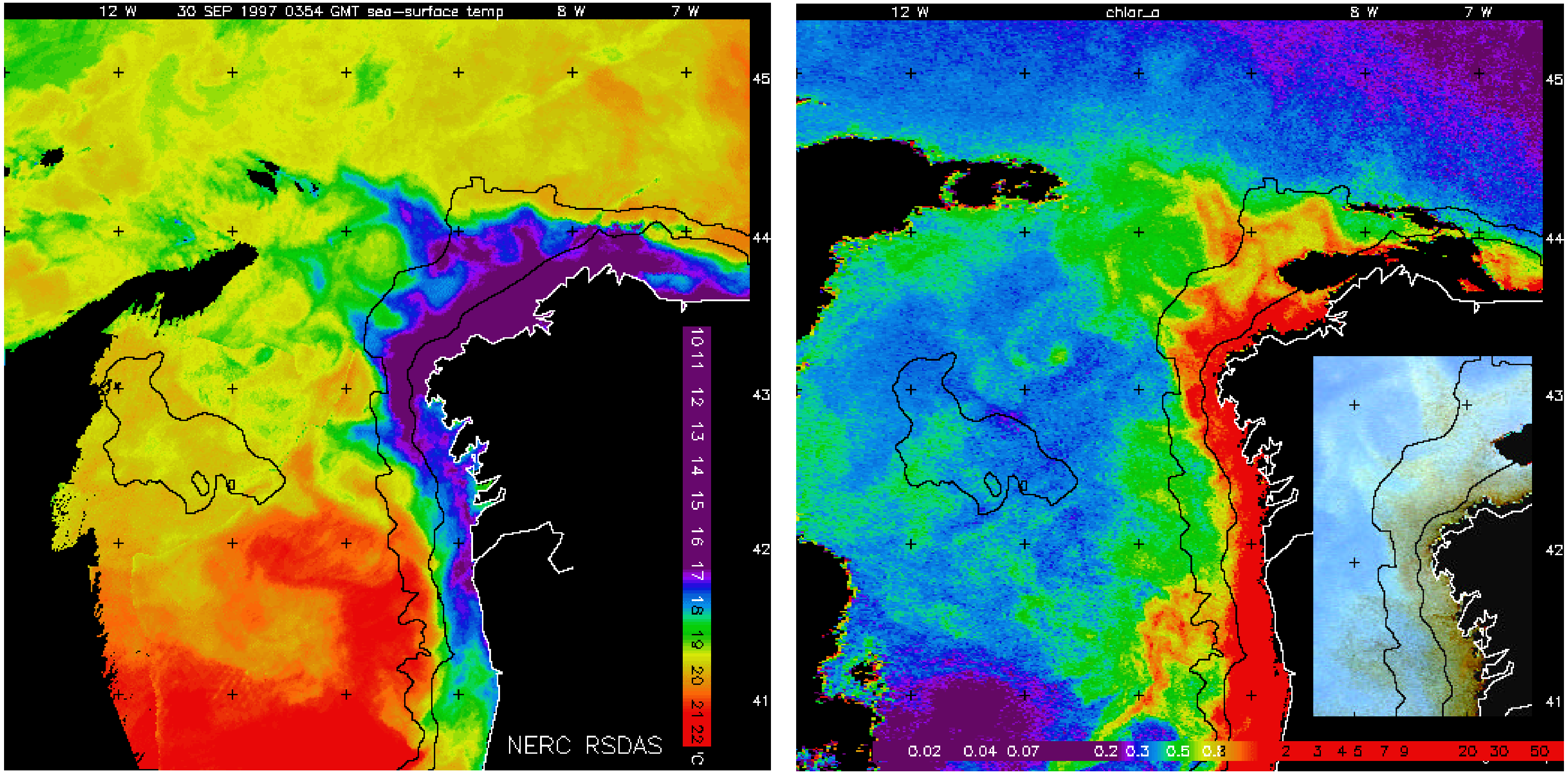


(c) 15 March 1998



(d) 15 March 1998 Chlorophyll

Figure 4. (a) SST image from 21st January 1998 (just after CD110 cruise), illustrating the warm Navidad current. (b) SeaWiFS true-colour composite from the same day (using 555, 510, 443 nm channels) showing increased concentrations of suspended particulate material near the coast. (c) SST image from 15th March 1998 (during Poseidon cruise). (d) SeaWiFS chlorophyll map from the same day showing increased concentration near the coast possibly associated with a Spring bloom.



(a) 30 September 1997 SST

(b) 30 September 1997 Chlorophyll concentration and colour composite

Figure 5. (a) SST image from 30th September 1997 showing upwelling conditions, filaments, and an eddy (near 44N 10W) in Galician Sea. (b) SeaWiFS chlorophyll map from the same day, with high concentrations seen within the upwelling zone. Inset is the corresponding true-colour composite, confirming that the high-chlorophyll water appears green.