MERIS VALIDATION IN THE NORTH WEST MEDITERRANEAN AND MASCARENE RIDGE (INDIAN OCEAN)

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Abstract

A time series of measurements of phytoplankton pigments and MERIS chlorophyll (Level 2) data at a site in the north-west Mediterranean were obtained during the validation phase of the ENVISAT mission (May to October 2002). In addition match-ups were obtained in the Mascarene Ridge area of the Indian Ocean from 1st June to 12th July 2002. This paper evaluates the quality of the satellite data by examining the available Level 1 and Level 2 data, and compares the satellite and *in situ* chlorophyll. As not all the images have been received, the results in this paper represent an interim report only.

1. INTRODUCTION

The objectives of this study were to obtain time series of measurements of phytoplankton pigments and MERIS chlorophyll (Level 2) data at a site in the north-west Mediterranean, close to the Blanes canyon, for the MERIS validation period (6 months after the first images were available, May to October 2002). A second objective was to obtain measurements of pigments and MERIS chlorophyll (Level 2) during a cruise in the Mascarene Ridge region of the Indian Ocean in June and July 2002. The aim of this paper is to evaluate the number of good quality match-ups of MERIS and in situ data and to evaluate the accuracy of the MERIS chlorophyll data.

Other aims of the work are to develop regional algorithms for pigments using a) MERIS match-ups (one pixel/surrounding pixels) and b) in situ remote sensing reflectance at MERIS wavelengths using measurements of sky irradiance (Eo) and profiles of downwelling irradiance (Ed) and upwelling radiance (Lu). Optical measurements were made during both periods of fieldwork, but these will not be reported in this paper.

Also of interest is the influence of spatial and vertical heterogeneity of pigment distribution on the accuracy of pigment retrieval. For this purpose sub-surface measurements along transects at high spatial resolution were made of upwelling and downwelling irradiance and fluorescence, and profiles of fluorescence and pigments were measured on station. Again, because of the short time-scale for evaluation of the MERIS chlorophyll data, this study will be presented at a later date.

One of the reasons for choosing the Blanes canyon area was that it was possible there to obtain a time series of measurements for the entire MERIS validation period. An additional opportunity of working in the Indian Ocean arose as part of the cruise work plan was devoted to MERIS and AATSR validation.

2. STUDY SITES

2.1. NW Mediterranean

The continental shelf off Blanes is relatively wide for the Mediterranean, with the 1000 m isobath extending to about 35 Km offshore. The Blanes canyon is a major feature in the bottom morphology bringing the 200 m isobath to only about 5 Km from the shoreline. The canyon bottom drops to more than 2000 m within about 15 Km and bisects the Catalan current flowing SW all along the NW Mediterranean coast. During periods of high precipitation in winter there may be some influence of inorganic and biogenic particles, but during spring and summer the particles are generally phytoplankton (Granata, *et. al.,* 2001*).* The study took place during overpasses of the ENVISAT satellite from 1st May to 30th October, from the 8 m long vessel *Itxasbide*. Fig.1 shows the study area.

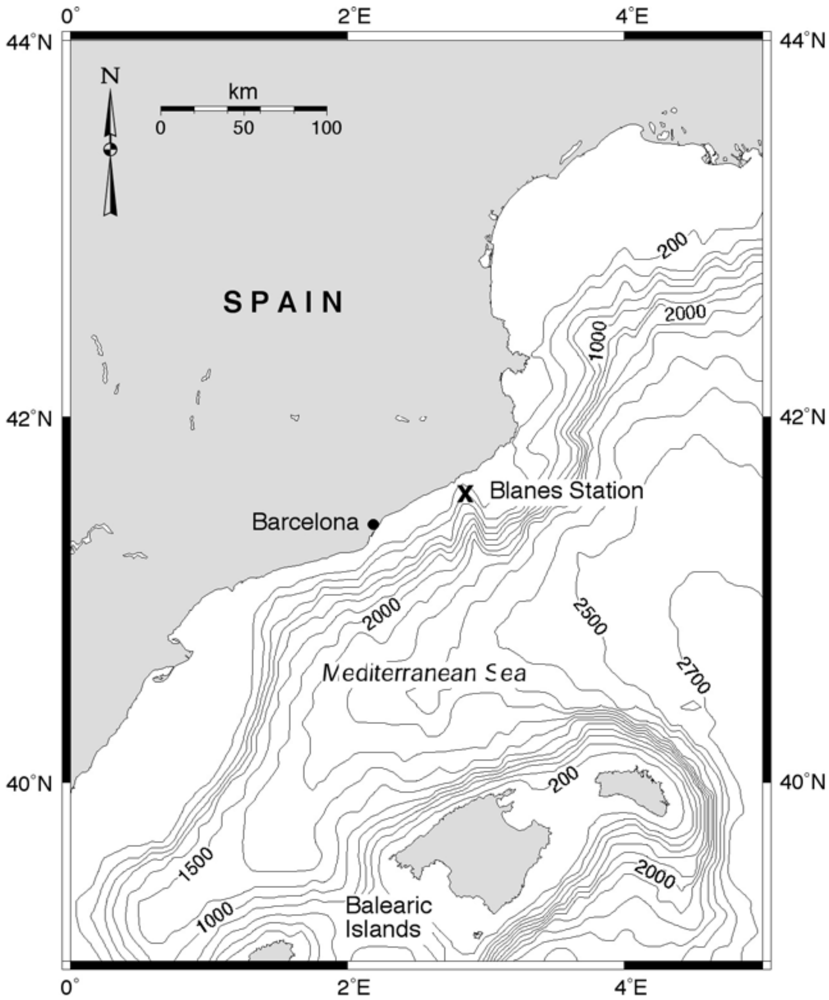

Fig.1. Map of the study area, showing the position of the time series sampling station.

2.2. Mascarene Ridge. The study of the Mascarene Ridge (MR) (between 5 and 21° S, 55 to 65°W) took place between 1st June and 11th July 2002, on RRS Charles Darwin. The cruise track (Fig.2) covered the full extent of the MR, firstly proceeding south from the Seychelles down the eastern side of the MR, surveying the deep water (up to 3000m), and then traversing northwards from Mauritius to the Seychelles sampling the shallower waters (shallowest depth was 200 m) over the sills along the Ridge system, and finally turning to the south towards Mauritius again in the deeper waters off the west of the MR.

3. METHODS

3.1 Western Mediterranean

A time series of measurements were made during ENVISAT overpasses (approximately every 3 days) at a site 4 miles off the coast of Blanes, Spain (49 39.15°N, 2 52.67°E). A list of the days on which measurements were made is shown in Table 1. Measurements of surface downwelling irradiance were made with a Satlantic sensor (OCR507 mounted on a mast at the highest point of the vessel and powered by a 12V battery). Profiles to 60m of downwelling irradiance and upwelling radiance were made using downwelling irradiance (OCI200) and upwelling radiance (OCR200) Satlantic sensors mounted on a small rig and operated via a 12V battery. Measurements were made with the sun on the starboard side to prevent ship shadow affecting the measurements. Within 30 minutes prior to the light profiles water sampling was carried out with Niskin bottles at various depths down to 200 m after a profile was carried out to this depth with a Seabird 19+ self-recording CTD fitted with a WETSTAR flow-through fluorometer. Secchi disk readings and meteorological observations were also made.

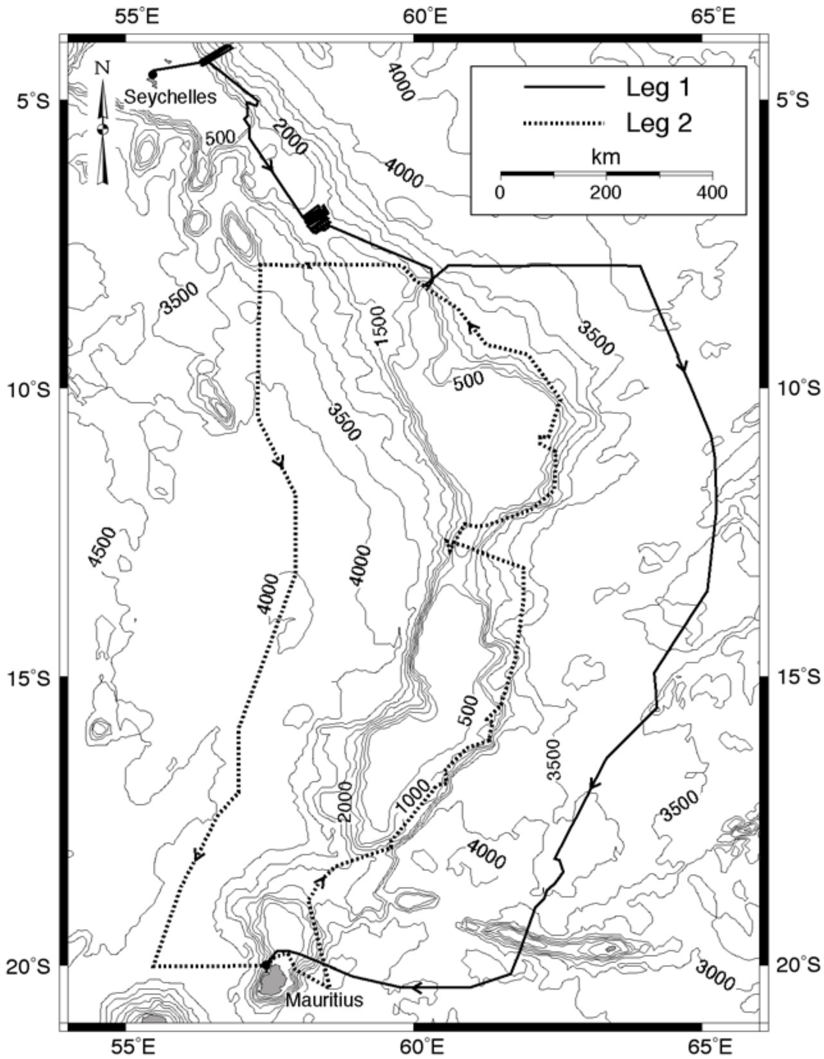

Fig.2. The transect of the RRS Charles Darwin during CD141 in the Mascarene Ridge area.

The light sensors were calibrated at Satlantic, Canada, immediately prior to the fieldwork activities, and calibrated at Plymouth Marine Laboratory in December 2002, prior to be sent back to Satlantic for post-cruise evaluation and calibration. The calibration at PML in December 2002 was used in the study of the inter-calibration of instruments for the MAVT (Gerald Moore, this volume).

Water samples were collected at 1, 5, 10, 25, 50, 75, 100, 125, 160 and 185 m depths for nutrients (nitrate, nitrite, phosphate and silicic acid), pigment and phytoplankton taxonomic analysis. Chlorophyll pigments were analysed at the CEAB by the spectrophotometric method and Chlorophyll a, b and c were computed following Jeffrey and Humphrey (1975). For this purpose, 3 L of water were filtered from all samples through 45 mm GF/F Whatman filters. Pigment analyses from 1, 5 and 50 m depth samples using high performance liquid chromatography (HPLC) were carried out at SOC following the method of Gibb *et al.* (2001). Duplicate samples of 0.75 L were filtered through 25 mm GF/F Whatman filters. The filters were stored at -70°C until the analyses were carried out. The HPLC was calibrated using pigment standards from DHI, Denmark. The following pigments were quantified: chl c3, chl c2, peridinin, 19'butanoyloxyfucoxanthin, fucoxanthin, 19'hexanoyloxyfucoxanthin, alloxanthin, diadinoxanthin, violaxanthin, zeaxanthin, DV-chl b, chl b, DV-chl a, chl a, b-carotene, and phaeopigments.

Several transects of sub-surface fluorescence, Ed and Eu were made using a towed instrument, Lightfish (Robinson, *et al,*1995*)*. Meteorological conditions including wave height and Meteosat images at the time of the cruises were obtained from the web of the *Servei Català de Meteorologia* (http://www.gencat.es/servmet/).

3.2 Mascarene Ridge
Measurements were made at the time of ENVISAT overpasses (approximately every 3 days) on cloud free days. A list of these is shown in Table 2. A downwelling irradiance sensor was interfaced with a data acquisition module at Satlantic (MVD500) and mounted on the foremast. Profiles of downwelling irradiance and upwelling radiance to 60m were made using a small rig deployed from a crane using a slip ring winch on the aft deck from the starboard side. Measurements were made of downwelling irradiance (OCI200) and upwelling radiance (OCR200), with the sun on the starboard side to prevent ship shadow affecting the measurements. The same calibration procedures were carried out as for the NW Mediterranean.

A profiling CTD (SeaBird) and fluorometer (Chelsea Instruments, Mark III) were deployed immediately before the Satlantic profiles. Water samples were taken for pigment and phytoplankton taxonomic analysis on the CTD upcast using the Niskin bottles mounted on the rosette on the CTD frame. These were taken during every CTD, which sampled the top 200 m in detail. 6 samples were taken in the top 200m, filtered and stored in liquid nitrogen. The water was filtered using GF/F Whatman filter papers, taking 2 replicated for each depth, and then stored in liquid nitrogen. The pigments were identified and quantified by high performance liquid chromatography (HPLC) at SOC nutrients following the method described above for the NW Mediterranean. Water samples were also taken for nutrients.

Intercomparison of Chlorophyll pigments:
The inter-comparison of pigments measured by the MAVT laboratories was carried out by both SOC, for chlorophyll-a measured by HPLC, and by CEAB, for chlorophyll-a measured by the spectrophotometric method. This was carried out on 2 occasions: August and November 2002. The results of the two exercises are contained in the paper on inter-comparison of chlorophyll-a (Kai Sorensen, this volume).

4. RESULTS
4.1. MERIS data quality
4.1.1 NW Med:
34 sets of measurements were made. Table 1 shows the satellite data, which is being made available for this site. To summarise this table: Level 0 data for 6 images is not yet available (LO n/a), 8 images are contaminated by cloud, 3 images are still awaited (A), 15 have not been processed by ESA to date (NL) and the *in situ* chlorophyll (spectrophotometric) is not available for 12. So for the purpose of this paper there are 10 match-ups with chlorophyll data.

The procedure was to view the Level 1 images using ENVIVIEW and to make an overall assessment of the cloud cover. Then VISAT was used to select the match-up location from the Level 2 chlor-a images. A summary of the data quality from the flags for the matchup location is shown in Table 1. The columns marked 'dust' and continental aerosol are the two aerosol flags. Wind speeds were in all cases less than 2 ms^{-1}. The SMILE correction was performed on all images to up to 14^{th} October. Level 2 images were examined for camera artefacts. In fact the image for 14^{th} October shows that although it was SMILE corrected, there is banding to the east of the study site (camera 4). 4 images are shown in Fig. 6, at the end of this paper. They are all Level 2 chlor-a images. The dates for these are 24.05.2002,12.06.2002, 17.07.2002 and 14.10.2002. The quality of the images is summarised in Table 2. Only the dates with 'n' in the cloud, glint, dust and continental aerosol columns are entirely 'error flag free'. However, as this analysis is not complete yet, all the match-ups in this table have been used for the chlorophyll-a comparison.

For the comparison of satellite and *in situ* chlorophyll, firstly the Level 2 chlorophyll-a value was selected for the closest pixel to the ships position; secondly the surrounding 9 pixels were sampled and the average and standard deviation were calculated (Tables 1 and 2). The chlorophyll a data from an average of the measurements in the mean optical depth (25m), was then merged into the table, with the standard deviation of replicate measurements. In the Spanish study measurements of chlorophyll-a were made both using spectrophotometric analysis and also the pigments chla, phaeopigments and DV-chl a using HPLC (following the MAVT protocols, 2002). However, for this comparison only the spectrophotometric measurements of chlorophyll a have been included.

Table 1. Status of MERIS data for Blanes. Data column: where there is a y in the image column, an image has been received; in situ column indicates whether there is in situ data.

Date	Data		Data quality				Satellite chll				In-situ chl	
	Image	In situ	Cloud	Glint	Dust	Cont.aer.	1 pix	Mean	Sd (n)	n	Avg	std
20020514											0.430	0.244
20020517	y		y								0.778	0.771
20020520	NL										0.253	0.162
20020524	Y		n	n	y	n	0.302	0.238	0.129	9	0.222	0.133
20020527	L 0 n/a										0.191	0.069
20020530	y		y	y	y	n	0.000	0.433	0.188	5	0.128	0.020
20020602	y	n										
20020603	NL	y									0.055	0.028
20020605	y	n										
20020610	NL	y									0.082	0.026
20020611	NL	n										
20020612	y	n	n	y	n	n	0.356	0.392	0.051	9		
20020615	y	n										
20020618	L 0 n/a	y									0.215	0.071
20020621	y	y	y								0.127	0.077
20020625	NL	y									0.112	0.046
20020628	L 0 n/a	y									0.153	0.024
20020701	y	y	y	y	y		0.001	0.044	0.071	3	0.150	0.034
20020704	y	y	y								0.165	0.039
20020707	y	n										
20020708	NL	y									0.158	0.039
20020710	y	n										
20020717	MER	y	n	n	n	n	0.397	0.418	0.034	9	0.143	0.031
20020723	y	y	n	y		y	0.550	0.550	0.029	9	0.160	0.042
20020725	NL	y									0.164	0.121
20020726	y	n										
20020729	NL	y									0.126	0.009
20020802	y	y	y	n							0.190	0.076
20020805	L 0 n/a	y									0.163	0.073
20020808	A	y									0.340	0.137
20020811	Y	n										
20020812	NL	y									0.240	0.095
20020814	Y	y	y	y		y	0.419	0.333	0.052	5	0.190	0.037
20020818	NL	y									0.143	0.061
20020821							0.442	0.437	0.010	9	0.196	0.083
20020824	Y	n										
20020827	Y	y	y								0.334	0.026
20020830	Y	y	n (?)	y		y	0.337	0.332	0.028	9	0.387	0.340
20020906	L 0 n/a	y										
20020909	NL	y									0.325	0.066
20020912	Y	y	y								0.321	0.070
20020915	L 0 n/a	y									0.389	0.087
20020918	Y	y	(y)	y	y		0.086	0.104	0.032	9	0.220	0.144
20020925		y									0.253	0.140
20020928	A	n										
20021001	A	y									0.253	0.070
20021007	NL	y									0.273	0.063
20021011	Y	n										
20021014	Y	y	n	n	n	n	0.722	0.715	0.207	9	0.307	0.044
20021017	Y	n										
20021020	Y	n										
20021023	Y	n										
20021028	NL	y										
20021030	NL	y										

Table 2. Matchup table for Blanes data. The *in situ* chlorophyll data over the top 25m has been averaged, and the standard deviation of replicate samples is also shown. Satellite chlorophyll is presented as one pixel, a mean of n surrounding pixels, and the standard deviation of this, where n is the number of pixels. Data available: Sat=Level 1 data has been examined; *in situ*=Satlantic profiles are available.

Date	Data available		Data quality				*In-situ* chlorophyll Unweighted 25m		Satellite chlorophyll			
	Sat	*In situ*	Cloud	Glint	Dust	Cont. aerosol	Avg.	std	Single pixel	Mean of 9	Sd (n)	n
20020524	y		n	n	y	n	0.222	0.133	0.302	0.238	0.129	9
20020530	y		y	y	y	n	0.128	0.020	0.000	0.433	0.188	5
20020701	y	y	y	y	y		0.150	0.034	0.001	0.044	0.071	3
20020717		y	n	n	n	n	0.143	0.031	0.397	0.418	0.034	9
20020723	y	y	n	y		y	0.160	0.042	0.550	0.550	0.029	9
20020814	y	y	y	y		y	0.190	0.037	0.419	0.333	0.052	5
20020821							0.196	0.083	0.442	0.437	0.010	9
20020830	y	y	n (?)	y		y	0.387	0.340	0.337	0.332	0.028	9
20020918	y	y	(y)	y	y		0.220	0.144	0.086	0.104	0.032	9
20021014	y	y	n	n	n	n	0.307	0.044	0.722	0.715	0.207	9

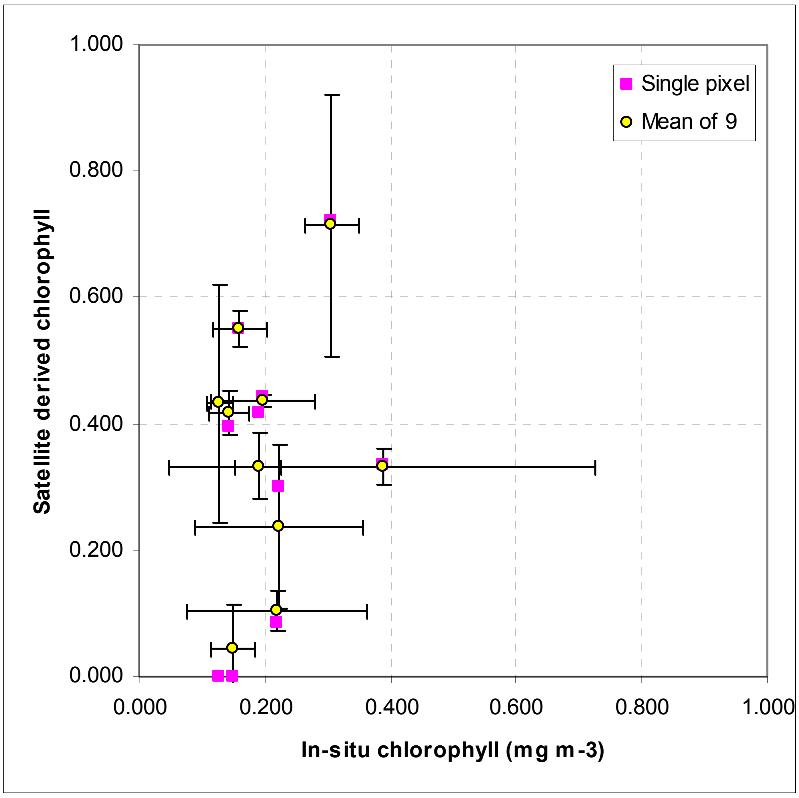

Fig.3. Level 2 chlor-a vs in situ chlorophyll-a (spectrophotometric). The horizontal error bars represent the sample standard deviation. The Level 2 chlor-a data is presented as a yellow symbol for single pixels, a pink symbol for the mean of 9 pixels and the error bars which represent the standard deviation**.**

A comparison of the Level 2 chlor-a and the in situ data for the Blanes match-ups is shown in Fig. 3. The chloropyll values were all quite low (less than 0.4 mg m^{-m3}), and so a statistical relationship between them has not been attempted. Indeed the diagram indicates that the standard deviation of the surrounding pixels is larger than any trend in the data. However this data set will be merged with the remaining match-up data, and then used with the much larger MAVT database for algorithm development.

A comparison has been made of a MERIS (Level 2) reflectance spectrum with the matching remote sensing reflectance spectrum from the profiles of downwelling irradiance and upwelling radiance. Remote sensing reflectance was calculated using surface values of Lu and Ed, which were obtained by extrapolating the profiles to the surface (MAVT Protocols, 2002). Figure 4 shows this for the 14th October 2002. The remote sensing reflectance is shown for both the downcast and the upcast, which were separate in time by approximately 10 minutes. MERIS reflectance is slightly higher in the blue and green part of the spectrum and a little lower at wavelengths greater than 600 nm. Further spectral comparisions will be made when the data set is complete.

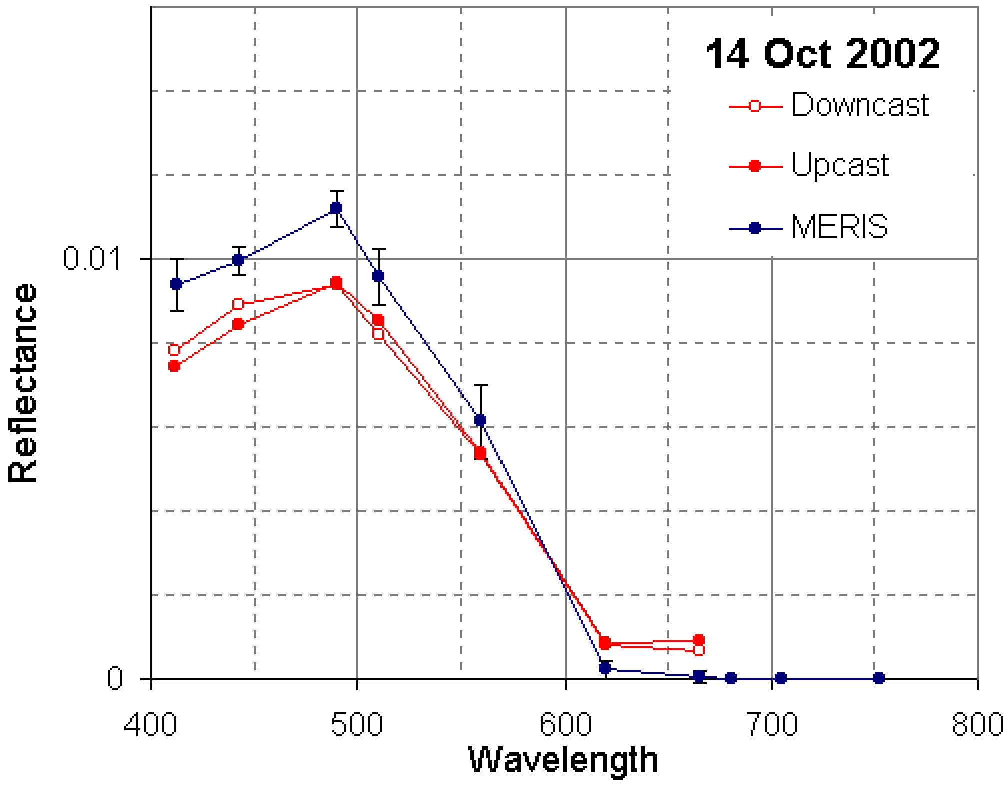

Fig. 4. MERIS reflectance and Satlantic remote sensing reflectance at 1m on 14th October 2002.

4.1.2.Mascarene Ridge

There were 10 successful ENVISAT match-ups with *in situ* data. Of these 4 images have been delivered but they all have scattered cloud, or cloud edge near the relevant pixels. Therefore they have not been taken beyond the Level 1 analysis stage. There are 2 images awaited and 4 have not been listed but will be available in due course.

Mascarene Ridge Match-ups				
Station	Latitude (S)	Longitude (E)	Date	status
CD0409	05 13.48	57 17.18	06/04/02	NL
CD0601	07 09.25	58 05.55	06/05/02	NL
CD0901	07 59.99	61 27.91	06/08/02	NL
CD1101	07 59.9	63 21.99	06/09/02	NL
CD1802	16 29.02	63 26.95	15/06/2002	Y

CD2101	19 45.94	61 55.15	18/06/2002	Y
CD2901	18 36.83	58 25.13	24/06/2002	Y
CD3301	14 12.78	61 56.17	27/06/2002	Y
CD4501	10 45.29	62 30.38	07/01/02	A
CD5001	8 01.87	58 10.56	07/03/02	A

Table 3. Mascarene Ridge match-up information

4.2. Spatial distribution of phytoplankton in the NW Mediterranean
Conditions varied from a surface mixed layer in May to a deep chlorophyll maximum in August but due to unstable and cool weather conditions the surface mixed layer showed relatively high chlorophyll concentrations at times throughout the period. This can be observed in the contour plot of Chlorophyll a and fluorescence in Figure 4. Along with the information on spatial variability at sub-pixel and several pixel scales an evaluation will be made of the dependence of vertical distribution of chlorophyll for algorithm accuracy.

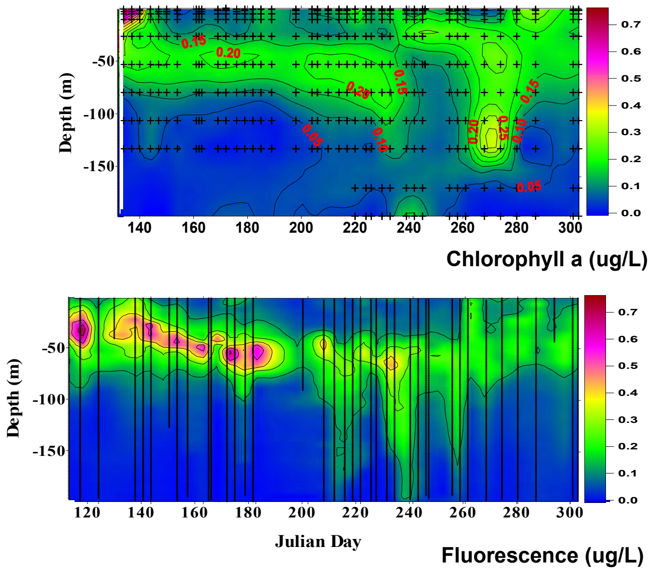

Fig. 5. Contour plots of fluorescance (from the profiling CTD) and chlorophyll-a from spectrophotometric measurements made on water samples taken at the CTD stations.

5. FUTURE WORK
A number of areas of work are to be completed:

1. The duplicated pigment measurements for the Spanish data set analysed using the HPLC and the spectrophotometer have not yet been compared. The HPLC measurements have not been compared yet with the satellite chlorophyll-a.
2. There are still a number of images for both the NW Mediterranean and the Mascarene Ridge which have not yet been received. The quality of these images will be evaluated, as for the ones described in this paper.

3. If the range of pigment values is high enough pigment algorithms for 2 areas will be calculated from the MERIS data.
4. The in situ optical data will be used to calculate remote sensing reflectance, and in situ pigment algorithms will be calculated for the 2 areas.
5. Scales of spatial variability will be calculated, using the sub-surface data from the transects.
6. An assessment will be made of the effect on the retrieved pigment accuracy of the pigment depth distribution.
7. The oceanographic data including CTD and fluorescence measurements from the 2 areas will be explored in relation to historical data.

6. ACKNOWLEDGEMENTS

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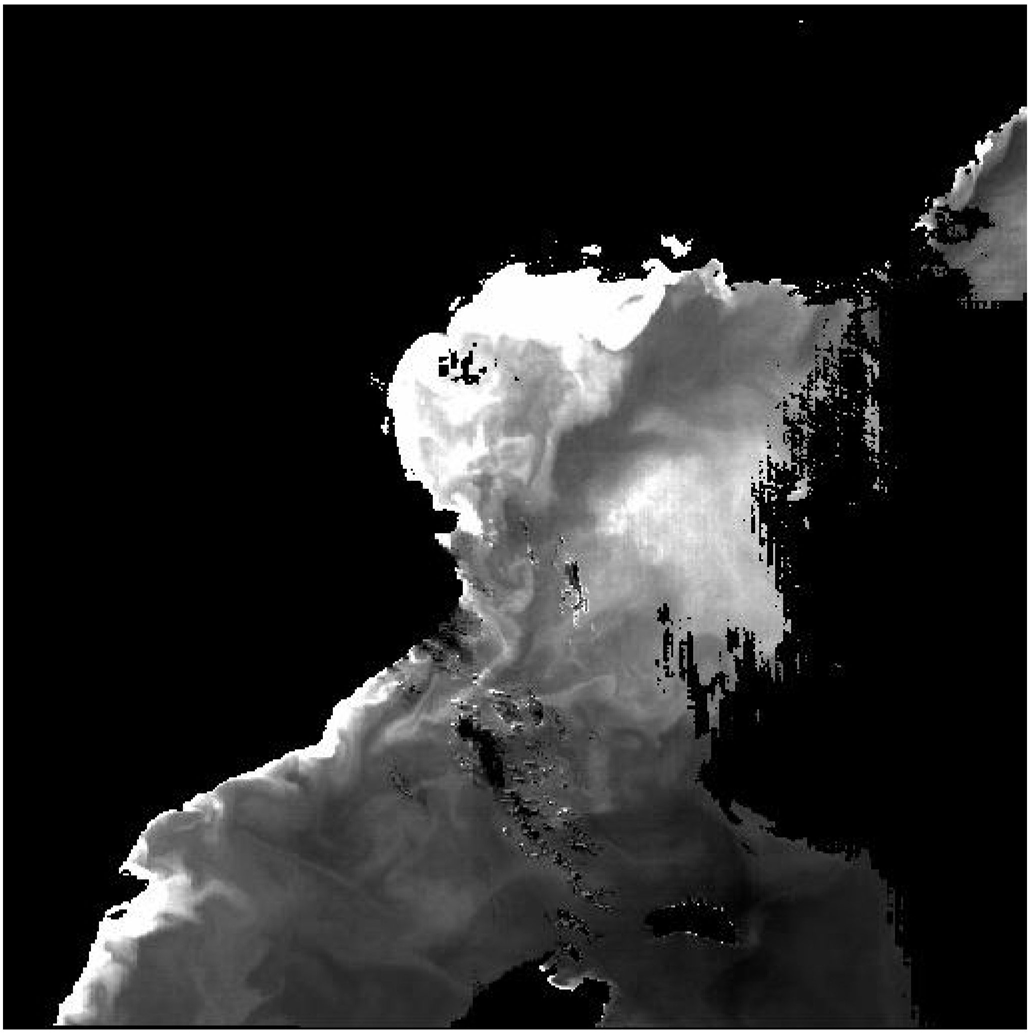

Fig.6a. L2 chlor-a map 24.05.2002

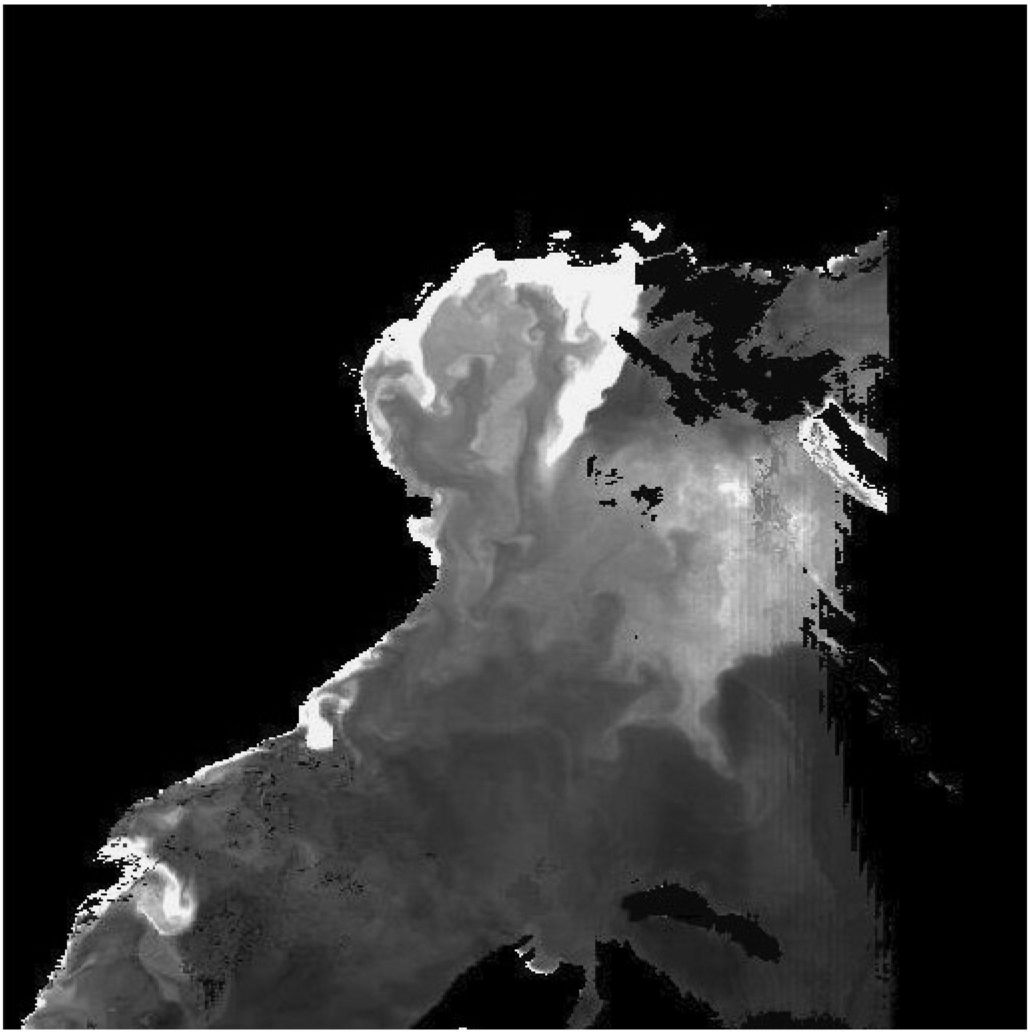
Fig.6b. L2 chlor-a map 12.06.2002

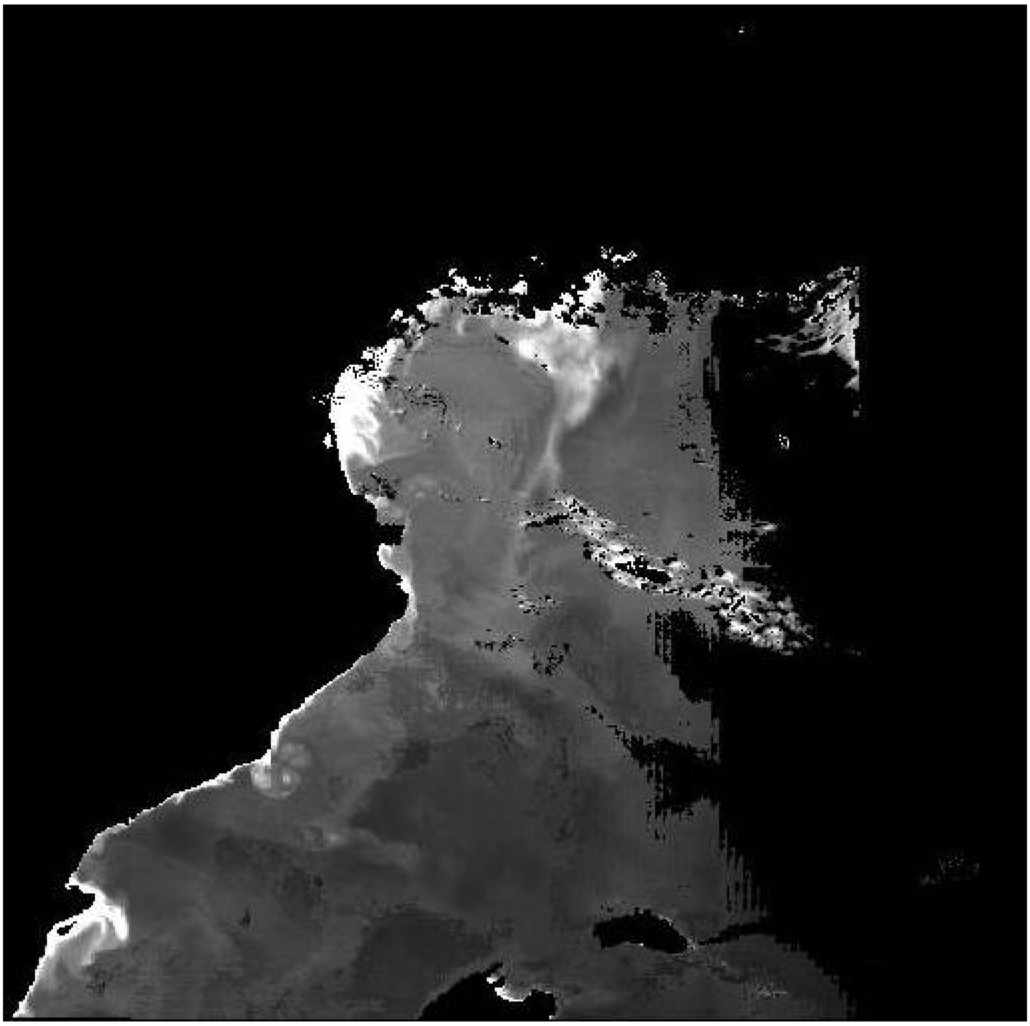
Fig. 6c. L2 chlor-a map 17.07.2002

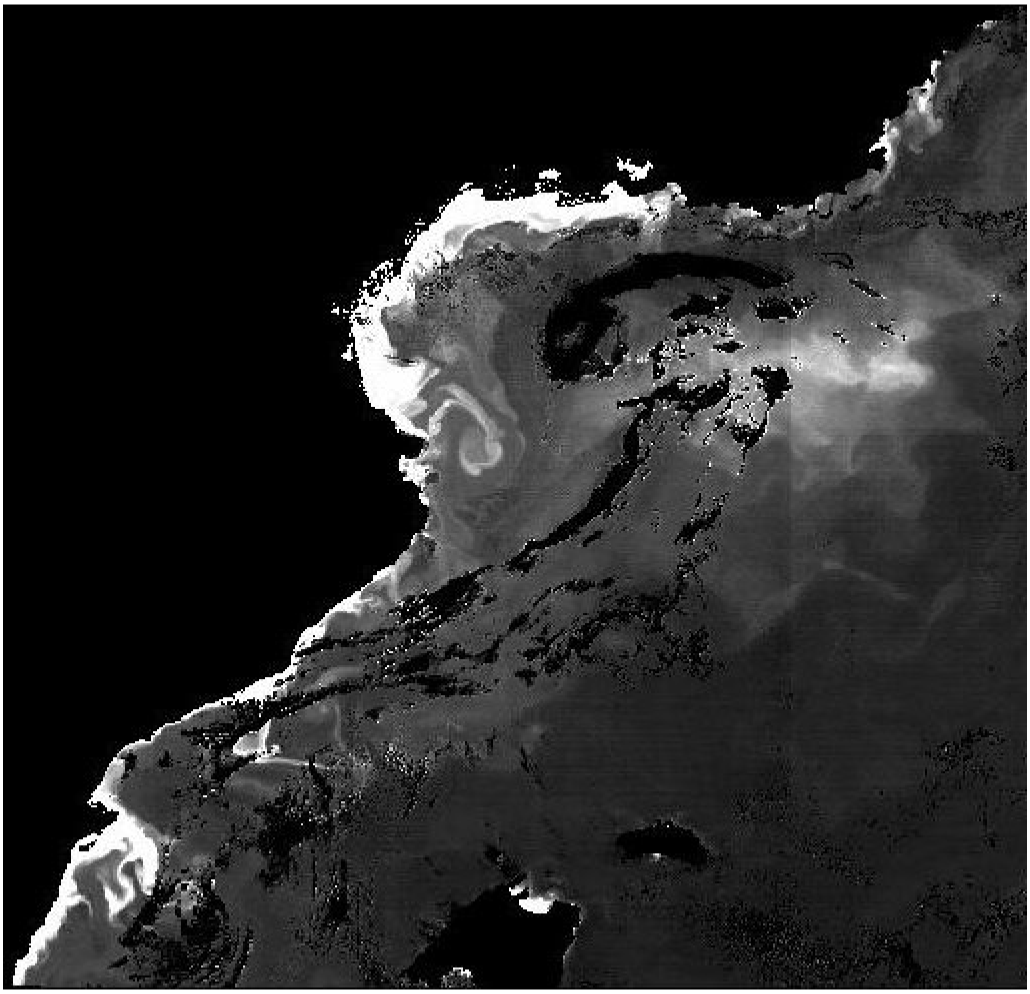
Fig.6d. L2 Chlor-a map 14.10.2002