A BLOOM TALE

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What is a bloom within the sea ?

It is a sudden increase of the population of vegetal organisms, namely the microscopic phytoplanktonic cells that are floating in the upper layer of the ocean. Such an increase is induced by favorable (both physical and chemical) conditions. The marine spring bloom can be spectacular, as it is for terrestrial vegetation; however, it does not extend everywhere in all parts of the ocean. On the contrary, there are specific places where such explosive events may occur. The Northern Mediterranean Sea is one of these places. The ocean color satellite imagery allows this phenomenon to be observed and described in great details regarding its spatial extension and temporal evolution.

A brief explanation may help to understand the very cause of a vernal bloom.
In winter, the cooling of the upper layers leads to an increase of the water density, and thus triggers a sinking of these waters and a vigorous vertical mixing. This mixing results in a chemical homogenization within the water column, and brings back the nutrients that were accumulated in the deep layers to the depleted surface layer. Like the "fertilizers" for terrestrial vegetation, the nutrients are essentially nitrate and phosphate. Their presence is indispensable for the growth of the tiny phytoplanktonic (or algal) cells.

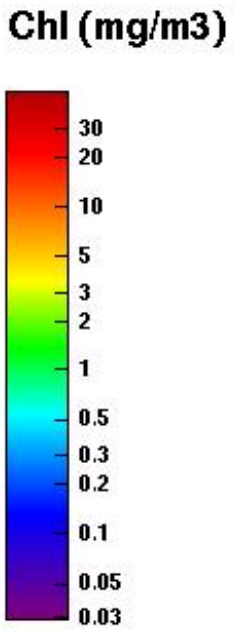
Nevertheless, the availability of nutrients is necessary but not sufficient. Indeed, any vegetal growth is based on the photosynthesis process, and photosynthesis requires solar light. During the deep vertical mixing process, the wandering cells experience huge variations between the upper, well lit, layers, and the darkness of the deep, which is unfavorable for photosynthesis. Therefore the vertically dispersed algal population cannot significantly develop.
The situation becomes quite different, when the warming of the near surface layer is significant (some time during Spring), and thus stabilizes this layer as well as its algal population. Exposed to the sunlight, the nutrient replete vegetal population can rapidly grow. Within a few days (with a cell division rate of about 1 per day, or more), the algal bloom starts. Yet, temporary adverse weather conditions, leading to a destabilization of the water column, may break it. Ineluctably, however, the algal population will enjoy again, some time later in the spring, good steady conditions supporting an explosive development.

What happens next ?
This actively growing population will consume nearly all the nutrients which were available within the stable and well lit upper layer. As a nutrient re-injection has become impossible in absence of vertical mixing with the lower levels, the population is slowly extinguishing. Such a system, with a low residual algal biomass will prevail during the whole summer.

Satellite-borne Ocean Color

Such sensors are able to detect the shift from the deep blue color, typical of desert waters, to the various green colors when phytoplankton are present in variable concentration. Thanks to appropriate corrections and algorithms applied to the information provided by these sensors, it is possible to quantify this color shift in terms of chlorophyll concentration. Remind that chlorophyll is the ubiquitous pigment common to all (terrestrial or marine) vegetal organisms.

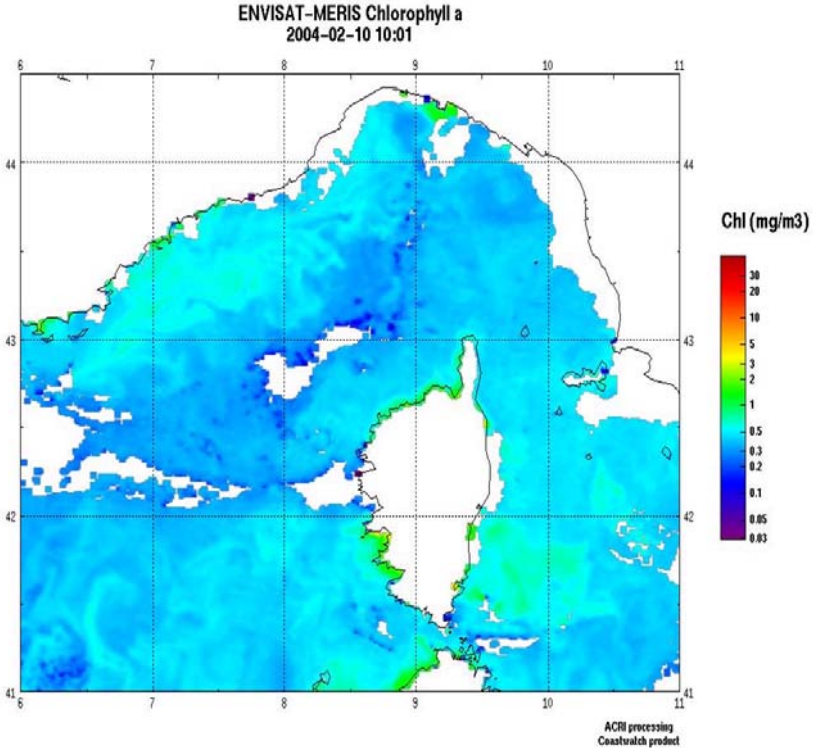
The **MERIS** sensor, launched in 2002 on the ENVISAT satellite by the European Space Agency (ESA), looks permanently at the entire ocean. The series of images below are an illustration of its capacity in describing the vernal bloom as it occurred this year (2004) in the Liguro-Provencal basin.



It is worth noting that the colors seen on the following images are the result of a color encoding of the digital counts. The arbitrary color scale, however, somehow mimics the visual impression, at least in the middle of its range. The very low chlorophyll concentrations (Chl = 0.03 to 0.07 mg m^{-3}), observable in some part of the whole ocean (but not in the North Mediterranean Sea at the season considered) are colored in purple and violet. The progression between dark blue to light blue, and then to green, corresponds to Chl ranging from 0.07 to about 1 mg m^{-3}, approximately. For higher concentrations, "unrealistic" colors, from yellow to red, are used. Clouds are visualized as white patches; white color is also used when the common algorithm fails to quantify chlorophyll (e.g. in turbid coastal zones, or in river plumes).

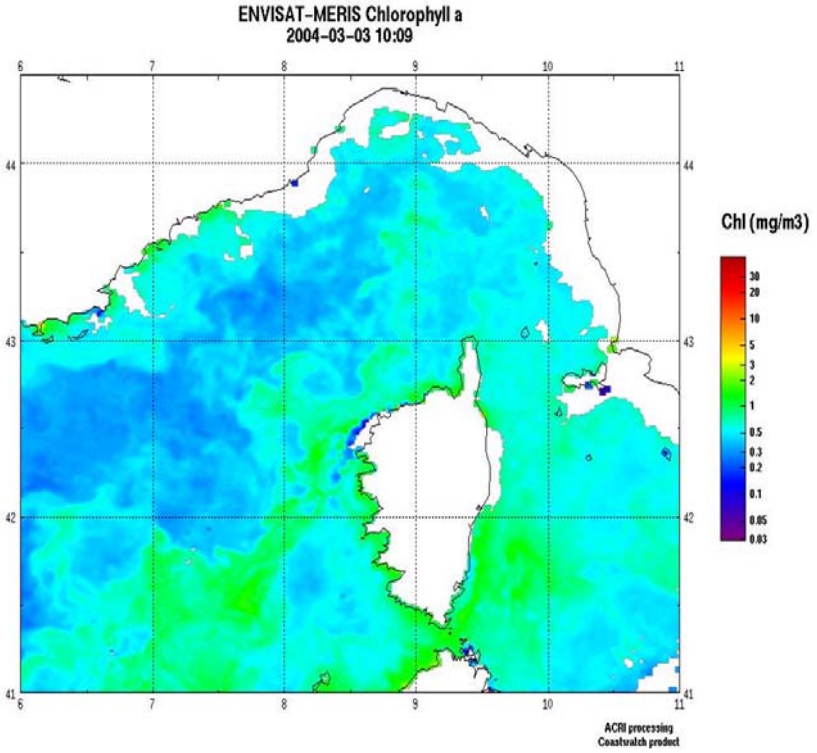
The vernal bloom in the Liguro-Provencal basin, as seen by MERIS

On the first scene (Feb. 10, 2004), the chlorophyll concentration (Chl) is low everywhere in the basin, with a minimum in the center of the basin which is the seat of the most intense vertical mixing because the surface temperature is minimal (about 13 °C).



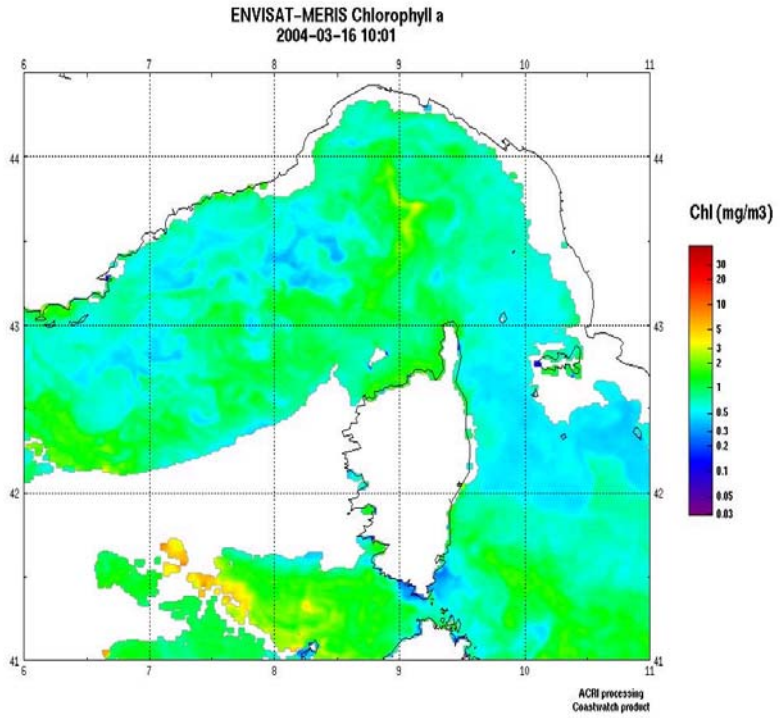
February 10, 2004 – Chlorophyll a

On the third of March, a significant increase in vegetal biomass appears, particularly in the southern part and around Corsica, whereas, the central part of the basin (and of the Tyrrhenian basin) remains "blue", with low (< 0.5 mg m^{-3}) Chl.



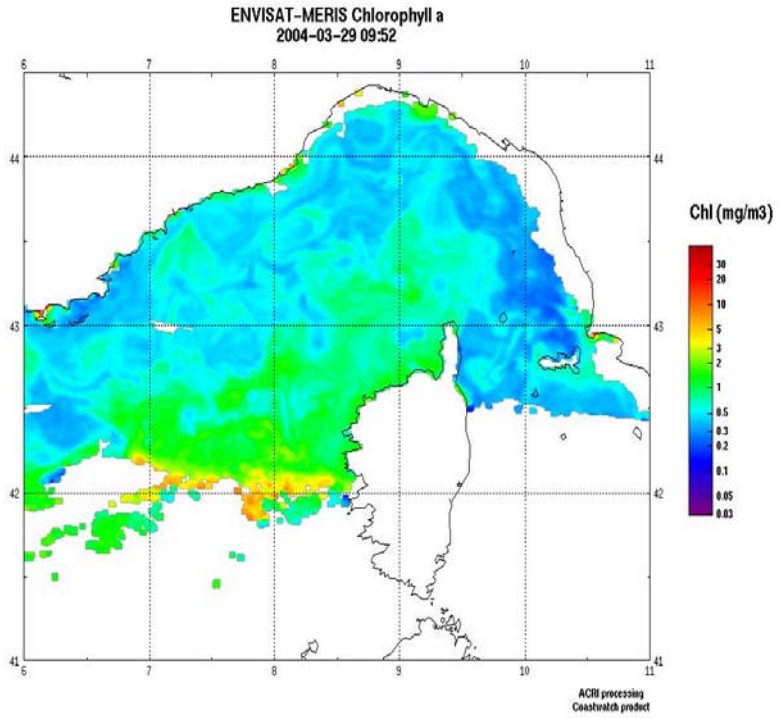
March 3, 2004 – Chlorophyll a

13 days later (March, 16), the situation has considerably evolved; a bloom extends in the whole basin (including the Tyrrhenian sea), leaving however, a blue spot (at midway between the Riviera and Corsica) in the center where vertical mixing persists,

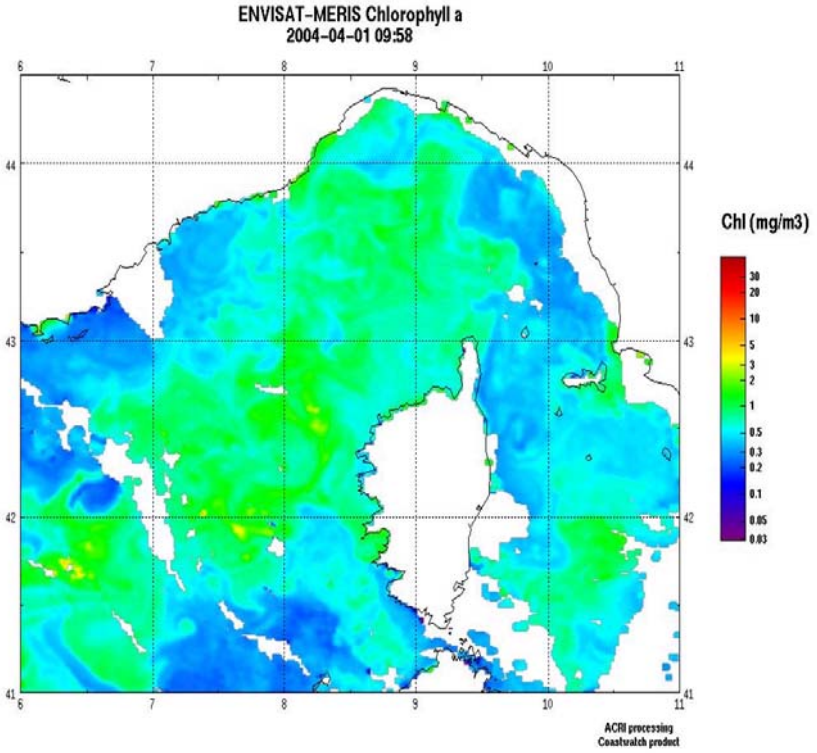


March 16, 2004 – Chlorophyll a

This bloom was a temporary event, as on the 29th of March, and after unfavorable weather conditions, the generalized bloom is partly destroyed. On the first of April, the basin again experiences a new extended bloom, with high concentrations of about 2 mg m^{-3} (even more in some cores, along the 42 °N parallel). In contrast, the extreme southern part (South of 41°30 N) is again blue, (compare with the image of March 16); actually the blooming period is already terminated for this zone.

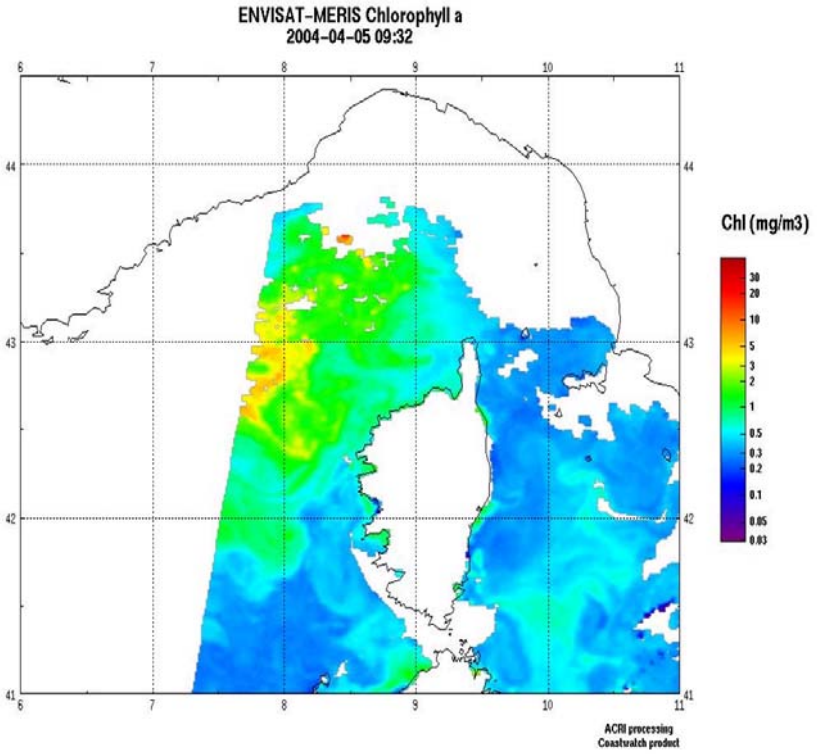


March 29, 2004 – Chlorophyll a

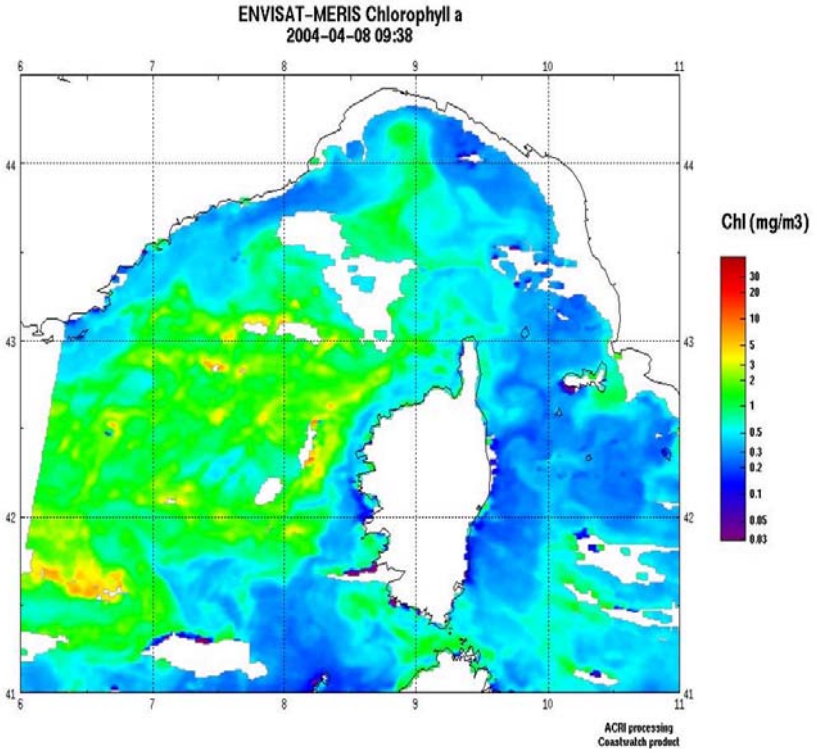


April 1, 2004 – Chlorophyll a

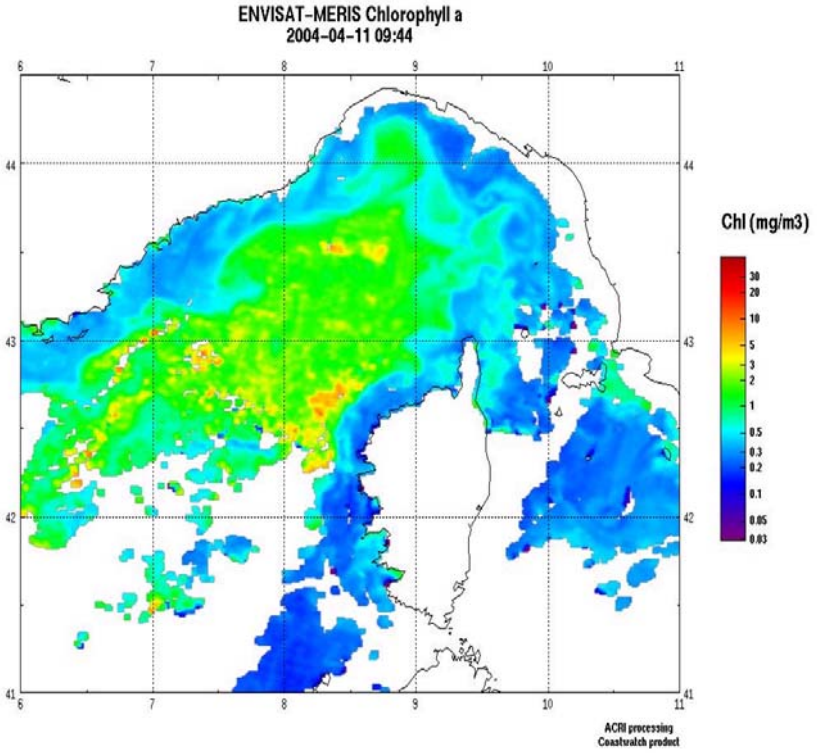
The bloom intensifies four days later (April 5) and lasts until the 11th, with exceptionally high (>3 mg m^{-3}) Chl values - for the Mediterranean Sea-. This central core is surrounded by blue Chl-poor waters circulating counterclockwise, from the west coast of Corsica, inside the Gulf of Genoa, and then following the Riviera coast (the so-called Ligurian current).



April 5, 2004 – Chlorophyll a

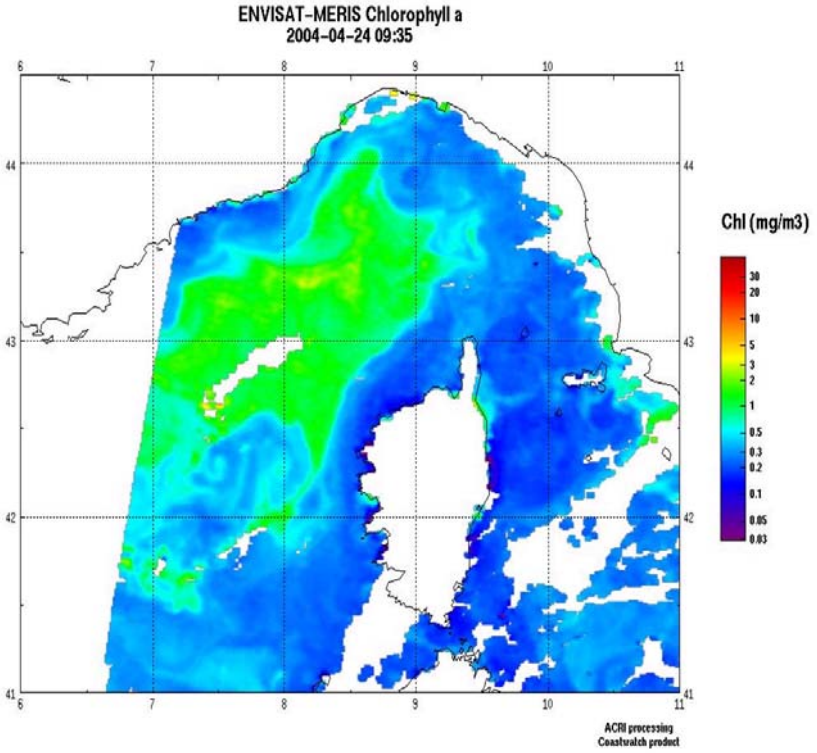


April 8, 2004 – Chlorophyll a

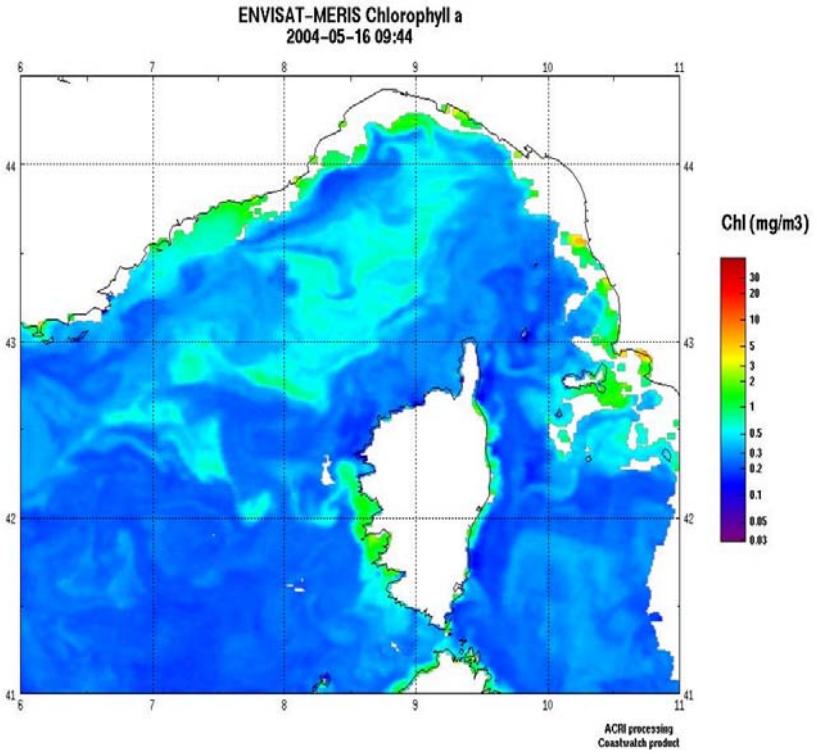


April 11, 2004 – Chlorophyll a

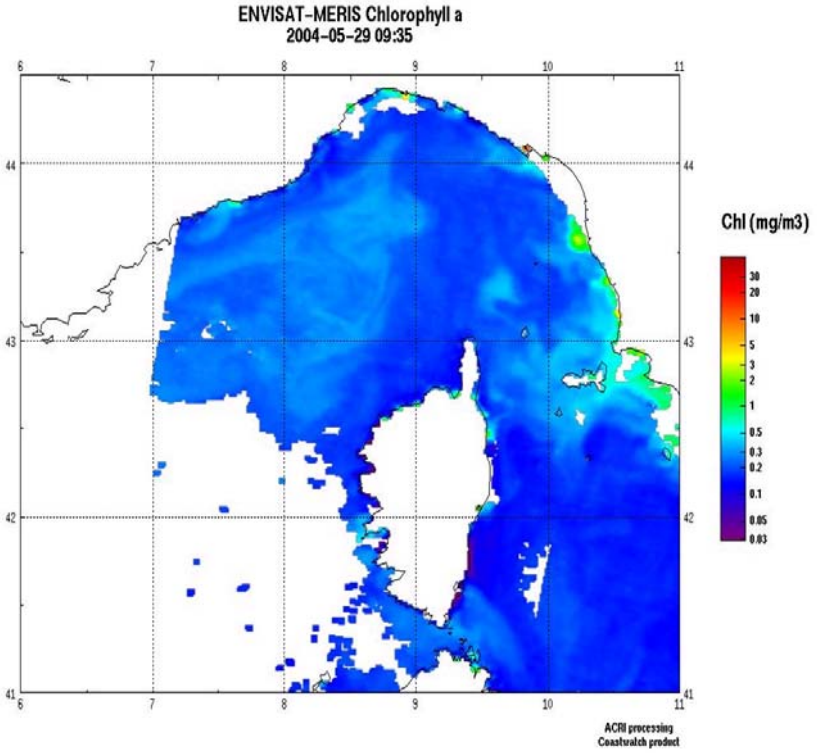
Still present on the 24th of April, the high Chl central spot is progressively weakening (May 16 and May 29), and the bloom event is at its end in early June, corresponding to the establishment of the typical summer situation (June to September).



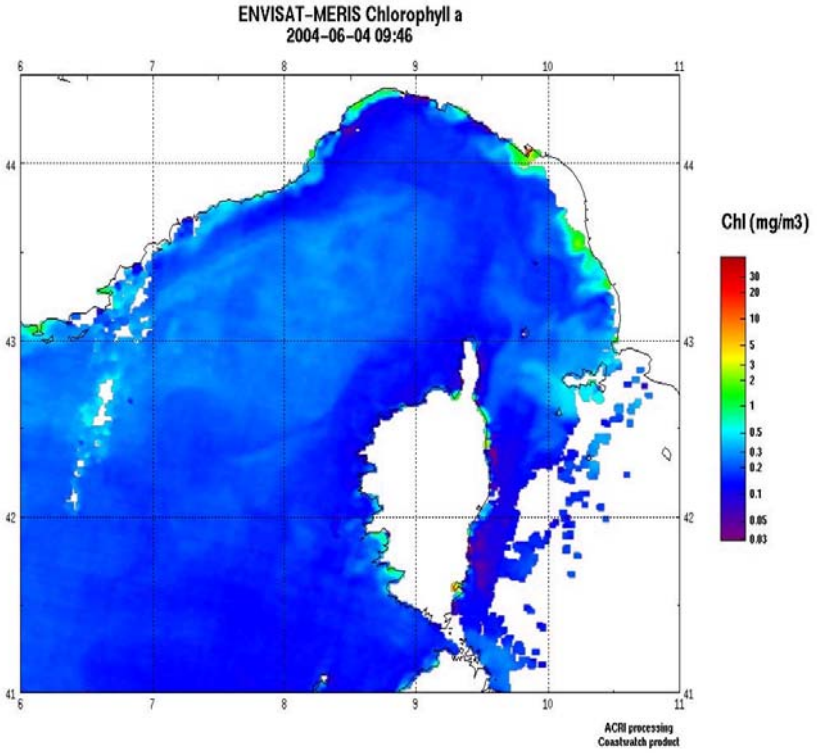
April 24, 2004 – Chlorophyll a



May 16, 2004 – Chlorophyll a



May 29, 2004 – Chlorophyll a



June 4, 2004 – Chlorophyll a

The series of MERIS scenes for the year 2003 (not shown here) demonstrate that if the timing of the bloom was slightly different, due to differing meteorological conditions, the phenomenon was roughly the same. A rather intense bloom (Chl > 2 mg m^{-3}) occurred as early as the 10th of March, but was declining thereafter (March, 23). The cloud cover was

dense in April, and thus only a few remote sensed data were available; nevertheless they indicate the persistence of the bloom. In the beginning of May (3), rather high Chl (0.5 to 1 mg m^{-3}) were still present, and were thereafter gradually decreasing during this month.

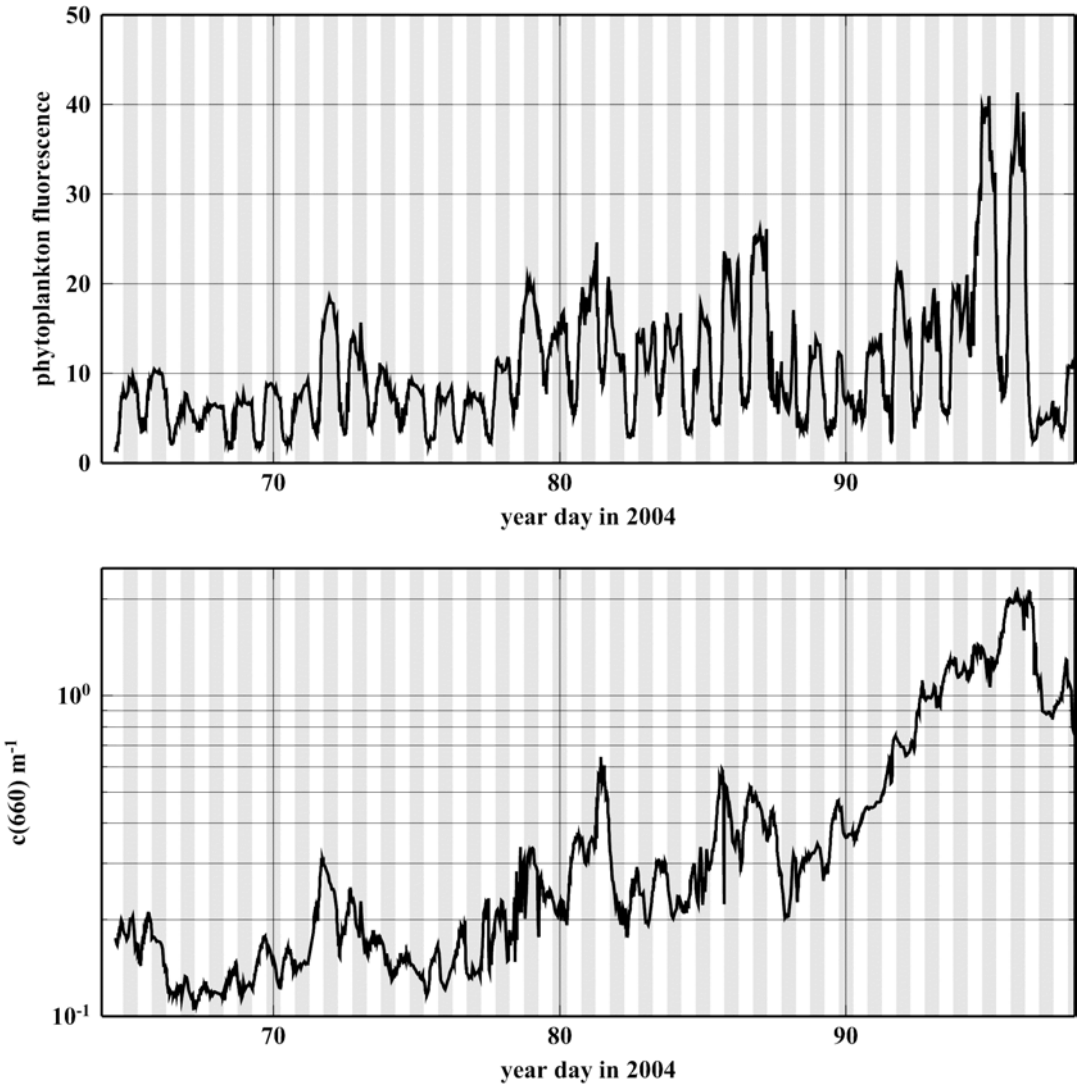
Another less marked bloom will happen, starting in October in the same zone. In contrast to the vernal bloom, the autumnal bloom results from the cooling of the warm surface layer which again triggers a limited convection (stronger at night), and thus induces a limited injection of nutrients in this well lit layer.

In reference to what was said before, intense algal blooms can only occur in these locations where the winter cooling is severe enough to produce an efficient vertical mixing, and thus a re-injection of nutrients in the upper layers. In absence of such strong cooling, the southernmost parts of the Mediterranean Sea do not experience spectacular blooms, only a seasonal weak variation in their chlorophyll content, with a smooth peak at the end of the winter.

In situ Observations

Operated by LOV (David Antoine, Chief scientist), an instrumented unmanned buoy named **"Boussole"** is anchored at 32 miles from Nice, on the transect between Nice and Calvi (location: 43°22 N, 7°54 E, bottom depth: 2440 m); it performs continuous measurements of several optical and biological parameters for calibration and validation of ocean color sensors (the MERIS sensor, in particular), as well as for a permanent oceanographic monitoring of the zone. The buoy is visited about each month for resupplying and refurbishment. Some instances of measurements during part (March, 4 – April, 7) of the bloom period are displayed.

The chlorophyll fluorescence signal is in keeping with the Chl concentration, in a complex manner, however. Indeed algal physiology is involved and complicates the interpretation of this signal. For instance, the fluorescence emission is depressed in the daytime and is maximal at night (when there is no photosynthesis), as clearly seen on the graph. The successive peaks observed at night are roughly proportional to the chlorophyll concentration.
The light attenuation coefficient (at 660 nm) is an indicator of the total amount of suspended material (including algal cells) present in the water. There is an obvious correlation between this parameter and the fluorescence signal (its maximum at night). The recorded values for the surface layer distinctly show the strong increase between the 1st and the 8th of April (day 91 to 98), in excellent correspondence with the MERIS information.



Time period: March 4 – April 8, 2004 – "Boussole" buoy