Satellite Derived Algal Bloom Timing in European Waters

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INTRODUCTION

The detection of algal blooms based on satellite chlorophyll *a* concentration (Chl) is receiving increased interest. Satellite Chl data is an essential component for early detection of harmful algal blooms (HABs, Stumpf & Tomlinson, 2005). The satellite data provides large scale information on biomass, usually as complement to other information sources giving information on harmfulness (Ruddick et al., 2008). Spring algal bloom (AB) timing information is useful for fish stock management since early spring diatom blooms determine food availability at the fish larval development stage (Platt et al., 2003). The frequency or magnitude of ABs in coastal/inland waters can be used as a quality indicator of the water ecosystem since phytoplankton rapidly respond to excessive nutrient influx from the agricultural or industrial activities (Beman et al., 2005). Algal bloom frequency or timing may also be used as an indicator of inter-annual variability or long term ecosystem trends (Kahru and Mitchell, 2008).

This paper focuses on the AB timing in European waters. Daily AB maps are generated using the AB detection technique described in Park et al. (2008). From these AB maps, the first day in a year when an AB has been detected is called the "AB timing". An algal bloom can occur when favourable conditions such as the availability of light and nutrient and water column stability are established. Although the spring AB timing in oceanic waters has been studied (e.g. Siegel et al. 2002) before, this study aims at providing qualitative understanding of factors governing the spatial variability of the AB timing with relevant and available satellite data such as PAR (Photosynthetically Available Radiation), SST (Sea Surface Temperature) and turbidity products.

The European waters covered in this study [35°N-72°N, 15°W-30°E] are shown in Figure 1. This area has great ecological diversity: waters range from very shallow (few metres) along the coastline and in the southern North Sea to very deep (thousands of metres) in offshore waters including the North East Atlantic Ocean and the Mediterranean Sea and from oligotrophic to eutrophic with both nitrate and phosphate limited waters and a wide range of dominant species according to location and season. The Chl concentrations range over more than 2 orders of magnitude from low concentration of less than 0.1 mg/m^3 in the offshore North East Atlantic Ocean and Mediterranean Sea (Claustre et al., 2002) to higher than 10 mg/m^3 in the coastal waters in the North Sea and in the Baltic Sea (Babin et al., 2003). Figure 1 (a) shows water depth and figure 1 (b) shows the 90 percentile Chl level in this area based on 2005-2006 MERIS Chl data.

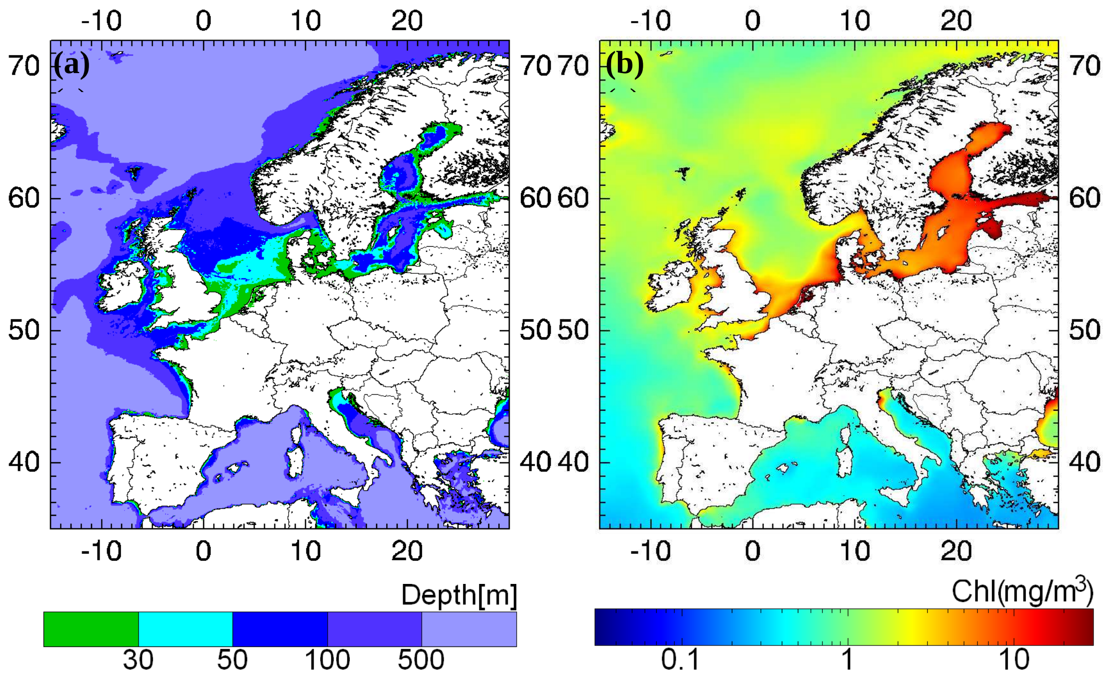

Figure 1. European waters: a bathymetry map (a) and a spatially smoothed 90 percentile Chl map based on 2005-2006 MERIS Chl (b)

DATA AND METHOD

Standard Chl products from MODIS (Moderate Resolution Imaging Spectroradiometer; http://modis.gsfc.nasa.gov) and MERIS (Medium Resolution Imaging Spectrometer; http://envisat.esa.int/instruments/meris) sensors are used in this study. In brief, the MODIS standard Chl product is designed for oceanic (case 1) waters. MERIS products include two Chl products - Chl1 and Chl2. Chl1 is considered appropriate for case 1 waters as is MODIS Chl, while Chl2 is designed for case 2 waters. Obviously, the case 1 water products (MODIS Chl and MERIS Chl1) may not be reliable in case 2 waters. More information on these products can be found in (Park et al, 2008) and references there in.

The Chl threshold used for AB detection was defined pixel by pixel as the 90 percentile based on recent years' (2005-2006) data. This relative definition of the threshold allows to deal with the large variability in Chl levels across the European waters. Setting this threshold by using satellite data from the same sensor as used for daily AB detection also has the advantage of mitigating the effect of systematic errors in satellite Chl caused by yellow substance or mineral particles. The 90 percentile map reveals small-scale spatial inhomogeneities due to the stochastic nature of algal blooms, which is undesirable as a threshold map. This small scale inhomogeneity was reduced by applying a spatial average with average box size proportional to the distance to coastal lines. The final threshold map for MERIS is shown in figure 1 (b). Daily Chl data are compared to the threshold, which produces a daily AB map.

This AB detection technique is applied to three years (2005-2007) of data. For each year, the AB timing (the first day an AB occurred) is determined.

RESULTS AND DISCUSSION

Chl time series in oceanic waters

Chl time series were extracted from daily satellite data for three oceanic waters – the southern Nowegian Sea , the Biscay Plain and the western Mediterranean Sea. The average values within a 5-by-5 degree box are shown in Figure 2. The PAR time series derived from SeaWiFS and the night time SST derived from MODIS are also shown.

In the northern Norwegian Sea (high latitudes, Fig.2(a)), the satellite Chl data is only available for mid-March to September due to lower sun elevations in winter. In this cold area (SST<10 °C, less than 5°C annual variation) the ecosystem is in a nutrient replete and light limited condition due to intensive vertical mixing and thus a deep mixed layer. The time-series shows that blooms may start as late as May when the water column becomes stabilized (Doney 2006) and the solar irradiation is strong enough (PAR is close to its highest level). Multiple Chl peaks during the May-September period indicate that nutrients are available in the euphotic zone. This high Chl during the summer distinguishes this area from other low-mid latitude areas.

In the Biscay Plain (temperate North East Atlantic Ocean, Fig. 2(b)), the satellite Chl data is available except for the December-January period. The spring bloom is detected in the beginning of April after winter mixing. SST remains close to it lowest level. As SST increases, the water column stratifies preventing the uptake of nutrients from the deeper layers and this results in decreased Chl. The lowest Chl corresponds to the highest SST, which indicates a nutrient limited ecosystem.

In the western Mediterranean Sea (subtropical, Fig. 2(c)), the satellite Chl data is available throughout the year. Bloom levels are reached in February when SST is at its lowest level or even earlier. Deep water convection (Bricaud et al. 2002) brings nutrients to euphotic depth. After the blooms in March-April, Chl decreases to its lowest in July-August, when strong stratification takes place. This summer Chl remains well below the AB threshold as compared to the two other locations, which indicates a strongly nutrient limited ecosystem. Afterwards, Chl gradually increases as SST decreases probably by increasing nutrient supply owing to a deepening of the mixed layer.

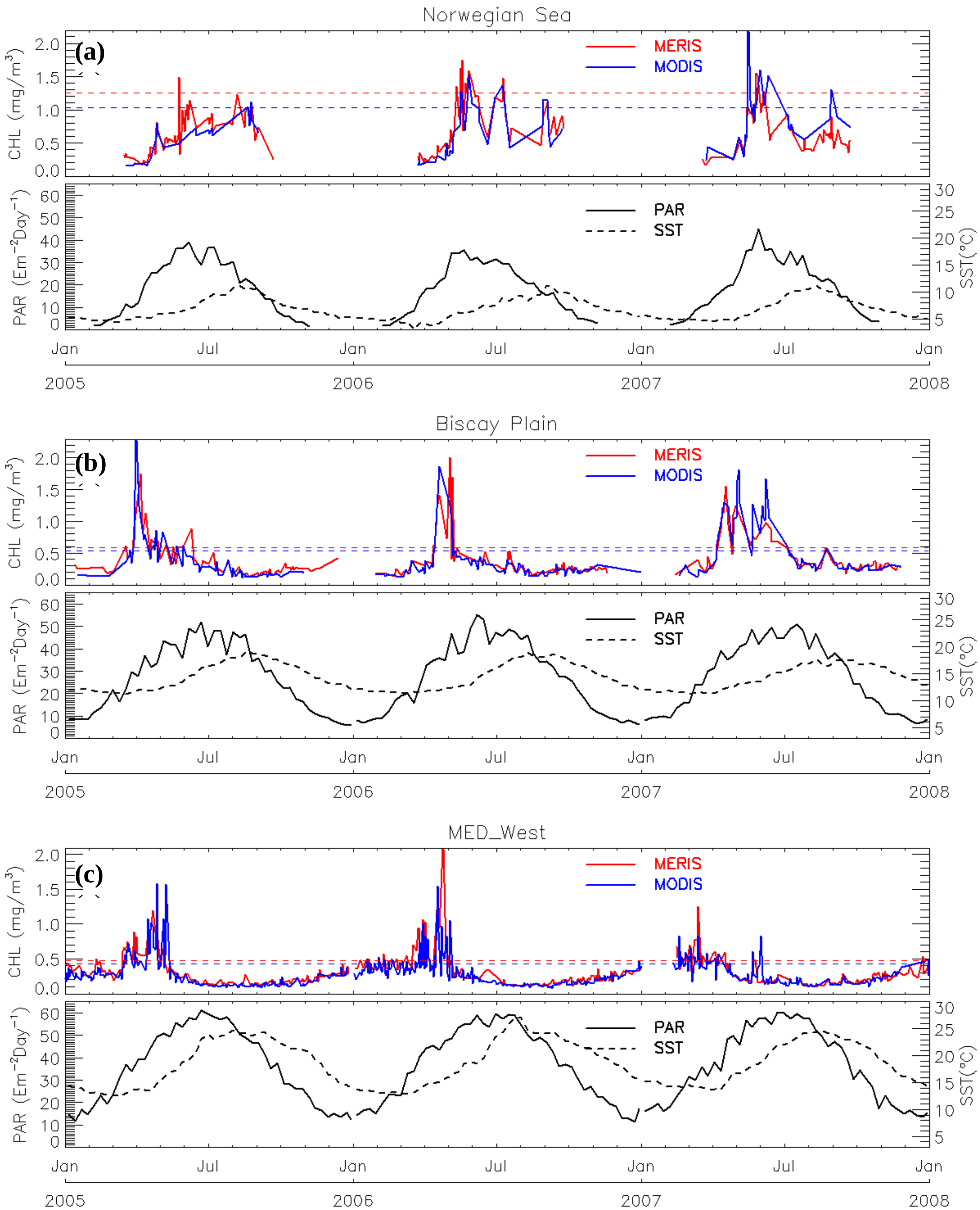

Figure 2. Chl time series in three different oceanic waters: northern Norwegian Sea (a), Biscay plain (b), and western Mediterranean Sea (c). The time data is the mean value over a 5°x5° box centred at (68°N,0°E), (47.5°N, 12.5°W) and (40°N, 5°E), respectively. The horizontal dashed lines indicate the AB threshold for MERIS (red) and MODIS (blue).PAR and SST are shown by solid and dashed black lines respectively.

Algal Bloom timing in European waters

Figure 3 shows the AB timing for the European waters as Julian day number, computed by the method described earlier. Despite inter-annual differences, it is seen that the spring bloom progresses from lower latitudes (Mediterranean Sea) toward higher latitudes (Nordic waters). This corresponds to the hypothesis that light is the limiting factor for algal growth since nutrients are available from deep water mixing during winter. Also blooms occur earlier in shallower coastal waters (North Sea: 53°N, 4°E) than in deeper waters (North of Ireland: 60°N, 10°W).

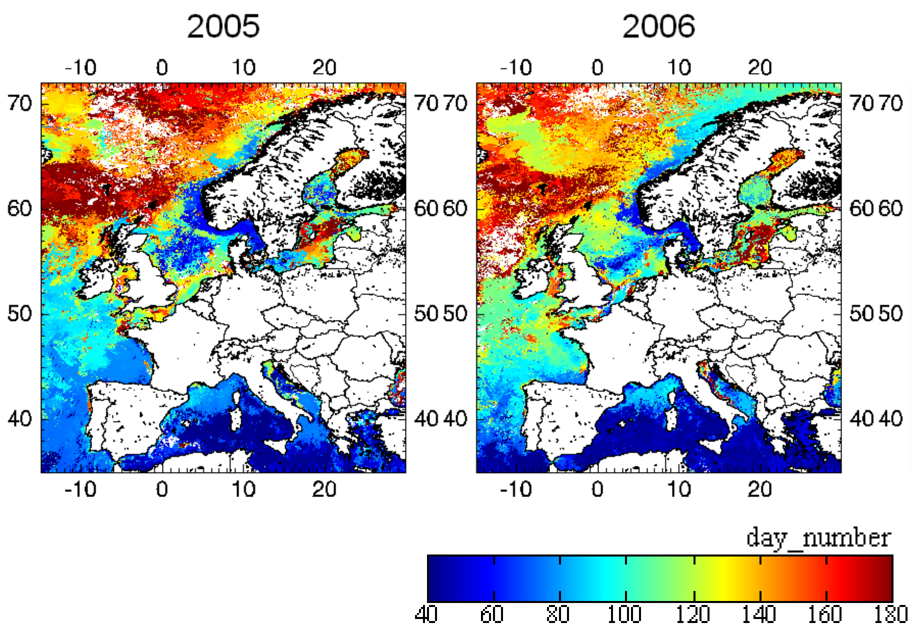

Figure 3. AB timing in European waters for 2005 (left), 2006(middle) and 2007 (right). White areas denote land and pixels where no bloom was detected in the year.

Algal bloom timing in the North Sea

Figure 4 shows the algal bloom timing map for the North Sea. Although some significant inter-annual variability is evident, the spring bloom occurs first (early March) in clear waters that may be either shallow (over the Dogger Bank (55°N, 3°E)) or stratified (along the Norwegian coast) and in the nutrient-rich waters of the Belgian and Dutch coasts (March/April). Later (April/May) blooms occurred in deeper clear water like the northern North Sea (58°N, 1°E) and in turbid waters such as the German Bight (54°N, 8°E), and East Anglia (53°N, 2°E). This also indicates the importance of light availability within the mixed layer for the spring bloom. Light is available within the mixed layer for clear shallow or stratified water columns, while it is not for deep mixed layer or turbid water columns.

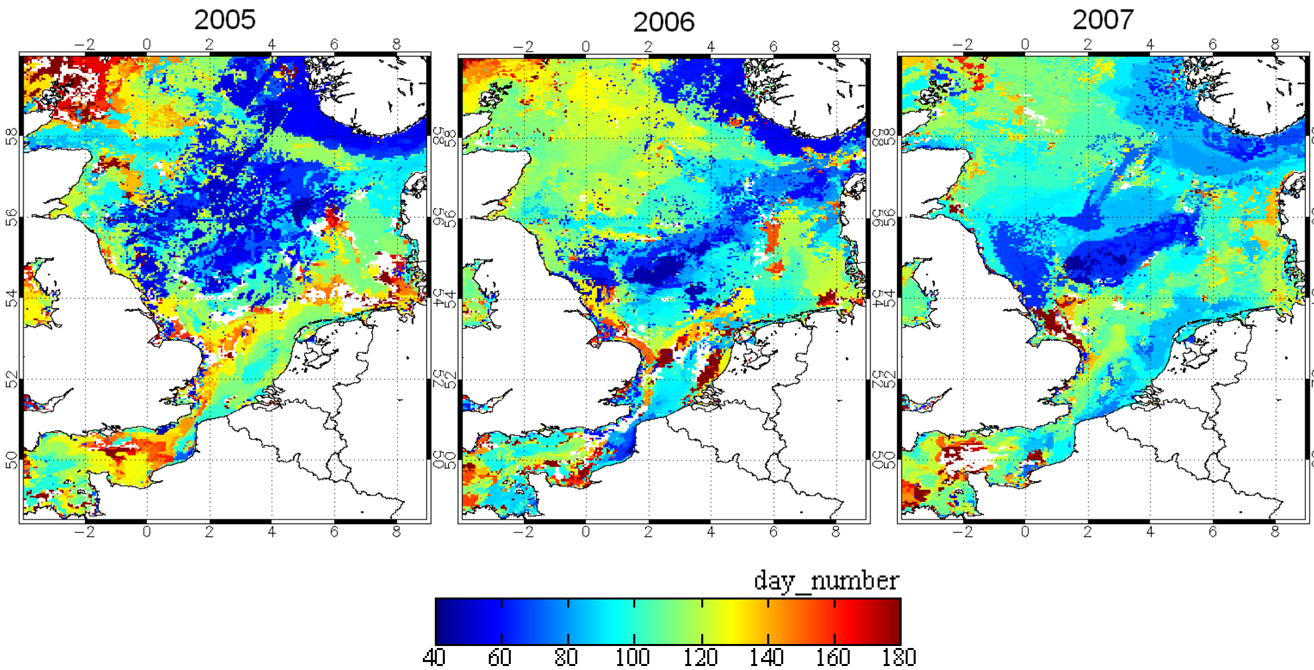

Figure 4. AB timing in North Sea waters for 2005 (left), 2006(middle) and 2007 (right). White areas denote land and pixels where no bloom was detected in the year.

CONCLUSIONS

This paper describes a first attempt at satellite based estimations of timing of spring algal blooms across most European coastal waters. The working definition of an algal bloom was determined through a Chl threshold defined pixel by pixel as the 90 percentile based on a recent years' (2005-2006) data. Analysis of the daily algal bloom image data shows an overall trend of blooms starting at lower latitudes and moving toward higher latitudes, likely reflecting light limited water columns in mid- and northern European waters. In the North Sea, earlier blooms are observed in clear shallow (or stratified) waters and later blooms are observed in turbid or oceanic deep waters. This provides large scale support for previous studies based on in situ measurements and indicating that light availability in mixed layers is likely to be a critical factor.

ACKNOWLEGEMENTS

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