A harmful algal bloom warning system for the North Sea: a combination of remote sensing and computer models for algal growth and bloom transport.

Hans J. van der Woerd, R. Pasterkamp, Institute for Environmental Studies,
Vrije Universiteit, De Boelelaan 1087, 1081HV Amsterdam, The Netherlands.
hans.van.der.woerd@ivm.vu.nl

A. Blauw, WL | Delft Hydraulics, P.O. Box 177, NL-2600 MH, Delft, The Netherlands

L. Peperzak, NIOZ, P.O. Box 59, NL-1790 AB Den Burg, The Netherlands

ABSTRACT

Phaeocystis globosa blooms in The Netherlands can cause damage to the ecosystem and commercial shellfish by producing benthic anoxia. In the past years the Dutch early warning system relied on samples from just one coastal station in which *P. globosa* cells were counted. In this paper the early detection and monitoring of growth and transport of these harmful algal blooms in Dutch coastal waters is investigated in hind cast for the year 2003. Turbidity and chlorophyll-a maps are derived from the MERIS satellite spectrometer with the HYDROPT algorithm. The chlorophyll-a maps are compared to in-situ measurements and the outcome of a coupled algal growth and transport model. The *Phaeocystis globosa* abundance and chlorophyll-a concentrations in 2003 observed by field monitoring were well reproduced by both the model and the MERIS remote sensing images. The system became operational in Spring 2006.

Key words: *Phaeocystis globosa*, harmful algal bloom (HAB), MERIS, North Sea

INTRODUCTION

In 2001, a massive bloom of the prymnesiophyte *Phaeocystis globosa* caused severe anoxia in a saline lake and large economic damage to the commercial shellfish industry in the south-eastern part of the North Sea. There is evidence that this Harmful Algal Bloom (HAB) originated in the Voordelta offshore and was being transported to near-shore where it had harmful effects (Peperzak, in preparation). Problems as encountered in 2001 could be prevented in the future by relocating mussel banks to waters less affected by high biomass blooms. However, to apply management options, the extension of such blooms, their development and their transport by coastal currents has to be known.

One obvious monitoring and early detection method of high biomass HABS is the use of satellite imagery, a technique that has been applied in a variety of blooms (see the review by Stumpf and Tomlinson, 2005). Optical detection of elevated chlorophyll-a levels by the new generation ocean colour imaging spectrometers (SeaWiFS, MODIS and MERIS) are becoming an integrated part of off-shore HAB detection (Stumpf *et al*., 2003). *P. globosa* blooms consist of millions of cells per litre, hence contain high amounts of chlorophyll-a, and should be detected by remote sensing. Indeed Tang *et al*. (2004) demonstrated that SeaWiFS is able to detect *P. globosa* in clear oceanic waters off the South-Eastern coast of Vietnam in 2002.

An important prerequisite for the application of *P. globosa* detection in the southern North Sea is the development of reliable retrieval algorithms for chlorophyll-a in these extreme case-2 waters. It is well known that algorithms developed for case-1 waters can greatly overestimate the chlorophyll-a concentrations in estuaries and deltas (D'Sa and Miller, 2005). Nowadays retrieval schemes exist to detect and quantify chlorophyll-a concentrations in turbid coastal waters such as the North Sea. Also more information becomes available on the inherent optical properties in coastal waters (Babin *et al*., 2003). Recently, data from the MERIS instrument onboard the ENVISAT satellite, which was launched in March 2002, has shown that validated maps of chlorophyll-a can be produced for a range of hydrographical areas in the North Sea (Peters *et al*., 2005).

Predictions on the transport of these blooms can be made in various ways, ranging from coarse predictions based on the expected averaged wind conditions, to sophisticated predictions using weather forecasts from meteorological models. Here we propose a novel method, combining remote sensing information with computer models to calculate both the development of the bloom and its transport to areas at risk. We assess the ability of the MERIS instrument to produce timely and accurate information of a HAB in the coastal areas of the southern North Sea. The outcome of a hindcast simulation for spring 2003 is presented when a major bloom of *P. globosa* has been observed in the Voordelta.

STUDY AREA DESCRIPTION

The southern North Sea is one of the most eutrophicated marine systems in the world. Large rivers such as the Rhine and Meuse and other smaller rivers discharge in a relatively shallow shelf sea, enclosed between the United Kingdom and continental Europe. Although the area is naturally rich in nutrients, eutrophication has increased considerably during the 20th century, due to anthropogenic inputs. Due to eutrophication, intensity and frequency of harmful algal blooms by *Phaeocystis* has increased (Cadee & Hegeman, 2002).

This study focuses on the southern part of the Dutch coastal zone near the province of Zeeland in The Netherlands (Fig. 1). This area is shown in more detail in Fig. 2. The Voordelta is a complex water system where many different water masses meet. The main fresh water and nutrient input in the area is via the Nieuwe Waterweg, with the harbour of Rotterdam (A) and via the Haringvliet (B), which discharge fresh water from the rivers Rhine and Meuse. The area is extremely complex in terms of inherent optical properties of the water constituents with large gradients in nutrients, sediment composition and dissolved organic matter. Reflection spectra are characterized by high values in the green part of the spectrum due to high sediment concentrations

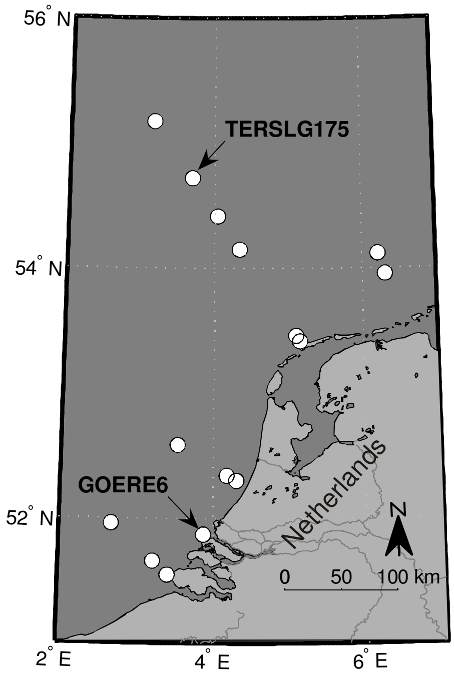

Figure 1. ***Overview of the Dutch coastal zone and the position of the monitoring stations of Rijkswaterstaat (White Dots).***

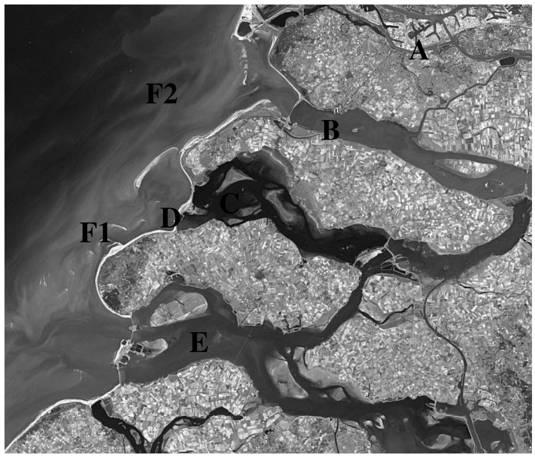

Figure 2. ***A grey-scale ASTER image of Zeeland on September 24, 2002***.

The algal bloom impact area is characterized by estuaries and lakes adjacent to the shallow North Sea with depths less 20 meters (Fig. 2.). The North Sea itself is usually well-mixed due to strong tidal currents. Saline lake Grevelingen (C) has a permanently stratified water column and is connected to the North Sea via a sluice in the Brouwersdam (D). The Oosterschelde estuary (E), an area of intense mussel cultivation, has well mixed tidal gullies. Because mussels are cultivated on the sea-bottom, the cultivation areas are located in sheltered areas, where water turbulence is reduced. The two points F1 (GOERE6) and F2 (WALCH2) indicate the position of in-situ measuring stations of Rijkswaterstaat.

DATA AND METHODS

The Dutch Ministry of Transport and Public Works has maintained a continuous monitoring programme since the 1970's measuring many chemical and biological variables on a large number of sampling locations in both fresh water and marine waters. Samples at the North Sea are taken along a set of transects, at several distances off the coast (e.g. 2, 5, 10, 20, 50, 70, 100 km) on approximately a monthly schedule (see Fig. 1). Measured variables include a.o. suspended matter, chlorophyll-a and phytoplankton species composition (www.waterbase.nl).

In addition a dedicated measurement campaign during the period April-May 2003 was carried out to collect samples for *Phaeocystis* cell counts up to 5 times a week at the entrance of Lake Grevelingen at the Brouwersdam (D in Fig. 2). Every Friday the results of the previous week became available. Occasionally also samples from the stations F1 and F2 and one station in the Oosterschelde (Wissenkerke) are available.

Remote sensing is a rich source of information on water quality in the North Sea. Yearly atlases of suspended particulate matter, based on SeaWiFS imagery, are available (Van der Woerd & Pasterkamp, 2004). More recently, the European project REVAMP (Peters *et al*., 2005) has shown that images from the MEdium Resolution Imaging Spectrometer Instrument (MERIS) can be validated with *in situ* measurements and can produce reliable maps of chlorophyll-a concentration for the North Sea. An average of 38 cloud-free and good-quality MERIS observations was available in the year 2003 for any position in the southern North Sea.

The MERIS observations were processed from L2 (IPF 4.07) with the HYDROPT inverse algorithm. This algorithm derives the chlorophyll concentrations by minimizing the difference between the observed and modeled (HYDROLIGHT) reflectance spectra (Pasterkamp & Van der Woerd, 2006). The HYDROLIGHT radiative transfer code (Mobley, 1994) predicts the observed remote sensing reflectance under any angle as a function of absorption and scattering within the water, taking into account the angular distribution of the down-welling radiance and the transmission function through the air-water interface. We have parameterised the model with a single optical model that performs optimal for the Dutch coastal zone (data can be found in Pasterkamp *et al*., 2006).

The inversion of this model is accomplished by a non-linear optimization scheme (Levenberg-Marquardt). The concentrations are found by fitting the modeled remote sensing reflectance spectrum to an observed reflectance spectrum, by altering the concentrations of chlorophyll-a, suspended particulate matter and absorption by colored dissolved organic matter (Garver & Siegel, 1997). Apart from the concentrations, the algorithm also calculates a normalized sum of the squared difference between modeled and observed MERIS reflectance in 8 optical bands (412 to 708 nm; the fluorescence band at 680.1 nm is excluded) and a standard error in the retrieved concentrations.

A southern North Sea model especially dedicated to simulate the dynamics of the Rhine river plume (GEM Generic Ecological Model) was used **(**Blauw and Los, submitted; De Kok *et al*., 2001; Gerritsen *et al.,* 2001).**)**. This model consists of modules that simulate phytoplankton dynamics and hydrodynamics. Nutrient cycles of nitrogen, phosphorus and silicate and phytoplankton dynamics are simulated in 3 steps: inorganic nutrients, nutrients in phytoplankton biomass and nutrients in dead organic matter. State variables for phytoplankton are 4 species groups: diatoms, flagellates, dinoflagellates and *Phaeocystis*, which have each been subdivided in 3 physiological states: energy limited, nitrogen limited and phosphorus limited. Competition between phytoplankton species is simulated by linear programming, which selects for the best-adapted (combination of) species depending on environmental conditions (Los & Brinkman, 1988).

Attenuation coefficients for light in the water column are determined as the sum of extinction by phytoplankton, particulate organic matter, humic substances and background attenuation. Transport of substances within the model and water temperature forcing are based on flow information from the hydrodynamic model. River nutrients inputs are based on daily observations of discharges and circa 2-weekly observations of concentrations near the river mouths (www.waterbase.nl). In this study the model was used in two modes: a full biogeochemical mode where the modelling started from January 2003 and a hydrodynamic mode where the transport of water masses (including elevated levels of algae) was simulated.

Recently a new method has been developed for approximation of spatial and temporal variability of suspended matter concentrations (Blauw *et al*., 2006, in prep.). A correlation between turbidity and averaged wind speed during the preceding week was used in combination with remote sensing data to construct a forcing function for suspended matter concentrations. Monthly composites of remote sensing data on total suspended matter concentrations observed by the MERIS satellite have been constructed, based on the HYDROPT algorithm. These monthly composites have been translated to the model grid and interpolated to create a spatial and seasonal pattern of suspended particular matter.

INTEGRATED MONITORING

In Fig. 3 the combination of information sources is shown. Before the presentation of the outcome of the hindcast simulation it is essential to test how these sources compare. In this section three aspects are covered: (a) The use of the chlorophyll-a pigments as a proxy for *P. globosa* cell concentrations and (b) the inter-comparison of chlorophyll-a measurements in the laboratory and those derived from MERIS and from the model.

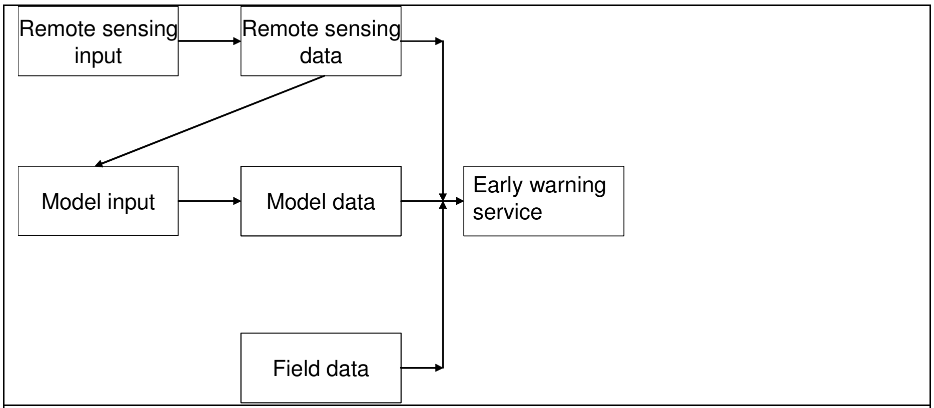

Figure 3. ***Schematic representation of the merging of information.***

The relation between *P. globosa* and Chlorophyll-a.
Remote sensing cannot (yet) discriminate between the occurrence of *P. globosa* and other algal species. Instead, it measures the chlorophyll-a concentration. Therefore, one of the key elements of the service is the relation between *P. globosa* cell counts and *in situ* HPLC-measured chlorophyll-*a* concentration in the Voordelta. In Fig. 4 the data from January-June 2003 from monitoring stations Walcheren 2, Walcheren 20 en Goeree6 have been collected. The lines are calculated chlorophyll-*a* values based on a carbon content of 1.2 pmol per *Phaeocystis* non-flagellated cell (Rousseau et al., 1990) and a carbon to chlorophyll-*a* ratio of 50 (full line) and 10 (thin line).

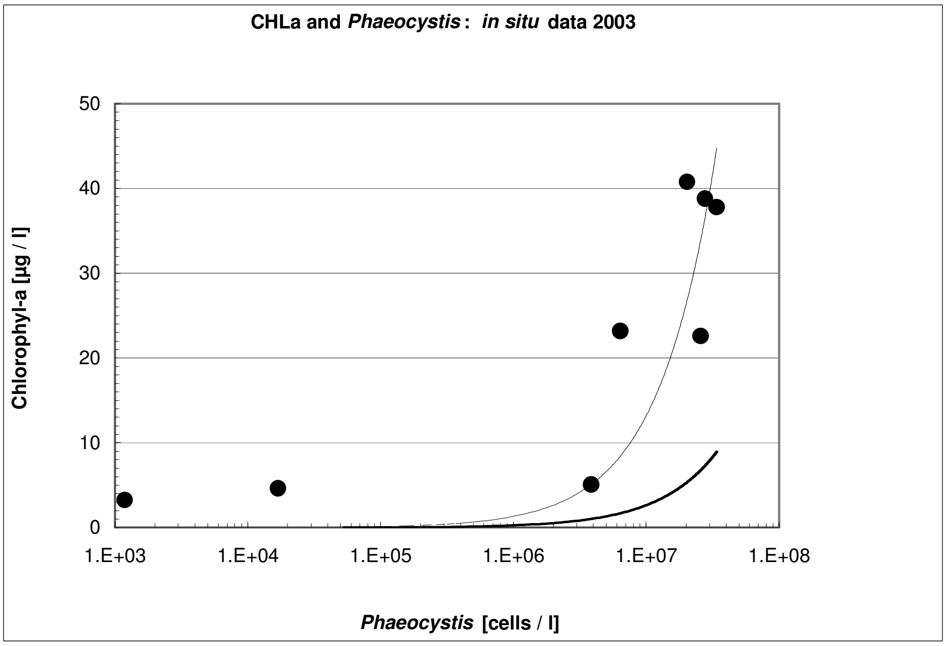

Figure 4. ***Relation between Phaeocystis globosa cell counts and in situ HPLC-measured chlorophyll-a concentration in the Voordelta.***

Note that *diatoms* characterize algal growth in the Dutch coastal zone in spring and summer with a bloom of the *prymnesiophyte P. globosa* in April-May (Peperzak, 2003, thesis). Because *P. globosa* is the main phytoplankton component in April-May blooms in Dutch coastal waters, the relationship is valid at extreme *P. globosa* concentrations, i.e. in a bloom period. If the *Phaeocystis*-bloom is defined as a cell concentration exceeding 10 million per litre, the equivalent definition for chlorophyll-*a* concentration is roughly 10 µg per litre. This suggests that chlorophyll-a can be interpreted in the following way:
If the chlorophyll-*a* concentration is between 10 and 20 µg per litre, the concentration is exceeding background levels and if *P. globosa* is present a bloom event is likely to take place. If the chlorophyll-*a* concentration is in excess of 20 µg per litre, the concentration is at bloom level.

Compatibility remote sensing and laboratory-derived chlorophyll-a.
Because of the rapidly changing conditions on the North Sea, remote sensing and in-situ measurements are only directly comparable when sampled within a small time window (~1 hour), unfortunately this is only rarely the case. In Fig. 5 the temporal distribution of chlorophyll-a measurement over the year for in situ and remote sensing is presented at station Goeree 6. Reflectance values in 8 bands were extracted from the MERIS level 2 imagery at the location of the monitoring station (nearest neighbour interpolation) and processed with the HYDROPT algorithm to give the chlorophyll-a concentration. Clearly the patterns are similar, showing a pronounced bloom in April-May and a hint of two more periods of elevated chlorophyll-a levels. Although presenting a consistent temporal behaviour over the year, the direct comparison of individual measurements is not possible, given the strong temporal variation on a time-scale of hours and days (McCandliss *et al.,* 2002).

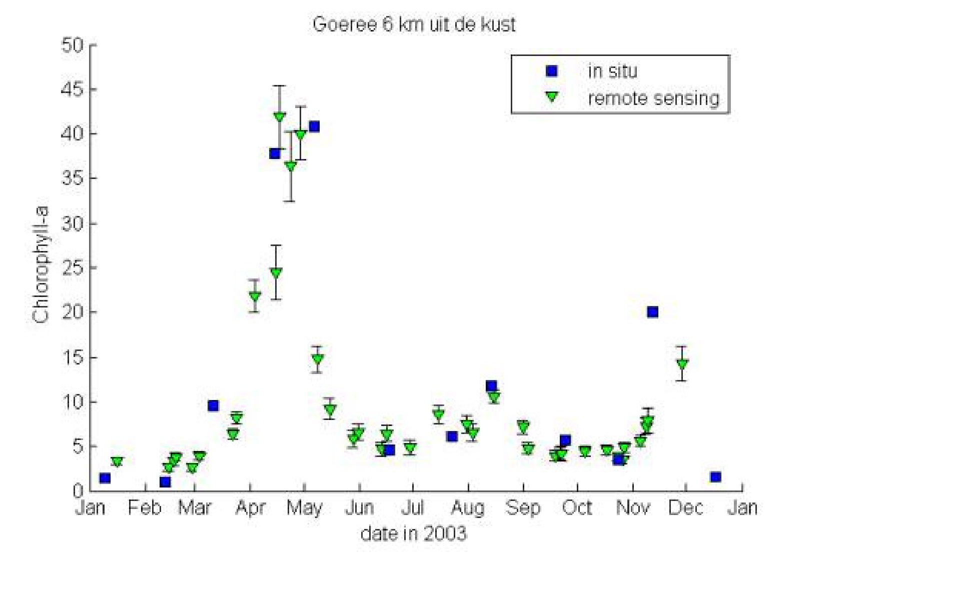

Figure 5. ***Time series of chlorophyll-a concentration (mg m^{-3}) in 2003 for in situ (blue squares) and remote sensing data (green triangles) at Goeree 6.***

Pasterkamp *et al*. (2006) have assessed the accuracy of the outcome of the algorithm by comparing MERIS data and *in situ* time series for 14 Dutch monitoring stations. The analyses of yearly geometric means for Dutch monitoring stations show that in-situ and MERIS derived chlorophyll-a values are highly correlated (correlation coefficient of 0.97). The relative root-mean square difference (RMS) between remote sensing and in-situ is 15%. Considering the fact that in spring time a positive discrimination must be made between a level of say 10 (± 2) and 20 (± 4) mg m^{-3}, the derived accuracy is sufficient for bloom detection.

RESULTS

Information on the spatial evolution of the algal biomass (expressed as chlorophyll-a concentrations of all species) is provided in Fig. 6 where the outcome of the phytoplankton model is depicted on 8 days in March and April 2003. It shows that a phytoplankton bloom develops first *within* the Oosterschelde estuary already in mid March. This can be related to the combination of smaller depth and lower turbidity, compared to the near coastal zone. The peak of the bloom in the Voordelta area is during the first 2 weeks of April. Note that all model results show a decline in biomass in the first week of April, a result that is reproduced in the Brouwersdam data (see below). All evidence suggests that the period between 10 and 20 of April is the maximum of the bloom in the near coastal zone outside the Brouwersdam. At 23 April the bloom is already declining.

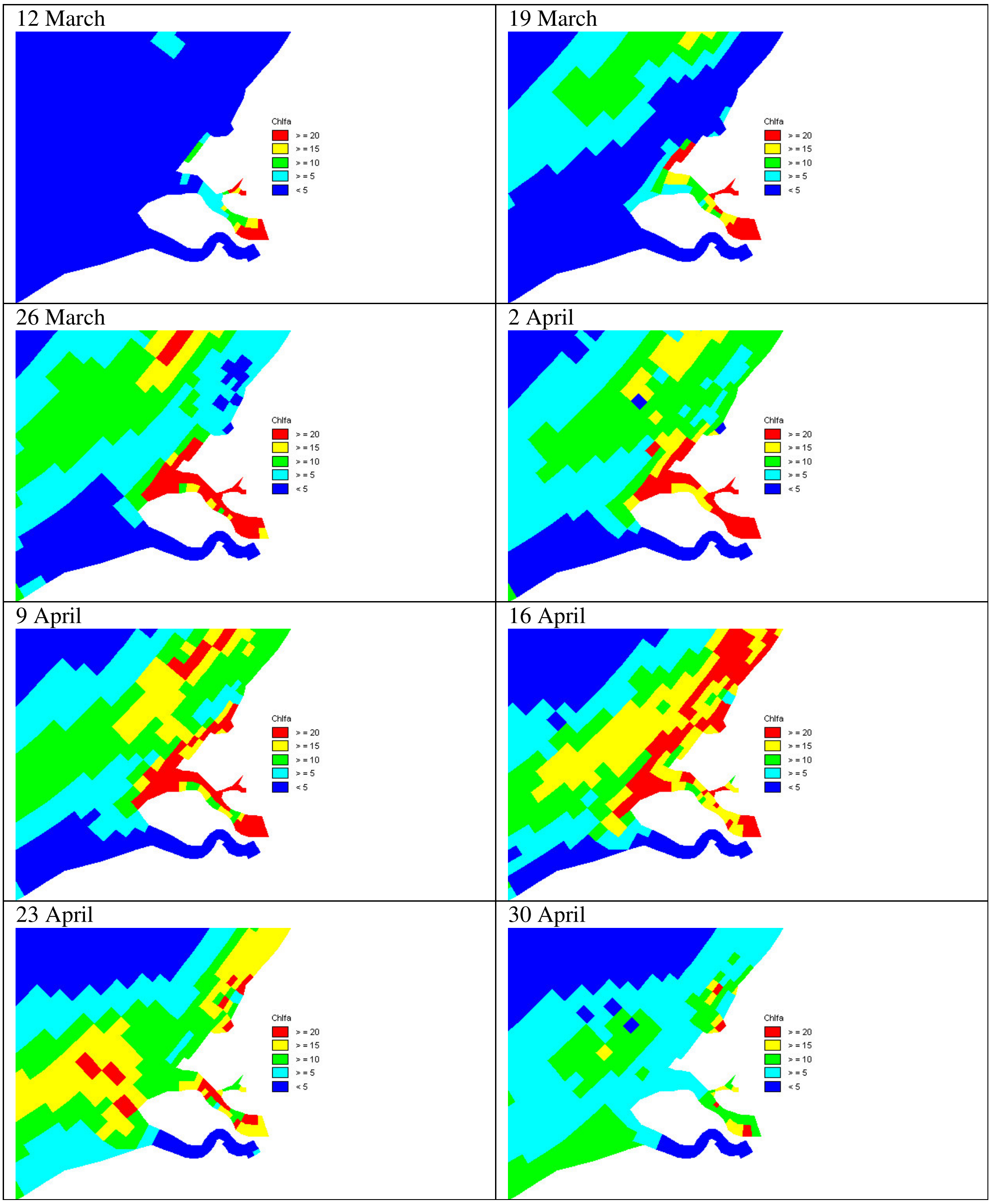

Figure 6. Bloom development and decay, expressed as chlorophyll-a levels simulated by the phytoplankton model.

The full set of MERIS images contain many clouded scenes and the Voordelta in particular is only six days fully covered in the bloom period. The most important images are shown in Fig. 7. On March 24th high CHL value are observed in the eastern part of the Oosterschelde.

Unfortunately, the next image is on April 13, when a bloom is already prominent close to the coast. The bloom appears to be reduced in the two May images.

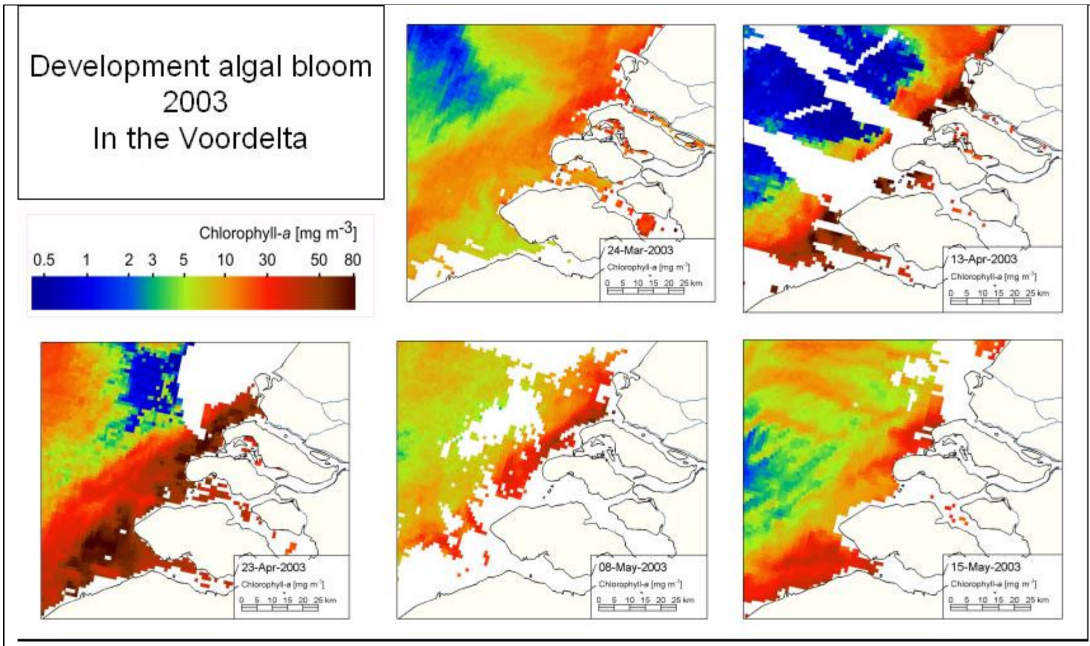

Figure 7. Development of an algal bloom in 2003. The best images for this region have been selected from the MERIS archive. White indicates land, clouds or bad data

The field data collected by Rijkswaterstaat at 5 stations, including Brouwersdam are used for the inter-comparison with remote sensing and model results. Figure 8 shows the field data on *Phaeocystis* concentrations in the Voordelta area. Chlorophyll-a concentrations above the 10 µg/l threshold are first observed in the Oosterschelde area at April 1st. *Phaeocystis* concentrations above the 10 million cells/L threshold are first observed in the Oosterschelde at April 15th. This demonstrates that early in the spring bloom (March, begin of April) the diatoms dominate the chlorophyll-a values measured by MERIS. The Brouwersdam measurements, taken with a flowcytometer, started at the last day of March. After April 11 the bloom critical level was exceeded. Apparently no measurements were taken in the weekend of 12, 13 April, such that the first positive detection of a HAB was at April 14, the same day that a remote sensing HAB detection would have confirmed the bloom in the whole coastal area. The *Phaeocystis* returned to sub-critical levels at the Brouwersdam (assuming a reference level of 10 million cells/L*)* in the beginning of May 2003.

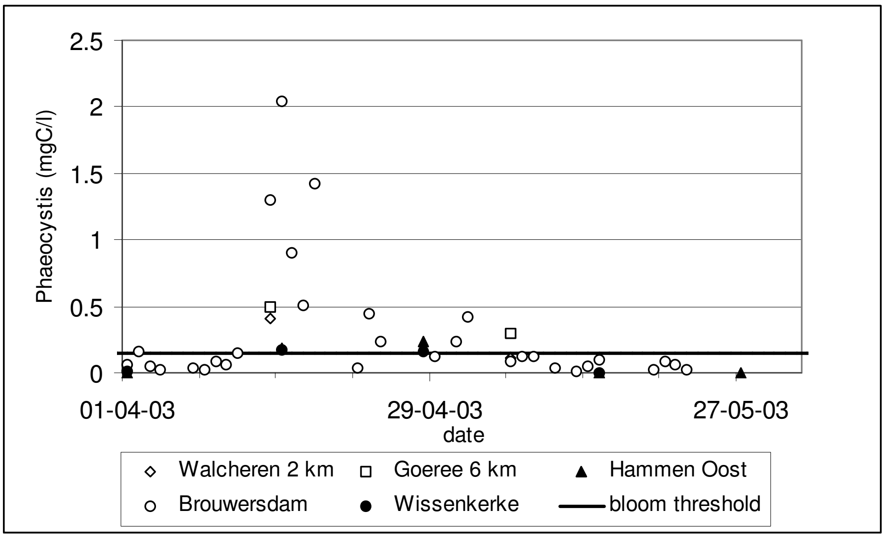

Figure 8 Field observations of Phaeocystis in spring 2003 at 5 locations in the Voordelta area.

DISCUSSION AND CONCLUSIONS

Since 1999 NOAA (US) has developed a system that provides information on the location and extent of *Karenia brevis* blooms in the Gulf of Mexico (Stumpf *et al.,* 2003 and Tomlinson *et* ***al.,*** 2004). In this study we have assessed if a comparable early warning system can be developed for the detection of coastal blooms of *P. globosa*. There is a need for such a system after the 2001 HAB event and the possible increase in HAB frequency due enhanced nutrient supply to the coastal zone in winter and spring as a result of changing climate conditions (Peperzak, 2003**).**

From the 2003 hind cast exercise it is clear that the remote sensing information has been severely restricted by clouds. Based on the MERIS data alone the early warning for elevated levels would have been issued on Monday April 14, the first processing day after a non-obscured observation of the area on April 13. Bloom levels (above 20 µg per litre) were confirmed at April 13 and April 15. However, the transition from background level (confirmed at March 24) to bloom has not been covered. There are at Goeree 6 a total of 6 reliable remote sensing measurements of the full bloom, compared to 2 *in-situ* data points. The decline of the bloom was well covered, going at Goeree 6 from 25 to 19 µg per litre in a period 6 days at the end of April.

No mussel mortality due to the 2003 algal blooms has been reported in the Oosterschelde, which makes it difficult to assess what would have been the correct day for the warning and whether a warning would have been appropriate at all. The local bloom in 2003 had a peak *Phaeocystis* biomass, observed in field data of 0.2 gC/m^3 only slightly lower than the values in 2001. It remains yet unclear why the bloom in 2001 caused mass mussel mortality and the bloom in 2003 did not, whereas observed *Phaeocystis* concentrations did not differ much. The criteria for “potentially harmful algal bloom” as a threshold of chlorophyll-a and *Phaeocystis* concentrations may need to be reconsidered (a bio-mass – toxicity/ anoxia paradox) to prevent false alarms.

In this study we have argued that a HAB early warning system in the Voordelta benefits most of an *integrated* use of in-situ and satellite data and results of bio-chemical modelling. MERIS observations can produce high-quality near-real-time chlorophyll maps, showing possible and actual HAB events. However, cloud cover severely restricted the capabilities of a warning system solely based on remote sensing data. Models, in theory, are capable of making predictions about HAB growth or movement for any time of day. However, ecological models for *P. globosa* are limited in their forecast capabilities (See however Breton *et al.,* 2006). In this study it was observed that the GEM model does give adequate description of the bloom transport, once it has been detected. The full biogeochemical model still remains too uncertain in its predictions if it is not tuned to observation regularly. Therefore the future reliable HAB warning system might require a GEM model with data-model assimilation.

In its present form, the three different information sources on the development of *P. globosa* blooms (in-situ, model and remote sensing) are used to describe and predict its transport in the southern North Sea. This early-warning system is to be tested by local water managers and shellfish growers for the years 2006-2008 in the MARCOAST project (**www.marcoast.org?).**

ACKNOWLEDGEMENTS

This project was partially financed by the Dutch User Support Programme under number GO-2003/82. We like to thank the EC for financial support in the FP5 programmes HABES and REVAMP. MERIS RR data for 2003 data were kindly provided by ESA (ESA Cat 1 proposal ID 1465).

REFERENCES

Babin,M., D.Stramski, G.M.Ferrari, H.Claustre, A.Bricaud, G.Obolensky & N.Hoepffner., 2003., Variations in the light absorption coefficients of phytoplankton, nonalgal particles, and dissolved organic matter in coastal waters around Europe. *Journal of Geophysical Research-Oceans*, Vol. 108, No. C7, p. 3211-3231.

Breton, E., Rousseau, V., Parent, J.Y., Ozer, J. & Lancelot, C., 2006. Hydroclimatic modulation of diatom/Phaeocystis blooms in nutrient-enriched Belgian coastal waters (North Sea). *Limnology and oceanography 51* (3): 1401-1409.

Cadee, G.C. & Hegeman J., 2002. Phytoplankton in the Marsdiep at the end of the 20th century; 30 years monitoring biomass, primary production, and Phaeocystis blooms. *J. Sea R.* 48 (2): 97-110.

De Kok, J. M., C. de Valk, J. H. Th. M. van Kester, E. de Goede & R. E. Uittenbogaard., 2001. Salinity and temperature stratification in the Rhine plume. *Estuar. Coast. Shelf Sci*. 53: 467-475.

D'Sa, E.J.& Miller, R.L., 2005. Bio-optical properties of coastal waters, in *Remote Sensing of Coastal Aquatic Environments*, R.L. Miller, C.E. del Castillo and B.A. McKee (eds.), Springer, Dordrecht, The Netherlands, ISBN 1-4020-3099-1, pp. 129-155.

Garver, S.A. & Siegel, D.A., 1997. Inherent optical property inversion of ocean color spectra and its biogeochemical interpretation. 1. Time seris from the Sargasso sea. *Journal of Geophysical Research-Oceans*. 102: 18607- 18625.

Gerritsen, H., J. G. Boon, T. van der Kaaij & R. J. Vos. 2001. Integrated modeling of Suspended Matter in the North Sea. *Estuar. Coast. Shelf Sci*. 53: 581-594.

Los, F. J.& J. J. Brinkman, 1988. Phytoplankton modelling by means of optimization: a 10-year experience with BLOOM II., Verhandlungen des Internationalen Vereinigung für theoretische und angewandte Limnologie 23: 790-795.

McCandliss, R.R., Jones S.E., Hearn, M., Latter,R. & Jago, C.F., 2002. Dynamics of suspended particles in coastal waters(southern North Sea) during a spring bloom, *J. Sea Res*., **47,** 285-302.

Mobley, C.D., 1994. Light and water; Radiative transfer in natural waters, Academic Press, London, 1994.

Pasterkamp, R. & Van der Woerd, H.J., 2006. Retrieval of chlorophyll-a from MERIS observations over coastal waters, *Remote. Sens. Env*. (submitted).

Pasterkamp, R., Van der Woerd, H.J. & Roberti, J.R, 2006. Validation of MERIS remote sensing products for the southern North Sea. *Remote. Sens. Env*. (submitted).

Peperzak L. 2003. Climate change and harmful algal blooms in the North Sea. *Acta Oecologica* 24, S139–S144.

Peters, S.W.M., M.A.Eleveld, R.Pasterkamp, H.J.van der Woerd, M.Devolder, S.Jans, Y.Park, K.G.Ruddick, T.Block, C.Brockmann, R.Doerffer, H.L.Kraseman, R. Röttgers, W.Schönfeld, P.V.Jørgensen, G.H.Tilstone, V. Martinez-Vicente, G.F.Moore, K.Sørensen, J. Høkedal, T.M. Johnsen, E.R. Lømsland & E.Aas, 2005. Atlas of Chlorophyll-a concentration for the North Sea based on MERIS imagery of 2003. ISBN 90-5192-026-1, Vrije Universiteit Amsterdam, The Netherlands.

Rousseau, V., S. Mathot & C. Lancelot, 1990. Conversion factors for the determination of *Phaeocystis sp.* Carbon biomass in the Southern Bight of the North Sea on the basis of microscopical observations., *Mar. Biol. 1*07: 305-314.

Stumpf,R.P., Culver,M.E., Tester,P.A., Tomlinson,M., Kirkpatrick,G.J., Pederson,B.A., Truby,E., Ransibrahmanakul,V. &Soracco,M., 2003, Monitoring Karenia brevis blooms in the Gulf of Mexico using satellite ocean color imagery and other data. *Harmful Algae*, 2, pp. 147-160.

Stumpf,R.P, & Tomlinson, M.C., 2005. Remote Sensing of Harmful Algal Blooms, in *Remote Sensing of Coastal Aquatic Environments,* R.L. Miller, C.E. del Castillo and B.A. McKee (eds), Springer, Dordrecht, The Netherlands, ISBN 1-4020-3099-1, pp. 277-296.

Tang, D.L., Kawamura, H., Doan-Nhu, H. & Takahashi, W., 2004. Remote sensing of a harmful algal bloom off the coast of southeastern Vietnam. *J. Geophysical Res*., **109**, C03014.

Tomlinson,M.C.; Stumpf,R.P.; Ransibrahmanakul,V.; Truby,E.W.; Kirkpatrick,G.J.; Pederson,B.A.; Vargo,G.A. & Heil,C.A., 2004. Evaluation of the use of SeaWiFS imagery for detecting Karenia brevis harmful algal blooms in the eastern Gulf of Mexico, *Rem. Sens. Environment*, 91, 293-303.

Van der Woerd, H.J. & Pasterkamp R., 2004. Mapping of the North sea turbid coastal waters using SeaWiFS data. *Can. J. Remote Sens*., **30**, 44-53.