UNIVERSITY OF AMSTERDAM

Monitoring and Prediction of Phytoplankton Dynamics in the North Sea

A.N. Blauw

Summary

The North Sea is a coastal shelf sea receiving water from many large rivers. Therefore the North Sea is rich in nutrients and phytoplankton. Phytoplankton forms the base of the marine food web and produces approximately 50% of total global primary production. Through the uptake of carbon dioxide for growth phytoplankton strongly affects the global climate. However, too high concentrations phytoplankton can also have negative impacts on ecosystems, such as oxygen depletion and shellfish mortality. To reduce negative impacts of algal blooms, countries bordering the North Sea agreed to reduce nutrient inputs from rivers with 50% compared to peak levels in 1985. They also agreed to regularly monitor concentrations of nutrients, phytoplankton and oxygen to check if eutrophication problems were reduced. Since then, measurements show a strong reduction of phosphate concentrations and a modest reduction of nitrate concentrations. A significant decrease of phytoplankton concentrations has not been observed. The absence of a significant trend may imply that nutrient reduction has not affected phytoplankton concentrations. Alternatively, phytoplankton concentrations may have decreased but this was not detected because the natural variability of phytoplankton concentrations masked this trend or because the monitoring frequency was too low to detect a significant trend.

During recent years, monitoring vessels of Rijkswaterstaat have collected water samples at fixed locations at sea to measure concentrations of phytoplankton and other variables. The monitoring frequency and the number of monitoring stations have been reduced in several phases to reduce costs. Yet, phytoplankton concentrations are strongly variable in space and time. Therefore, a high monitoring frequency at many locations is required to capture the natural variability of phytoplankton and detect trends. Novel automated monitoring methods are being developed that can acquire information on phytoplankton abundance at a high resolution in space and time, such as satellite remote sensing, moorings and automated measurements from ferries. The resulting high-resolution data sets enable characterization of phytoplankton variability at different time scales and identification of the mechanisms driving phytoplankton variability.

In this thesis phytoplankton variability in the North Sea is investigated with a range of traditional and novel monitoring methods. We characterized the variability in space and time and analysed the drivers of this variability at different time scales with various methods for data analysis and modeling. In this way we gained experience with the analysis and interpretation of data from automated monitoring methods. Our results demonstrate the potential power of these novel techniques, providing a much improved understanding of population fluctuations at several different time scales. Based on this understanding appropriate monitoring strategies can be designed to assess the response of phytoplankton to changes in nutrient inputs and global climate change.

Phytoplankton requires nutrients and light to maintain growth. Based on the availability of nutrients and light and current patterns we could reproduce observed spatial and seasonal patterns of phytoplankton in the southern North Sea with the Generic Ecological Model (GEM). Algal blooms of the species *Phaeocystis* can cause large economic losses for mussel farmers in the Eastern Scheldt and foam accumulation on beaches. We tested the feasibility of an early-warning system for *Phaeocystis* blooms in the Eastern Scheldt area combining satellite remote sensing, field measurements and the GEM model. For this purpose, we checked to what extent information on total phytoplankton and *Phaeocystis* in spring 2003 agreed between these different data sources.

The bloom period of total phytoplankton was similar in the different data sources. Available field data for *Phaeocystis* had too low temporal and spatial resolution to assess if model results for *Phaeocystis* and satellite data of chlorophyll were a good approximation of actual *Phaeocystis* concentrations.

As alternative approach to predict nuisance *Phaeocystis* bloom events we developed a fuzzy logic model. Fuzzy logic models use knowledge rules based on patterns in observed data and understanding of relevant processes. With this model the initiation of *Phaeocystis* blooms in Dutch coastal waters could be reproduced. Differences in long-term averaged *Phaeocystis* concentrations between stations were strongly associated with differences in local nutrient concentrations. Interannual variation in *Phaeocystis* concentrations could not be reliably assessed with the available data series, due to the low sampling frequency of once or twice per month. Video images of the beach with ARGUS camera's from a light house provided information on foam presence on the beach with an hourly resolution. These data showed a strong dependence of foam accumulation on wind conditions: foam was only visible during moderate to strong landward winds. Within the European research project HABES (Harmful Algal Blooms Expert Systems) similar fuzzy logic models have been developed for the 5 dominant harmful algal species in 5 marine areas throughout Europe. This showed that fuzzy logic models offer a good approach to synthesize all available knowledge about specific harmful algal blooms and use it for predictions. The approach enables to include all known aspects of bloom formation, even if not all underlying processes are understood in detail.

In the previous analyses the temporal resolution of observed data was often limiting a good assessment of phytoplankton variability. Automated moorings can provide data series with high temporal resolution. We analysed the data of four mooring stations in the North Sea to assess the extent and the drivers of phytoplankton variability. In coastal waters near the Thames estuary the tidal cycle was the dominant driver of short-term phytoplankton variability. Phytoplankton fluctuations showed strong 6-hour periodicity in phase with fluctuations in tidal current speeds, 12-hour periodicity in phase with ebb and flood and 15-day periodicity in phase with the spring-neap tidal cycle. This suggests that phytoplankton not only moves back and forth with the tide (with a 12-hour periodicity) but also sinks during decreasing tidal currents and mixes back to the surface at increasing tidal currents (with a 6-hour and 15-day periodicity); as if they dance with the tide. In deeper waters in the central North Sea, the tide had little impact on phytoplankton. Phytoplankton fluctuations in this area were predominantly controlled by vertical mixing and sinking induced by fluctuations in wind and solar irradiance. In Dutch coastal waters phytoplankton fluctuations were strongly associated with fluctuations in salinity due to the influence of fresh water from the river Rhine. At all four moorings sinking and mixing of phytoplankton particles appeared to be a dominant driver of fluctuations in phytoplankton concentrations.

The analyses in this thesis have shown that data series of high temporal resolution are required to detect changes in phytoplankton concentrations and underlying mechanisms. For accurate assessment of interannual variability in phytoplankton concentrations a sampling frequency of once or twice per week seems to be sufficient. To detect relations between phytoplankton change and environmental conditions an hourly to daily sampling frequency is required. Novel automated monitoring methods such as satellite remote sensing, moorings and sensors on board of ferries enable data acquisition at such high resolution.