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Numerical modelling of phytoplankton biomass in coastal waters

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Abstract

This paper introduces an effective tool for monitoring phytoplankton in open waters. In this study, phytoplankton is the principal component together with salinity and temperature for describing the water dynamics in the Danish marine waters. A major obstacle for accurate monitoring of phytoplankton (chl-*a*) is the very dynamic nature of phytoplankton and the water masses encompassing the algae. This can be overcome by combining the very coarse temporal resolution data from the traditional monitoring programme to validate hydrodynamic modelling together with remote sensing.

DHI Water and Environment's 3D modelling tool MIKE 3, which is a dynamical ecological model, has been applied to the Danish marine waters covering the Baltic sea through the inner Danish straits and extended to the North Sea. MIKE 3 is a commercially available software system that has been used in a wide variety of applications concerning 3D studies of hydrodynamics in the marine environment. MIKE 3 is an operational system with quick, less expensive and easily accessible assessments of the state and development in phytoplankton with appropriate scaling of resolutions. The paper concludes that a combination of traditional monitoring with ship, dynamical modelling of hydrodynamics and eutrophication in combination with remote sensing of chl-*a* concentrations of surface waters offers the ideal tools to enhance the temporal and spatial description of large water bodies. The results presented cover the period January to September 1999. The 3D model is verified and calibrated using in situ measurements from various monitoring stations in the Danish marine waters and validated against satellite images from SeaWiFS. The data basis for this study has been two national programmes both related to the monitoring of the coastal environment.

1. Introduction

The purpose of the present paper is to introduce an accurate tool for monitoring phytoplankton biomass in marine waters. The tool combines in situ data from the traditional monitoring system with numerical modelling and remotely sensed images

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of chl-*a*. Two operational approaches to monitor phytoplankton biomass distribution in open waters are presented, exemplified by a study concerning the seasonal development of phytoplankton in Danish marine waters.

Phytoplankton is a key component of the marine ecosystem using sunlight as energy supplier transforming inorganic nutrients into organic compounds, thus constituting the nutritional basis for all "higher" organisms in the food-web. Thus, phytoplankton is a principal component of monitoring programs for larger water bodies. However, a major obstacle for an accurate monitoring is the very dynamic nature of phytoplankton and the water masses encompassing the algae. Traditional monitoring is based on sampling at fixed stations visited by ship on a monthly, biweekly or weekly basis. Therefore, these data have a very coarse temporal resolution and a disadvantageous spatial limitation (Pickard and Emery, 1990; Lund-Hansen et al., 1994) considering the fact that the times-scale for phytoplankton dynamics is days. This scale is based on the hydrodynamic circulation and the different properties of the two water bodies mixing in the area (North Sea and Baltic Sea). Another inadequacy with respect to using the data for modelling is the time lag in accessibility of data due to the processing time from sampling time until data are available for the scientific and public communities. Finally, in situ measurements are rather expensive, and therefore, only relatively few measurements are carried out during the year compared to the large variation over time.

Thus, there is an increasing demand for operational systems that provide quick, inexpensive and easily accessible assessments of the state and development in phytoplankton abundance and composition as a supplement to the traditional monitoring. One step towards this is data acquisition through automatic buoy systems communicating directly to databases. This results in great improvements in the temporal scale of chl-*a* concentrations, but still leaves shortness in the description of the spatial distribution of the phytoplankton. The contribution of hydrodynamic modelling and remote sensing therefore holds a potential to enhance the temporal and spatial description of chl-*a* concentrations.

Hydrodynamic models favour the description of large water bodies with a relatively high spatial resolution and a high resolution in time (Aikman et al., 1996; Cañizares et al., 2001; Edelvang et al., 2001). The presented paper demonstrates that numerical models can reproduce ecosystem characteristics (concentrations and seasonal patterns of key elements) to a high standard. Remote sensing is becoming a more workable approach for the monitoring of marine waters as new satellites are currently launched and the temporal coverage by existing launched instruments is constantly improved. In the present study, data are obtained from the SeaWiFS instrument of (chl-*a*).

The aim of this study is to test the applicability of a 3D dynamic ecological model and to investigate the congruency between the chl-*a* concentrations and patterns obtained by model simulations and satellite images. The results presented cover the period from January to September 1999. The 3D model is verified and calibrated using in situ measurements from various monitoring stations in the Danish marine waters and validated against satellite images from SeaWiFS.

2. Study area

The study area includes the entire Baltic Sea, a large part of the North Sea and the interconnecting seas. The main focus is on the interconnecting seas, i.e., the Danish coastal waters. The hydrography of the Danish coastal waters is very dynamic, rather complex and greatly influenced by its location in the transition zone between two large water bodies: the brackish Baltic Sea (salinity ≅ 8) and the saline North Sea (salinity ≅ 34).

The Baltic Sea is connected to the North Sea through a complex of passages leading to Kattegat, Skagerrak and finally the North Sea (see Fig. 1). The controlling passages between the southern Baltic Sea and Kattegat are divided into three straits, the Sound (discharging about ~25% of the total water flow), the Great Belt (~65%) and the Little Belt (~10%) (Jakobsen and Ottavi, 1997). The freshwater inflow from the different rivers in the Baltic Sea results in a net outflow through the Danish Straits of approximately 15,000 m^3/s (Skogen et al., 1998; Edelvang et al., 2002). The outflow forms a permanent current, the Baltic Current (BC), along the west coast of