Synergy of Remote Sensing and Numerical Modelling for Suspended Matter Transport Monitoring

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Monitoring and modelling of suspended particulate matter (SPM) is an important task especially in coastal environments. SPM concentration is one of the major parameters that regulates the penetration of light into the ocean and hence the primary production.

In the past several SPM models have been developed for the North Sea. However, due to waves in shallow water and strong tidal currents in the southern part of the North Sea, this is a challenging task. In general there is a lack of measurements to determine appropriate exchange coefficients.

In many satellite borne ocean colour images of the North Sea a plume is visible, which is caused by the scattering at SPM in the upper ocean layer. The intensity and length of the plume depends on the wave and current climate. It is well known that the SPM plume is especially obvious shortly after strong storm events.

In this paper a SPM transport model is presented using the synergy of satellite borne ocean colour data and numerical modeling to derive the vertical exchange coefficients due to currents and waves. This results in a model that for the first time is able to reproduce the temporal and spatial evolution of the plume intensity.

The SPM model is a quasi 3d model which consists of 3 components: ocean dynamics, SPM vertical exchange and SPM exchange processes with the sea bed. The component for vertical exchange of SPM considers sedimentation and resuspension. The SPM exchange processes with the sea bed take into account erosion, bioturbation by benthos as well as diffusion in the bottom layers.

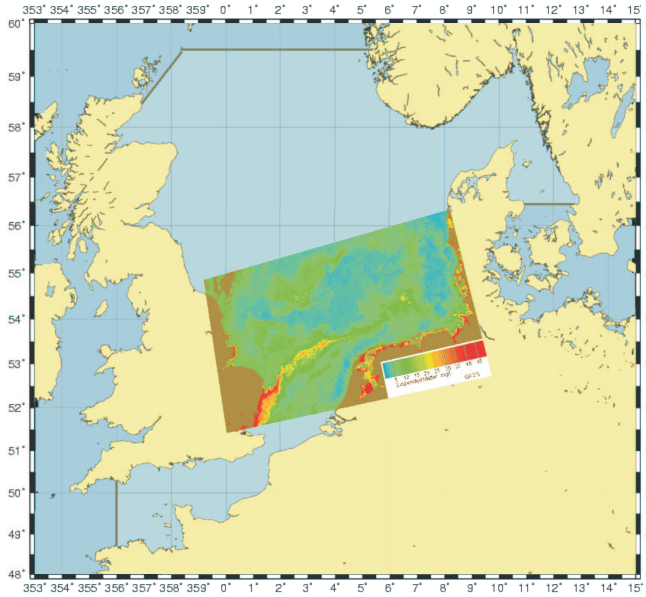

Fig. 1. SPM transport model area. Superimposed is the SPM surface concentration from a Coastal Zone Colour Scanner (CZCS) image.

I. Introduction

Similar to the approach followed by Puls et al. [1] the SPM model consists of 3 blocks: ocean dynamics, SPM vertical exchange and SPM exchange processes with a 4 layered sea bed.

Major changes were made in the model part of vertical exchange of SPM utilizing the synergy of ocean color data and SPM modeling to derive the vertical exchange coefficients.

Surface SPM concentrations derived from the ocean color data (Fig. 1) and mean SPM concentrations calculated by the model lead to new functions for the exchange coefficients. It is shown that the plume calculated with the new model agrees very well with the plume visible in ocean color images.

II. Model set-up

The ocean dynamics in the North Sea are computed on a grid with a spatial resolution of 3 nautical miles using a 2d set-up of the current model TRIM [2], which is driven with wind fields from the German Weather Service (DWD) and 16 fundamental modes of the tide signal at the open boundaries, the English Channel and the North Atlantic.

The wave fields are computed by the Bundesanstalt für Seeschiffahrt und Hydrographie (BSH) using the hybrid parametrical shallow water model HYPAS [3] at a resolution of 30 km every 6 h. To adjust the wave fields to the SPM model grid and water depths they were scaled with the Kitaigorodskii-factor [4] which describes energy dissipation in shallow water due to turbulent diffusion.

The SPM model component considers SPM which has a grain size of $< 20\mu$m and is divided up into 3 fractions according to the settling velocities. It takes into account sedimentation and resuspension in dependency of local shear velocities due to currents and waves.

Exchange processes with the seabed consider erosion, bioturbation by benthos as well as diffusion in the bottom layers (Fig. 2).

Sources of SPM are: rivers, open boundaries, sea bottom and the origin of the plume, the cliffs of Suffolk, Norfolk and Holderness. Erosion at the cliffs is taken into account using the yearly mean erosion rates estimated by Puls et al. [1] and the statistics of significant wave heights Hs in the years 1993-1995. Constant factors were estimated for storms (Hs $\geq$ 2 m) and calm conditions (Hs $<$ 2 m) to distribute the yearly erosion in dependence on significant wave height. Although this is a

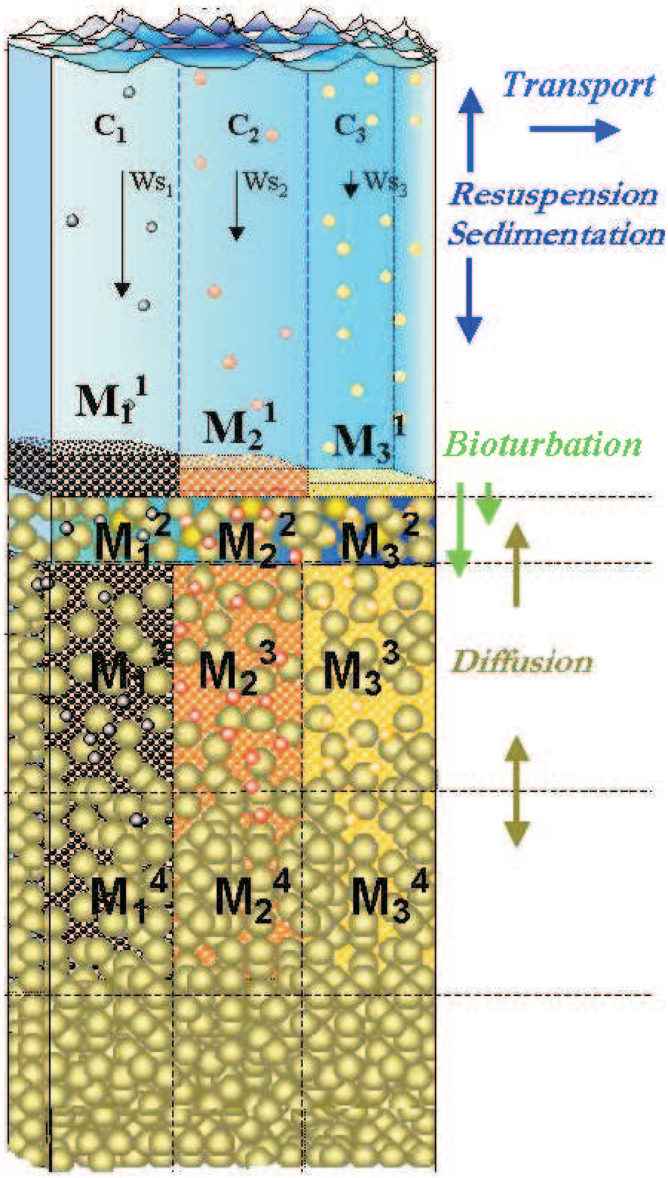

Fig. 2. Scheme of vertical exchange processes of SPM in the water column and bottom layers.

rather crude method the model results improved considerably compared to using yearly means of erosion rates.

A prerequisite of the success of the model is a careful adjustment of the bathymetry. Sandbanks are of great importance having a strong influence on the local current and wave fields which determine sedimentation and erosion rates as well as vertical exchange coefficients of SPM.

III. Estimation of vertical exchange of SPM.

The vertical concentration profile of SPM in the SPM model is derived according to:

$$C(z) = C_{\text{sur}} \exp \frac{w_s z}{A_v} \tag{1}$$

where C_{sur} is the surface SPM concentration, w_s settling velocity of SPM, A_v vertical exchange coefficient due to currents and waves ($A_v = A_v^{\text{cur}} + A_v^{\text{wav}}$) and z the vertical coordinate. The mean SPM concentration is defined as,

$$\bar{C} = \frac{1}{h} \int_0^h C(z) dz \tag{2}$$

where h is the water depth. Replacing $C(z)$ in (2) by (1) and solving the integral results in:

$$\bar{C} = \frac{C_{\text{sur}}}{h} \frac{A_v}{w_s} \left(\exp\left(\frac{w_s h}{A_v}\right) - 1 \right) \tag{3}$$

Assuming no vertical exchange due to waves the vertical exchange coefficient due to currents can be estimated from (3).

The surface SPM concentration C_{sur} is taken from ocean colour data of the Coastal Zone Colour Scanner (CZCS) [5] and from the Modular Optoelectronic Scanner (MOS) [6], and the mean SPM concentration from calculations of the SPM transport model.

Then the vertical exchange coefficient due to currents and representative for calm weather conditions results in:

$$A_v^{\text{cur}} = 0.16 u_* \frac{h}{z_0} u_*^{\left(\frac{h}{z_0}-1\right)} \exp\left(\frac{h}{z_0}\left(\ln\left(\frac{h}{z_0}\right) + 1.303\right)\right) \tag{4}$$

where U_* is the shear velocity due to currents and $z_0 = 0.1h$ is the roughness length of sandbanks.

In the same manner the vertical exchange coefficient due to waves is estimated by considering ocean colour images and the SPM model after a strong storm event:

$$A_v^{\text{wav}} = T U_{\text{wav}}^2 \tag{5}$$

where $T = 0.01$ s and U_{wav} is the average orbital wave velocity.

IV. Results

A comparison of SPM concentration at the ocean surface retrieved from the SPM model (using the vertical exchange coefficient formulas (4) and (5)) and MOS data of a different scene (not used for calibration) is shown in Fig. 3.

This is the typical situation after a strong storm in the German Bight in the North Sea. It can be seen that the SPM plume visible in the MOS data can be represented in intensity, space and time by the SPM model. In this particular case the significant wave height in the deeper parts ($\sim$ 30 m) of the German Bight was 5-6 m. The main contribution of SPM in the plume has its origin in the bottom deposits, which were resuspended during the storm by the high sea state.

V. Conclusion and Outlook

For the first time a numerical SPM transport model is capable to reproduce the plume in the North Sea correctly in intensity, space and time. This was achieved by improvement of

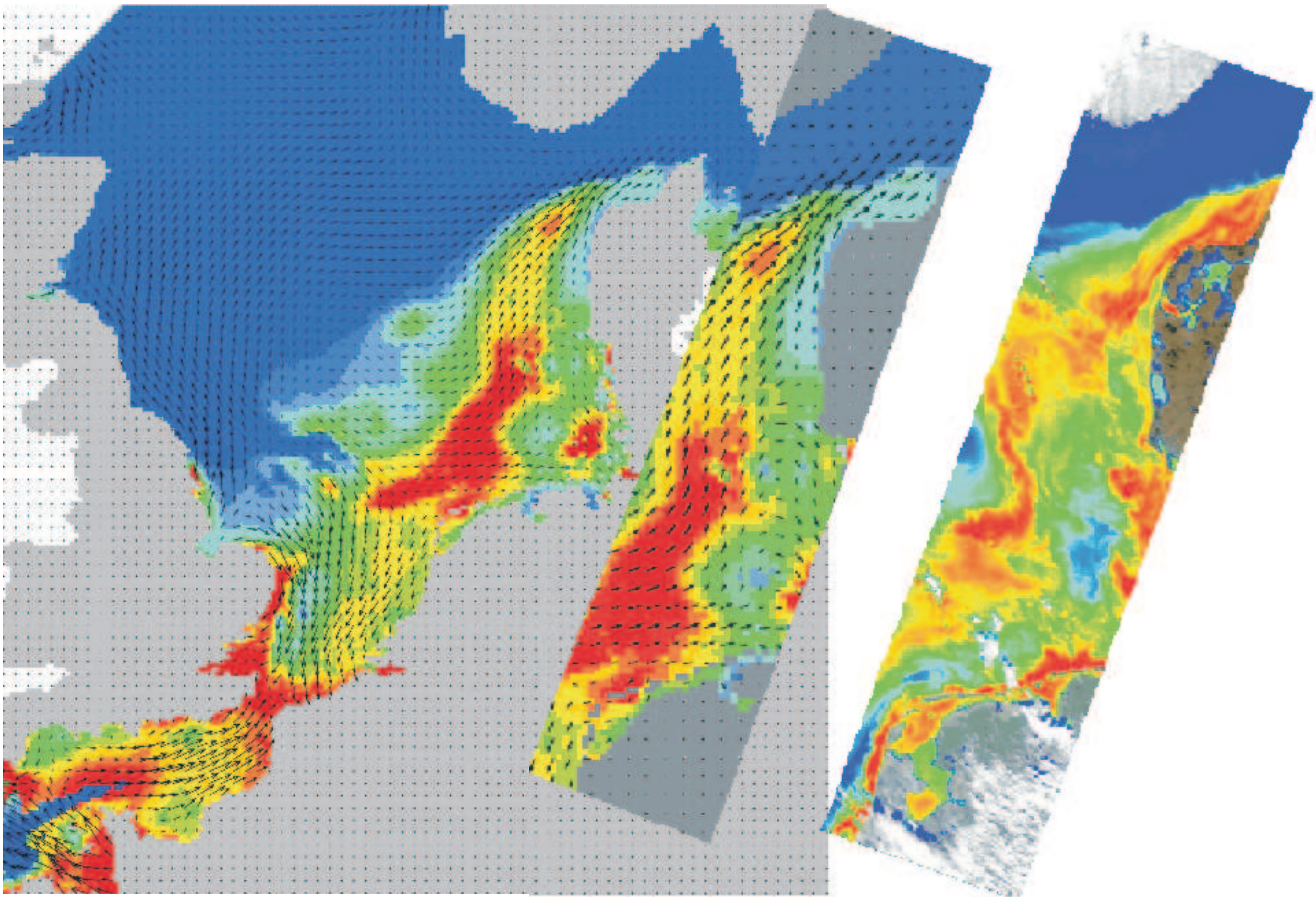

Fig. 3. Comparison of SPM surface concentration. Left: SPM model results. Right: results provided by the German space agency [6] as derived from a MOS image.

bathymetry (incorporation of sandbanks and other sometimes subscale features), dependency of cliff erosion on significant wave height and the vertical exchange due to waves and currents.

The vertical exchange coefficients were estimated using the synergy between ocean colour data and the numerical SPM model.

The SPM model component will be incorporated into the hydrodynamical routine 3d model of the BSH. Furthermore it is planned to extend the model to primary production calculation.

Acknowledgments

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