ECOTIM – ECOLOGICAL TIDAL MODEL

C. Kohlmeier

Introduction

ECOTIM is a complex ecosystem model which dynamically simulates the cycling of organic carbon, oxygen and the nutrients N, P and Si within the backbarrier system of the East Frisian island of Spiekeroog. The model has the capability to resolve the seasonal cycles as well as tidal processes. It consists of several interlinked modules describing the pelagic and benthic foodweb, the microbial loop including the distribution of detritus. The description of the biochemical and ecological processes is based mainly on ERSEM (BARETTA-BEKKER, 1995; BARETTA-BEKKER & BARETTA; 1997). The transport processes are described in an innovative way. A coupled transport model was developed where a Lagrangian description of the water movement in the pelagic part is linked to an Eulerian consideration of different benthic areas. The model is driven by the COCOA model (LENHART *et al*., 1997) at the North Sea boundary and forced by light and temperature.

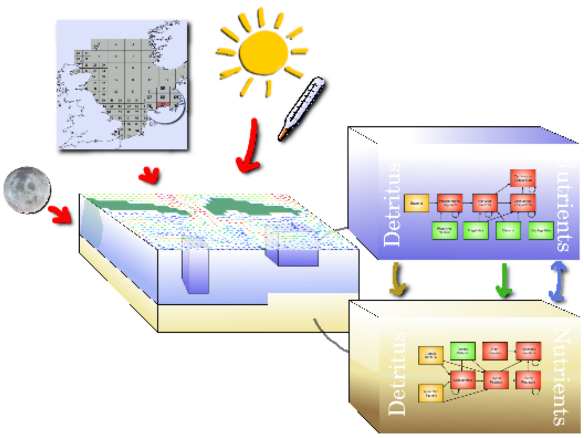

Fig. 1. The concept of ECOTIM: Lagrangian water bodies move along a surface velocity field. The whole ecosystem model is calculated in each water body. The water bodies interact with the benthic system below their actual position. The area of interaction with the benthic system depends on the tide. The boundary conditions are given by the North Sea model COCOA. The physical forcing is given by time series for light and water temperature.

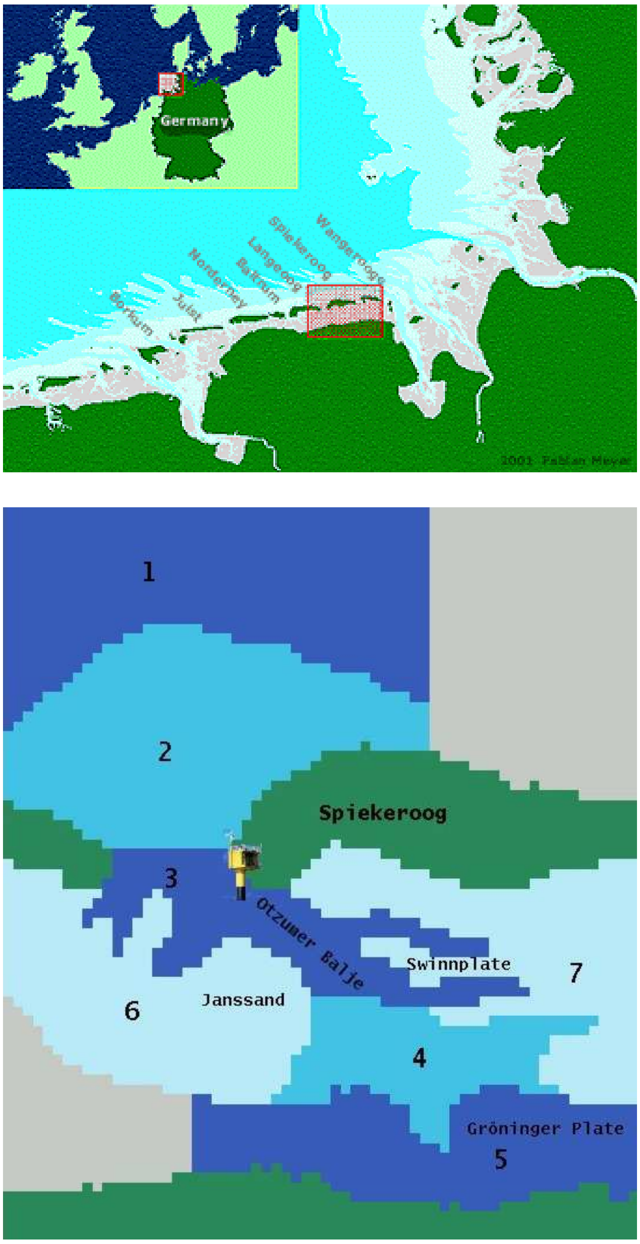

Fig. 2. The model area. The upper picture shows the location of the East Frisian Wadden Sea and the island of Spiekeroog. The bottom picture shows the modeled area and the location of the pole. Region 1 represents the linkage to the boundary model for the North Sea (COCOA).

The model area

The modeled area is part of the near-shore zone of the German Bight (Fig. 2) and in West-East direction reaches from the watershed behind Langeoog Island to the watershed behind Spiekeroog Island. In North-South direction the modeled area reaches from the 5 m water-depth line during tidal high water to the coast. Hence, the modeled area comprises the complete backbarrier system of Spiekeroog Island.

The back barrier system is subdivided into five boxes (nos. 3 - 7) plus one box (no. 2) between the North Sea (no. 1) and the backbarrier system. This subdivision is governed by the underlying depth profile. In these different model areas different characteristics like sediment type are taken into account.

Transport concept

The base for the water transport in the backbarrier system is a surface velocity field provided by E. STANEV (see STANEV *et al*., 2003). The movement of 100 water bodies along trajectories of this field is calculated. The resolution constitutes 200 m x 200 m. This concept has the main effect that the numerical dispersion is completely avoided. The problem of mass balance in this Lagrangian approach was solved by treating finite water bodies instead of point tracers. It is assumed that the volume of all tracers exceeds the volume within the system (box nos. 2 - 7) at high water. In that way the volume of the water bodies within the system at a certain time represents the real volume. Turbulent diffusion is considered by a randomized offset of water bodies. Diffusion between different water bodies is implemented by an exchange process. The sea level for every grid point of the field is simulated separately by considering the dominating tides (M2, M4 and S2). An additional transport for benthic material (detritus) is implemented as “normal” advective box transport.

Boundary conditions

Water bodies leaving the backbarrier system become mixed with North Sea water. The velocity of this mixing process determines to some extend the flushing time of the system. The concentrations of all dynamic states within the North Sea are calculated by the North Sea box model COCOA. To get more reasonable results, the North Sea values for the dissolved nutrients are reconstructed from measurements taken from the ECOMOD database. For their use, the measurements were analyzed by Fourier transformation. The resulting Fourier series provide values for every time step.

Benthic-pelagic-coupling

The concept of finite water bodies also solves the typical problems of coupling Lagrangian models to a sediment model. It is assumed that every water body has a certain depth depending on the actual sea level at its position. If the volume is fixed the area of interaction with a benthic region can be calculated from that depth. The exchange of nutrients due to diffusion, sinking of suspended material and algae can now be determined for every “Eulerian” benthic region and every Lagrangian water body above that region.

Pelagic system

The dynamically modeled state variables of the pelagic system are

- dissolved ammonium nitrate, phosphate and silicate;
- functional groups for diatoms, flagellates, picophytoplankton and dinoflagellates with varying CNP or CNPS ratios;
- functional groups for microzooplankton, heterotrophic flagellates and pelagic bacteria with varying CNP ratios;
- functional groups for carnivorous and omnivorous mesozooplankton;
- dissolved, particulate and refractory organic matter (CNPS);
- optimal light for the phytoplankton groups.

The food web of the pelagic system is shown in Fig. 3. Due to the ERSEM philosophy of a top-down approach the food web consists of functional groups and not of single species. Such pseudo-cannibalism within some groups may occur.

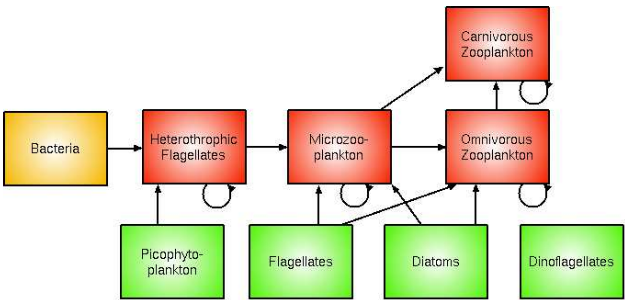

Fig 3. The pelagic food web. The arrows show the biomass flows. The circles denote pseudo-cannibalism within the functional groups. The fluxes from and to detritus and to the benthic system are omitted.

Benthic system

The dynamically modeled state variables of the benthic system are

- dissolved ammonium, nitrate, phosphate and silicate;
- one functional group for benthic diatoms with varying CNPS ratio;
- functional groups for aerobic and anaerobic bacteria with varying CNP ratios;
- functional groups for megabenthos, deposit feeders, filter feeders, meiobenthos and infaunal predators;
- dissolved, particulate and refractory organic matter (CNPS);
- optimal light for the benthic diatoms;
- penetration depths for oxygen, nitrate and the CNPS components of detritus.

The food web of the benthic system is shown in Fig. 4. As posted for the pelagic web the benthic system also consists of functional groups.

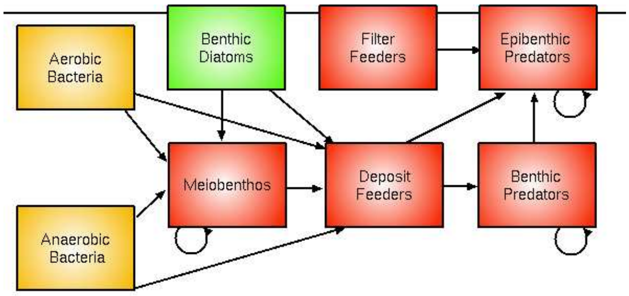

Fig 4. The benthic food web. The arrows show the biomass flows. The circles denotes pseudo cannibalism within the functional groups. The fluxes from and to detritus and the filtration fluxes are omitted.

Some tentative results

Horizontal nutrient gradients

Fig. 5 shows the annual signal of dissolved phosphate and silicate. The model results coincide very well with the measured data from the ELAWAT project (DITTMANN, 1999). The high variance in the concentrations during the tidal cycle is reproduced by the model. It can be seen that there is a gradient from the North Sea to the coast. This gradient basically depends on the shallowness of the water near the coast. The impact of sedimentation on the benthic system, remineralization and diffusive exchange between water and pore water increase with decreasing water depth. The resulting net inflow of nutrients into the backbarrier system is compensated by an outflow of organic material. The steepness of the gradient depends on the amount of an additional inflow of organic material into the system. Even if there is no additional transport of benthic material a gradient occurs, but in this case reasonable concentrations of benthic detritus cannot be expected. Fig. 6 compares simulation runs with and without additional impact of material into the benthic system. The additional impact of detritus into the backbarrier system leads to higher concentration of dissolved silicate in the pelagic system. The pelagic detritus concentration stays nearly unchanged. This mechanism was thoroughly investigated with conceptual models in EBENHÖH *et al.* (2003a,b). The results hold also for ammonium and phosphate.

Phytoplankton growth

Fig. 7 shows the modeled annual signal of the diatom abundance. The oscillations are a consequence of the tidal signal and the light signal. On a smaller scale of one week it can be seen that the primary production depends on the available light as a superposition of the actual irradiance and

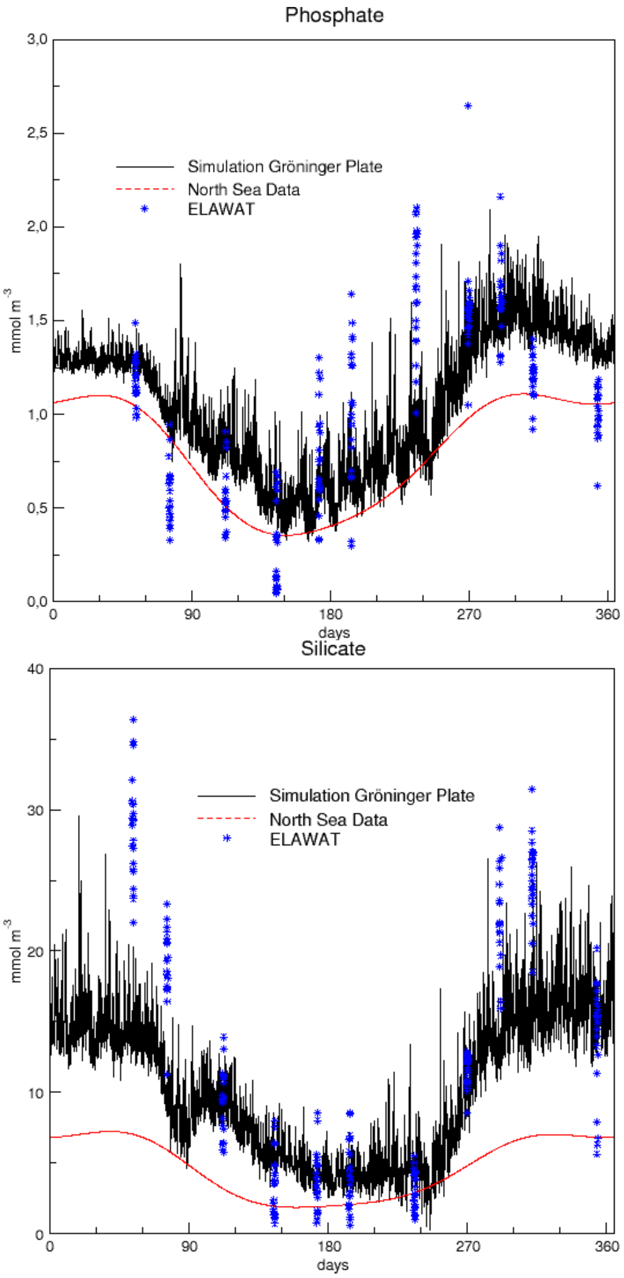

Fig 5. Phosphate and silicate concentration at the Gröninger Plate (solid) compared to measurements from the ELAWAT project (stars). The dotted line denotes the boundary conditions of the North Sea (Fourier series analyzed from measurements of the ECOMOD database). The concentrations are averaged over all water bodies over the benthic area 5 (see Fig. 1).

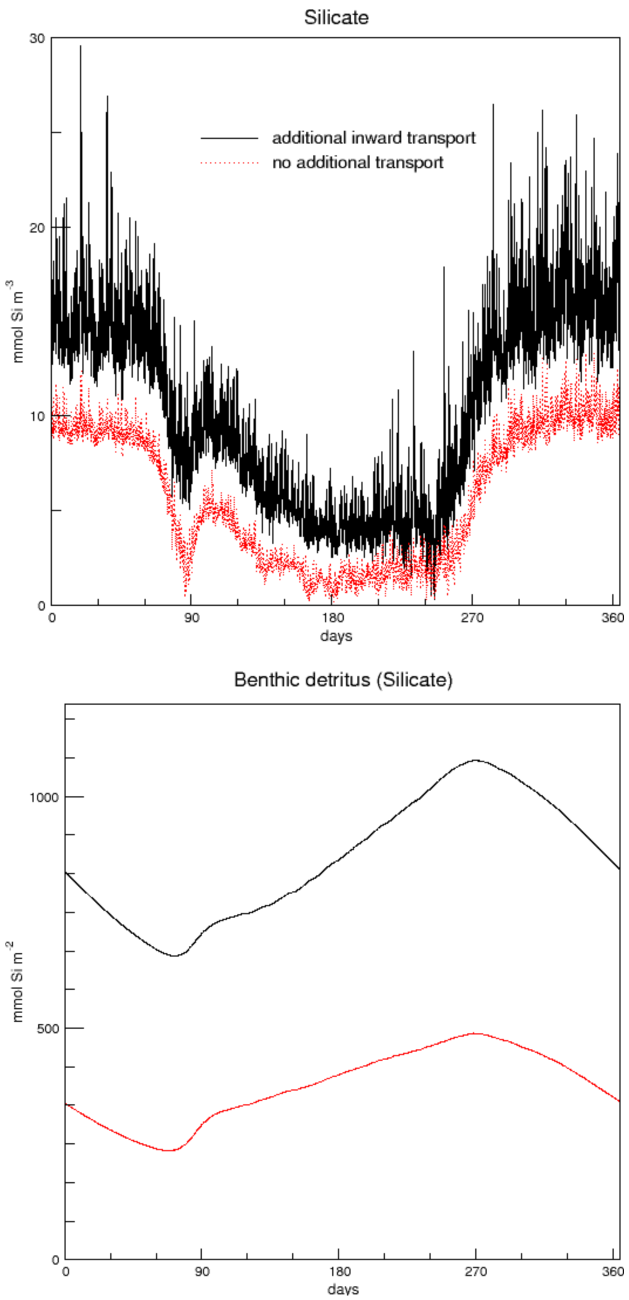

Fig 6. Pelagic silicate concentration with (solid) and without (dotted) particulate benthic inward transport (top) and corresponding benthic silicate detritus concentration (bottom). The pelagic detritus concentration stays nearly unchanged (not shown). On average the impact amounts to 2.8 mmol $m^{-2}d^{-1}$.

the extinction due to water depth and suspended material. The local minima in the primary production curve results from the light inhibition due to too high values of available light. Such high irradiance and low water depth do not necessarily result in high values of primary production.

Benthic behavior

The horizons of oxygen and nitrate within the benthic system are treated as dynamic state variables. The oxygen horizon determines the habitats for the aerobic bacteria and for zoobenthos as well as the amount of nitrification. The layer bounded by the oxygen and nitrate horizons determines the habitat of the anaerobic bacteria. Fig. 8 shows the penetration depth for oxygen and nitrate for box 5. Both curves show reasonable behavior with a higher penetration depth during winter than during summer.

Conclusions

The model at the recent stage can reproduce several observed properties of the ecosystem. In a next stage the parametrization has to be refined, and the physical forcing has to be improved for the year of interest. The model results can then be compared to the field and laboratory measurements related to the study area. After that the model is hopefully prepared for predictability studies.

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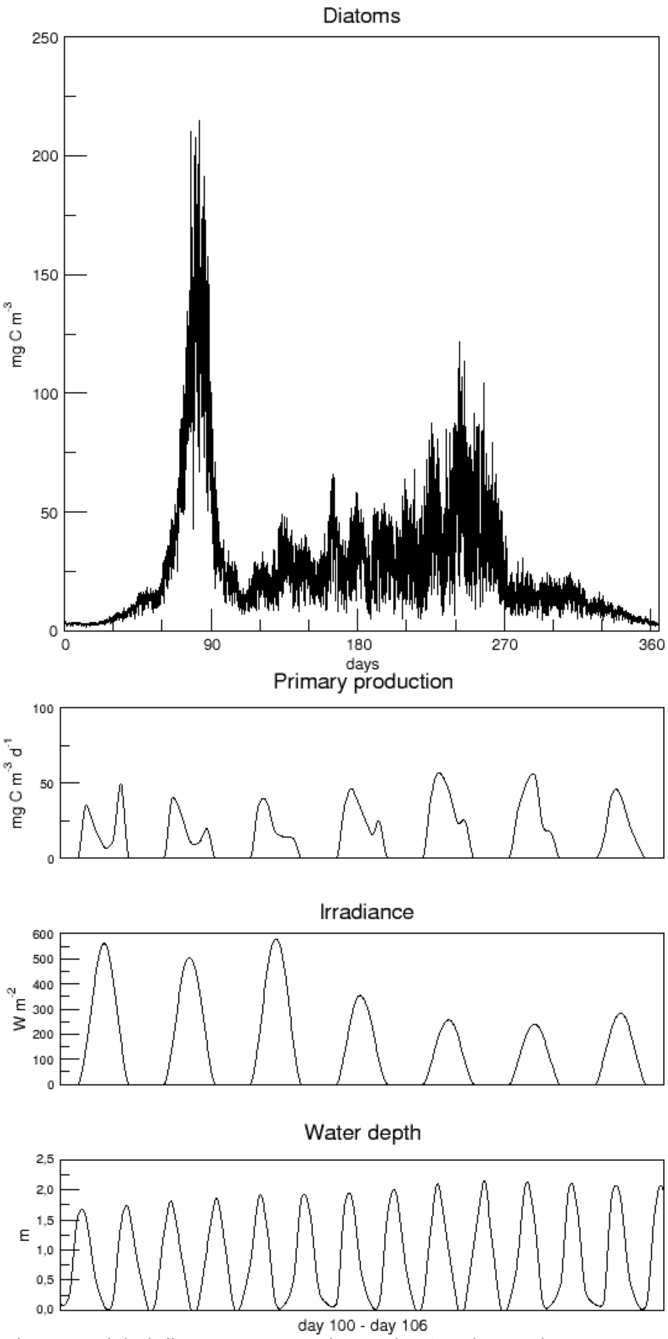

Fig. 7. Modeled diatom concentration at the Gröninger Plate over one year (top). The concentrations are averaged over all water bodies over the benthic area 5. Primary production, irradiance and water depth during one week in spring (bottom).

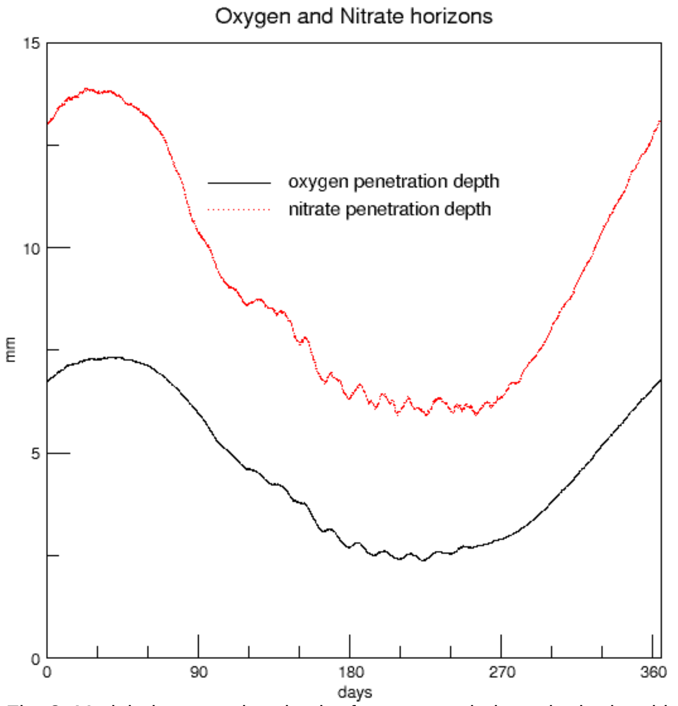

Fig. 8. Modeled penetration depth of oxygen and nitrate in the benthic area at the Gröninger Plate (box 5).

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Cora Kohlmeier, Institut für Biologie und Chemie des Meeres (ICBM), Carl von Ossietzky Universität Oldenburg, Carl-von-Ossietzky-Str. 9-11, Postfach 2503, D-26111 Oldenburg, Germany; phone +49 441 798 3067; fax: +49 441 798 3404; email: kohlmeier@icbm.de.