Pollutant Transport Monitoring and Prediction by Mathematical Modelling: North Sea and Adjacent Estuaries

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Pollution of the North Sea is due to various sources: atmospheric deposition, input by rivers and direct discharge, e.g. by industries or ships. An integrated concept is being developed, that combines field observation and the application of numerical models for transport processes in tidal rivers, estuaries and the North Sea.

Estuary

The observation system consists of highly sensitive devices that are operated partly in 'moving - boat' mode in rivers and estuaries in order to determine transport rates and net transports of water constituents. In-situ measurements are combined with moored systems and analyzing of samples by very sensitive methods. Hydrodynamic parameters are measured by horizontal and vertical profiling: current velocities by means of of a two-dimensional acoustic sensor, suspended matter concentration by optical light attenuation. The measurements are completed by sensors for CTD and orientation in space. Samples are taken and analyzed for trace element contents (e.g. heavy metals), organic and other inorganic pollutants (Michaelis, 1990).
In order to interpolate and interprete observations, as well as to predict transport of pollutants and to deepen our knowledge of estuarine processes (e.g. the role of the turbidity zone), a system of numerical models has been developed (fig. 1).

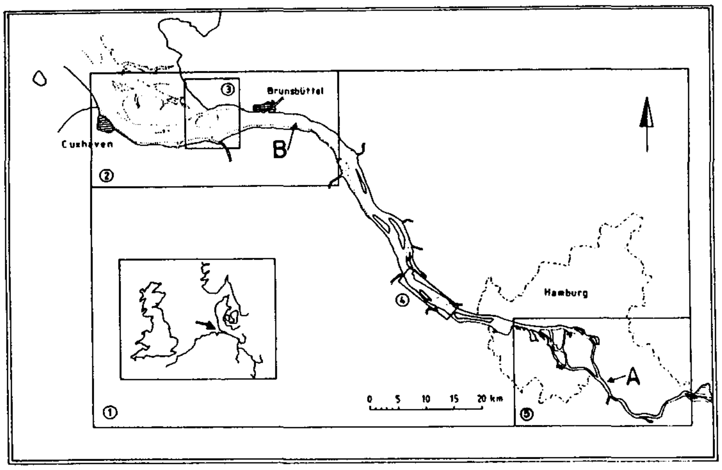

Fig. 1 The Elbe estuary. Numbered boxes indicate areas of sub-models of entire estuarine model system.

Due to flow properties models have to be essentially threedimensional in space, at least in the lower parts of the estuary where baroclinic effects prevail and large topographic gradients lead to very pronounced non - linear flow patterns dominated by the semi - diurnal tide.
The models are based upon the shallow water equations and solved by a finite difference scheme. They use an implicit formulation of the free surface variation and so allows for an economic time stepping procedure and treat flooding and falling dry of tidal flats. At open boundaries surface drag (wind field), tidal elevation and fresh water discharge are prescribed (Krohn and Duwe, 1990, Krohn et al., 1987).
Transport of conservative substances is simulated using a tracer random walk technique. An example for the brackish water zone (model area 2) and the fresh water zone (model area 4) is shown in figs. 2 and 3. They demonstrate the temporal evolution of a conservative substance distribution after instantaneous release as point source. It can be observed clearly that the longitudinal extent is much larger than the lateral one. This is due to the prevailing longitudinal

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current shear. Diffusion obviously plays a minor role. More details may be found in Duwe et al. (1987).

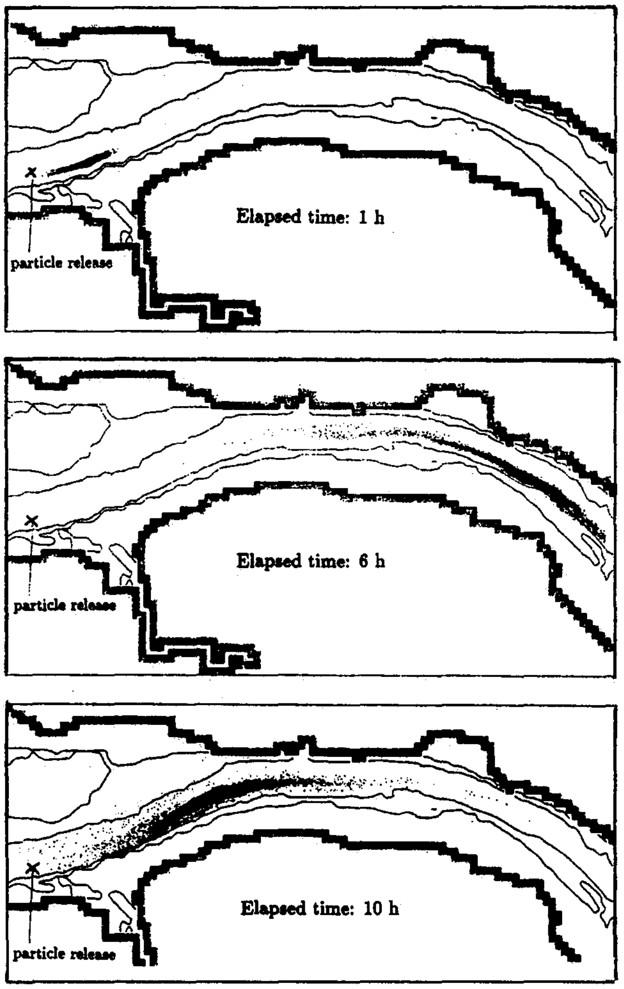

Fig. 2 Simulation of conservative substance transport by tracer method, number of particles: 10000, area: upper part of sub-model 2, brackish water zone. Cloud of dots indicates particle postions at three times after release at location 'X'. Tidal phases (from top to bottom): beginning of flood, end of flood, end of ebb.

The model will be improved in order to simulate the transport of non - conservative substances. This has been achieved, so far, by means of a one - dimensional model of the upper part of the estuary, see location 'A' in fig. 1. Hydrodynamics are based on St. Venant's equations and mass conservation. It computes water quality parameters under the action of the nitrogen and oxygen cycles including erosion, sedimentation and consolidation of suspended matter and heavy metal transport (Müller et al., 1990). Comparison of simulated and observed suspended matter concentrations over a tidal cycle at station 'A' in fig. 1 are depicted in fig. 4.

North Sea

In order to simulate the pollutant transport in the North Sea one has to take into account suspended matter transport. Especially heavy metals (strong environmental relevance have cadmium and mercury) are taken up by particles (clay, detritus, plankton). So an understanding of suspended matter transport is prerequisite for getting insight into pollutant transport. As wave action may modify bottom shear stresses, at least in shallow waters and during storm periods, the inclusion of surface waves turned out to have significant influence on sedimentation patterns. North Sea currents are due to tides at the open boundaries and to a very large extent to mass distribution and wind fields.

The suspended matter transport model uses current fields computed by a three - dimensional, time dependent (time step 40 minutes) model of the northwest European shelf sea (Backhaus, 1985), that is forced by the tide, baroclinicity and the actual six - hourly wind stress at the sea's surface.

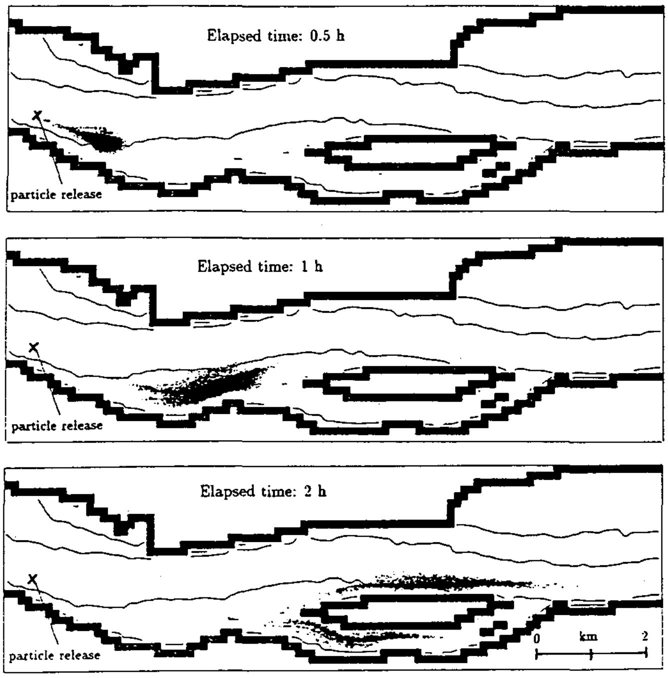

Fig. 3 Simulation of conservative substance transport by tracer method, number of particles: 10000, area: sub-model 4, fresh water zone. Cloud of dots indicates particle postions at three times after release at location 'X'. Tidal phases: flood

Suspended matter transport itself is simulated by a tracer method (Puls and Sündermann, 1990). At boundaries particle input is prescribed arising from river input (Elbe, Weser, Rhine, Thames, Tyne etc.), input at open boundaries (North Atlantic, English Channel, Baltic Sea), cliff erosion (especially at the English coast) as well as bottom erosion and direct dumping. The particles move due to the current field, diffusion and their settling velocity, the latter depending on origin (sea or river - borne) and season. The shear stress at the bottom responsible for erosion or sedimentation is calculated by the combined action of currents (from current model) and waves (from a wave model, see Brettschneider, 1986). Results of a comparison with data of a three month observation period in the North Sea are shown in fig. 5.

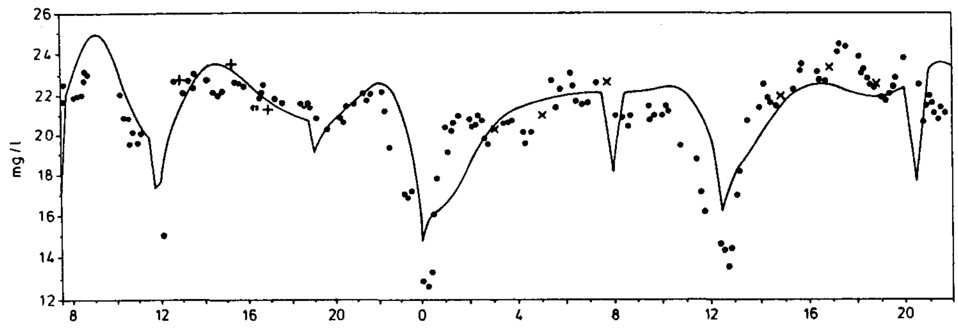

Fig. 4 Cross-sectional mean of suspended matter concentration. Results of 1-dimensional model (solid line) versus experimental data (full dots: based on light attenuation measurements, crosses: water samples), location 'A' (from Michaelis, 1990).

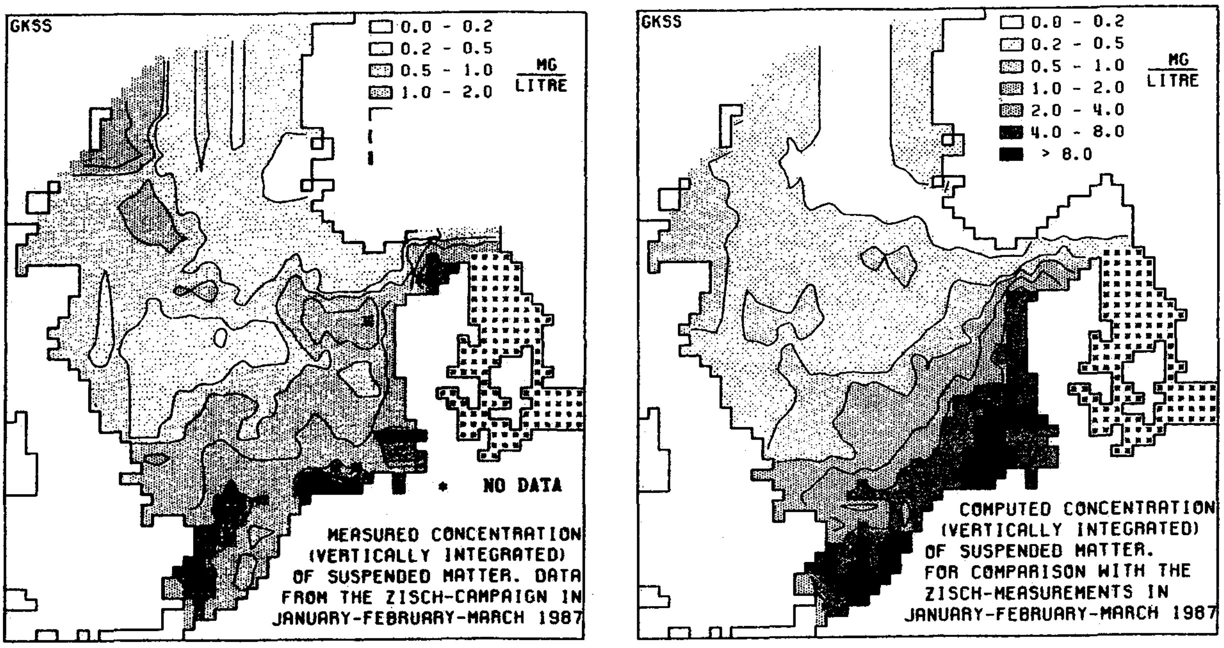

Fig. 5 Observed (left panel) and computed (right panel) suspended matter concentration

Backhaus, J.O. (1985). A Three - dimensional model for the simulation of shelf sea dynamics. *Deutsche Hydrogr. Zeitschr.* **38**, 165 - 187.

Brettschneider, G. (1986). Seegangsklimatologie Nordsee. *Mitt. Deutsche Meteorol. Ges.* **4**, pp.34 - 39

Duwe, K.C., Krohn, J., Pfeiffer, K., Riedel-Lorjé, J., Soetje, K.C. (1987). Ausbreitung von wassergefährdenden Stoffen in der südlichen Deutschen Bucht und im Elbeästuar nach Freisetzung durch Schiffe. *Report GKSS* 87/E/18.

Krohn, J., Duwe, K.C., Pfeiffer, K.D. (1987). A high resolving 3D model system for baroclinic estuarine dynamics and passive pollutant dispersion. In *Threedimensional models of marine and estuarine dynamics.* (Nihoul, J.C.J., Jamart, B.M., Eds.), pp. 555 - 571. Elsevier Oceanographic Series 45, Elsevier, Amsterdam.

Krohn, J., Lobmeyr, M. (1988). Application of two- and three - dimensional high resolving models to a small section of the Elbe estuary - a comparative study. *Report GKSS* 88/E/52.

Michaelis W. (1990). The BILEX concept - Research supporting public water quality surveillance in estuaries. In *Estuarine Water Quality Management* (W. Michaelis, Ed.), pp. 79 - 88. Coastal and Estuarine Studies 36, Springer Verlag, Berlin.

Müller, A., Grodd, M. & Weigel, H.P. (1990). Lower Weser monitoring and modelling. In *Estuarine Water Quality Management* (W. Michaelis, Ed.), pp. 79 - 88. Coastal and Estuarine Studies 36, Springer Verlag, Berlin.

Puls, W. and Sündermann, J. (1990). Simulation of suspended sediment dispersion in the North Sea. In *Physics of shallow estuaries and bays* (R.T. Cheng, Ed.). Springer Verlag, Berlin (in press).