AN INTEGRATED BIOGEOCHEMICAL MODEL SYSTEM FOR THE BALTIC SEA - A PILOT STUDY

Eleonor Marmefelt, Berit Arheimer and Joakim Langner
Swedish Meteorological and Hydrological Institute, S-601 76 Norrköping, Sweden.

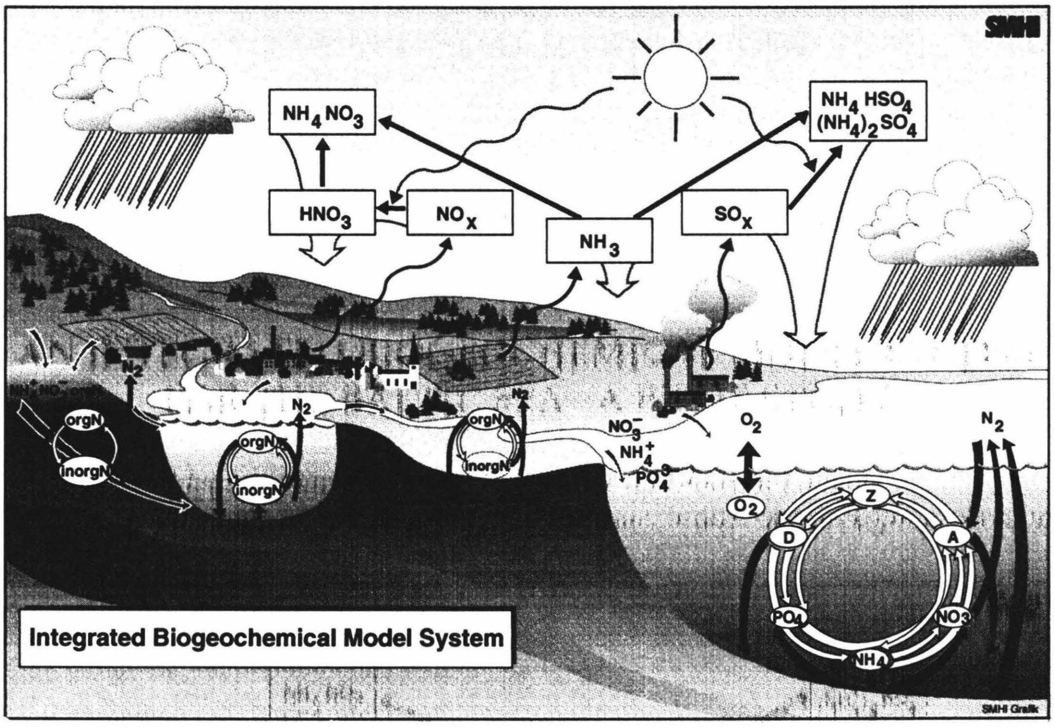

Figure 1 The integrated model system

An integrated biogeochemical model system for coastal waters is under development at the Swedish Meteorological and Hydrological Institute (SMHI), with special focus on the Baltic Sea. The model system consists of three models which simulate nitrogen transports and transformations in the atmosphere, in the fresh-water ecosystem and in the marine environment (Figure 1). The marine model also includes phosphorous. In a pilot study of the Baltic Sea, the model system has been applied to a limited area in the south-western part of the Baltic Proper, the Hanoe Bight.

The marine biogeochemical model is a nine variable model. As phosphorous, at present, is not included in the atmospheric or riverine models, inputs of land based phosphorous (which dominates the phosphorous loading) is taken from interpolations of measurements . The marine model deals with primary phytoplankton production, nitrogen fixation, oxygen consumption and secondary zooplankton production. Nitrogen fixation by cyanobacterias represents approximately 15 % of the annual primary production in the Baltic Proper and is essential for the Baltic nitrogen cycle. The biogeochemical model is a one-dimensional model with high vertical resolution. It is coupled to a hydrodynamical model with similar resolution (PROBE). Horizontal variations are taken into account by dividing the area into smaller subboxes. PROBE estimates the horizontal transports between the boxes, the vertical advection and the turbulent mixing every third hour. The biological processes are simulated on an hourly basis. In near future, the model will be extended to a three-dimensional version, for better resolution of the horizontal variations.

The nitrogen transport from land is obtained through the HBV-N model, which simulates organic and inorganic nitrogen separately. It is based on the hydrological model HBV where subbasins (1-100 km^2) are coupled so that the runoff from each subbasin is simulated on a daily basis, going from upstream subbasins to the mouth of the river. For each subbasin the nitrogen routine assigns nitrogen concentrations to the daily calculated water discharge from the root zone. These concentrations depend on e.g. land use, climatological region, soil type, crop yield, fertilisation and forest fertility. Additional sources of nitrogen considered in the model includes rural households, atmospheric deposition on lakes, industries and urban wastewater treatment plants. The water discharge of each subbasin is mixed with eventual lake water and water from upstream areas. Routines are included for simulation of biochemical removal of inorganic nitrogen and, additionally, biological growth and erosion processes resulting in elevated organic nitrogen concentrations. The HBV-N model is calibrated and validated against measured concentrations and water flow. It may be used for estimation of nitrogen discharge in ungauged areas and for source apportionment of the riverine nitrogen load on the sea.

The atmospheric input of oxidised and reduced nitrogen is taken from the annual assessments carried out with the MATCH-Sweden modelling system developed at SMHI. MATCH-Sweden combines model calculations, using a three dimensional atmospheric transport and chemistry model, with observations of air- and precipitation chemistry data and meteorological conditions to give a detailed mapping of concentrations and deposition of nitrogen compounds over Sweden and surrounding waters. It is possible to separate the contributions from national sources and sources outside Sweden.

The Hanoe Bight (7 500 km^2) has been divided into three coastal boxes and one box in the central part. Each box is modelled separately, but are individually coupled to surrounding boxes. In this way it is possible to catch the very specific dynamics of the bight with upwelling of cold nutrient rich water in the Blekinge archipelago and then transport it as a southward coastal current along the Swedish coast, despite the one-dimensional approach.

The land area draining to the bight (14 500 km^2) is divided into 427 subbasins in which daily water discharge and nitrogen concentrations are calculated. The area includes 20 meteorological observation stations, 7 sites with daily water discharge measurements and 45 sites with monthly or biweekly measurements of nitrogen concentrations, which have been used in the HBV-N model calibration.

Key components in the estimation of the atmospheric input of nitrogen are observed air- and precipitation chemistry data and observed precipitation data. 35 Swedish stations reporting monthly precipitation chemistry and 18 stations in Sweden and surrounding countries reporting daily air- and precipitation chemistry data were used together with 800 Swedish precipitation stations reporting daily precipitation as input to MATCH-Sweden. Biweekly estimates of deposition of oxidised and reduced nitrogen with a 20x20 km horizontal resolution for 1994 were then extracted as input for the hydrological and marine models.

The validation of the marine biogeochemical model has been concentrated to the western Hanoe Bight box, as it is best covered with data. This part of the Hanoe Bight represents an open coastal area. Monthly transport of inorganic nitrogen to the western Hanoe Bight box, illustrated in Figure 2, shows very clearly the importance of local

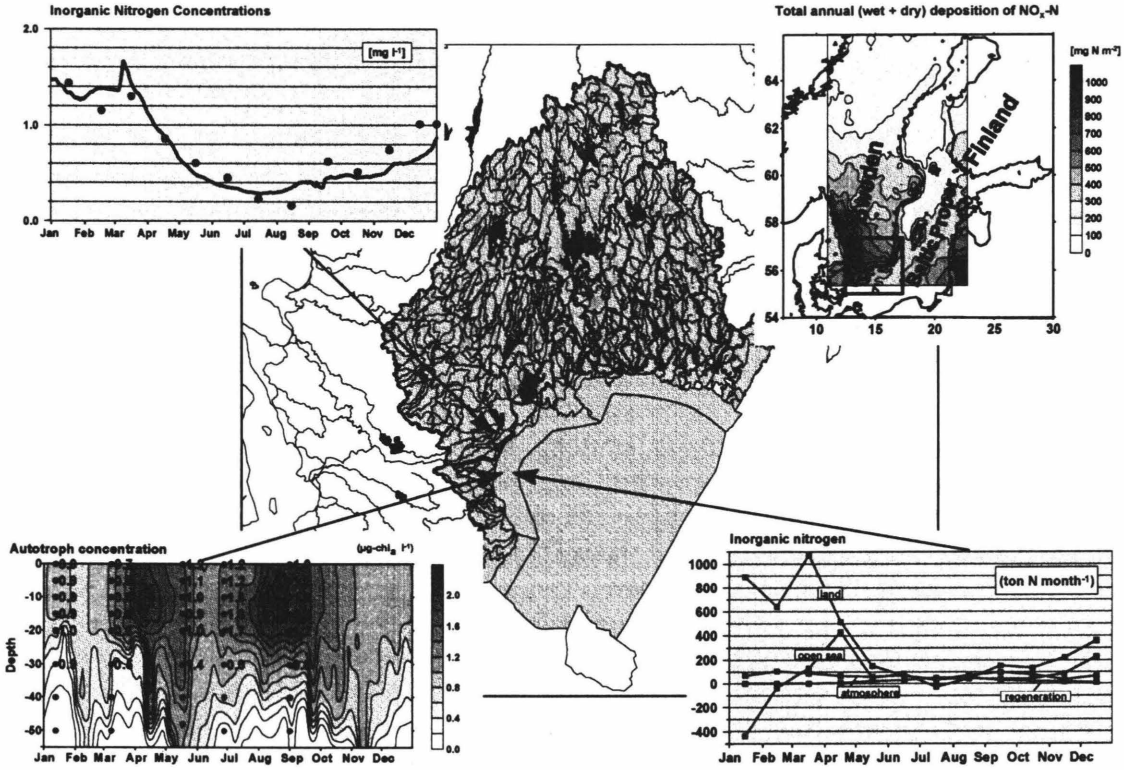

Figure 2 Results from the pilot study in the Hanoe Bight; simulated and measured riverine concentrations (upper left), calculated atmospheric deposition (upper right), simulated and measured autotroph concentrations in the coastal zone (lower left) and monthly average nitrogen transports to the coastal zone (lower right).

biological production in an open coastal zone. During the productive season, the coastal zone actually imports inorganic nitrogen from the open sea, as the biological consumption within the coastal zone is high. Export of inorganic nitrogen to the open sea is almost completely limited to the winter season.

Figure 2 also illustrates the dynamics of daily inorganic nitrogen concentrations in riverine water, and HBV-N model performance compared to measurements. In 1994 the total gross load of nitrogen on inland waters was 15 300 tonnes, but only 9 500 tonnes reached the sea. The retention is highest (45 %) in the northern part of the drainage basin where most of the lakes are located. Source apportionment showed that most of the riverine nitrogen origin from arable land (36 % for the Northern box, 57 % for the Western and 88 % for the Southern). Only for the Northern box the forest contribution was significant (23 %). 15 - 20 % of the net load could be assigned to point sources.

The atmospheric input depends strongly on location (Figure 2) with the highest input ($\approx$1.9 g N/m^2) in the western part of the study area and lower values to the east ($\approx$1.2 g N/m^2) and over the Hanoe Bight ($\approx$1 g N/m^2). The Swedish contribution is largest in the western part, 35 %, and smaller, 15 %, in the eastern part and over the Hanoe Bight.

The model system is supplied with a tool for presentation and analysis. Supplemented with monitoring data for the specific area of interest, the integrated biogeochemical model system provides a useful tool for environmental protection analyses; e.g. for interpretation of monitoring data as well as creating scenarios for studies of effects in changing the nutrient loads.