International Council for the Exploration of the Sea

ICES C.M. 1991/E:10
Marine Environmental
Quality Committee

PRISMA - An investigation of processes influencing pollutant fluxes in the North Sea

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Abstract

Marine scientists at the University of Hamburg have initiated a new research project, PRISMA, designed to elucidate transport, transfer and transformation processes of pollutants in the German Bight. PRISMA is a logical consequence of the ZISCH project, during which two comprehensive data sets for the various ecosystem compartments in the North Sea were obtained. The first is the result of large scale surveys during spring (1986) and winter (1987) covering several weeks each and having the purpose of describing the general distribution of contaminants and the biotic and abiotic ecosystem components within two seasons. The second was obtained for the German Bight during investigations of a high temporal resolution over a part of one seasonal cycle.

PRISMA is an interdisciplinary project in which biologists, chemists, meteorologists and physical oceanographers perform field measurements and numerical experiments aimed at understanding and quantifying the links between ecosystem components and contaminants in the German Bight. The continental coastal water of this region is relatively highly contaminated and has one of the longest residence times in the North Sea.

Three cruises will be carried out (13 April - 1 May 1991; 6 August - 1 September 1991; 7 April - 1 May 1992) with 3-4 ships working in a combined strategy: within a repeated station net (50 x 50 nm), drifting experiments will be performed according to the existing gradients. In the matrix of ecological parameters such as salinity, temperature, nutrients, phytoplankton, zooplankton, benthic populations and within the different compartments (atmosphere, water phase, suspended matter, organisms and sediment), selected pollutants such as Cd, Hg, Pb, α-HCH, γ-HCH, sPCB, phosphoric esters, and PCP will be determined.

In mesocosms in Heligoland Harbour, transfer and conversion of selected pollutants will be investigated in detail in natural and "composed" planktic ecosystems enclosed in large plastic bags (May, 1992).

Data obtained by remote sensing (CODAR for surface currents, satellite and airplane measurements of suspended matter distribution and transport) will complement that of the cruises.

In addition to the field measurements, numerical models are being developed to simulate the dispersion of dissolved and particulate contaminants in the water and in the atmosphere as well as their transfer within the ecosystem by plankton. These activities include the entire North Sea.

Introduction

PRISMA (Processes Influencing Pollutant Fluxes in the North Sea - German Bight) is a follow-up project of ZISCH (Water Exchange and Contamination of the North Sea). Both projects have been funded by the German Federal Ministry of Research and Technology, ZISCH running from 1984 to 1989 and PRISMA from 1990 to autumn of 1993. The objective of ZISCH was to obtain consistent, comprehensive data sets for the North Sea ecosystem on the whole together with the distribution of key contaminants within it as well as to develop and to implement various models of the air and water circulation in the North European Continental Shelf to calculate dispersion of contaminants in the atmosphere and in the sea for given situations (Beddig & Sündermann, 1988; Sündermann & Degens, 1989).

Although the North Sea has been one of the most intensively studied marine regions for decades, until the ZISCH surveys no large scale assessment of the geographical and seasonal distribution of contaminants had been carried out.
With regard to the geographical distribution, these surveys generally confirmed previous assumptions that contamination is greatest at coastal sites, but there were unexpected exceptions to this. For example, the concentrations of some contaminants in organisms and sediments were higher in the central North Sea than in coastal regions with more contaminated water masses (Dicke et al., 1987; Karbe et al., 1988; Kersten & Klatt, 1988; Knickmeyer & Steinhart, 1988a,b; Knickmeyer & Steinhart, 1989). Additional cruises - after the two ZISCH surveys - were carried out in the northeastern part of the North Sea and the adjacent Atlantic as well as in the German Bight to get more information on the processes causing the unexpected distributions of contaminants.

In order to investigate these questions in more detail, an interdisciplinary research program, PRISMA, was designed in which processes of pollutant transport, transfer between the different compartments and transformations could be analysed for a defined area during particular seasonal conditions. The program is comprised of field experiments supported by modeling of relevant processes in air and water, including sediment transport as well as the exchange of material between water and sediment and transfer of contaminants in food-webs. For logistical reasons, but also because of the relatively high contamination, the German Bight was selected as study area. Process modelling is also continued using the ZISCH data sets.

Experimental design

In the German Bight, an extended shallow area, river discharges, especially by the Elbe, are spreading mainly horizontally. Strong tidal currents and wind stirring cause vertical mixing which is inhibited only locally by seasonally modified freshwater discharges in the coastal area and thermal stratification in the parts deeper than 30 m. The German Bight is surrounded by tidal flats and characterized by different frontal systems which are dominated by river plume fronts of the Elbe.

The German Bight is centrally located in the continental coastal water which is relatively heavily contaminated, mainly by continental rivers (Anonymous, 1980), but also by atmospheric inputs and imports from the British coasts. During winter, this contamination is detectable, for example, by the high load of nitrate spreading along the continental coast, as can be seen in Fig. 1 (Brockmann and Kattner 1991). The nitrate input from the Elbe is only a small part of the nitrogen load in the continental coastal water moving in a coastal current mainly anticlockwise through the German Bight.

Transport, transfer and transformation of contaminants are interactive, controlled by physical, chemical as well as biological processes. Process studies in the open water are very difficult due to the advection of patches and concentration gradients causing permanent local changes. In shallow areas, additional changes of the vertical structures are caused by current shear.

Our approach for studying the transfer and transformation processes is to measure the concentration changes in the different compartments within a moving water mass and to put them in relation to one another.

The spring cruises will be performed during the late phytoplankton spring bloom, frequently dominated by *Phaeocystis globosa*. The summer cruise will take place at the time when thermocline breakdown and remobilization of nutrients can be expected.

The characterization of a drifting water mass of a certain depth has been performed in the German Bight, for instance, by rhodamine dyes (Joseph et al., 1964) but also by drifters of varying design (Witte, 1982). We decided to use a drift system consisting of a buoy with a drogue in the upper 10 m. This system has the advantage that it is very simple and easy to follow. A sediment trap is attached to the drogue. From two ships following the drifter, samples are taken at different depths every 6 hours. These are analysed for ecosystem

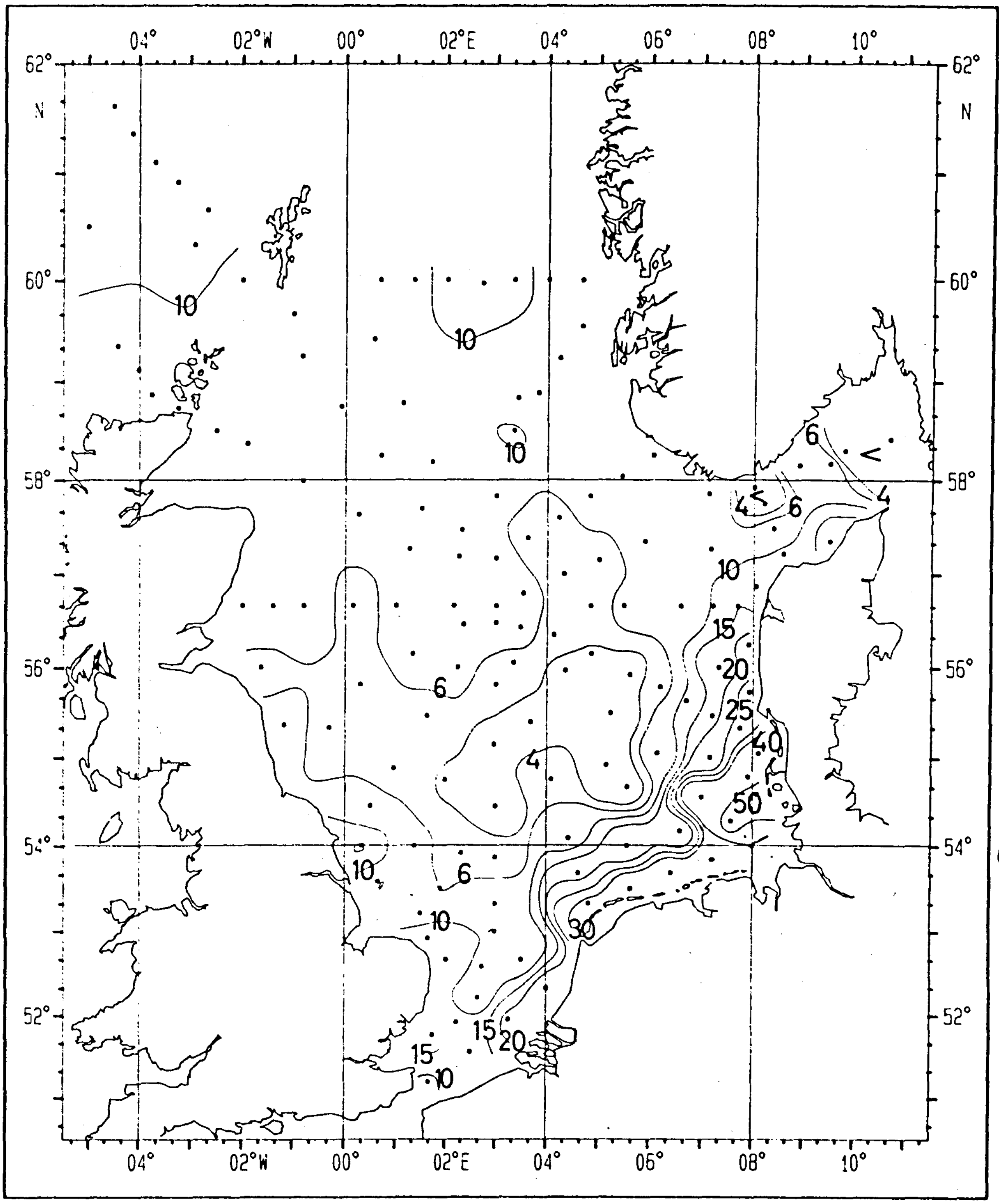

Fig. 1: Nitrate concentrations at the surface of the North Sea during winter 1987 (μM/l) (Brockmann and Kattner, 1991)

parameters such as nutrients, phyto- and zooplankton as well as for selected contaminants in water, sediment, suspended matter and organisms: heavy metals (mercury, copper, cadmium, lead) and pesticides (HCH, PCB and PCP and some phosphoric ester compounds). Around this drifting station, interim measurements of hydrographic parameters and nutrient and chlorophyll concentrations are carried out in order to detect small scale horizontal gradients. Using this strategy, we expect to be able to distinguish concentration changes at the central station - dominated by processes within the water column - from modifications of concentration gradients caused by advection.

Furthermore, the movement of water masses is followed by twice daily forecasting in order to detect drift paths of the buoy deviating significantly from the calculated drift directions. This is carried out by the hydrodynamic model driven by air pressure forecasts and tides routinely operated by the Federal Maritime and Hydrographic Agency in Hamburg (BSH). Hind-casting models are used later for detailed interpretation of the data sets (Backhaus & Hainbucher, 1987).

Since the hydrodynamics of the German Bight are quite variable, the drift area is surrounded by a station grid of about 50 x 50 nautical miles. Every 10 nm, measurements of ecosystem parameters such as nutrients, organics, phyto- and zooplankton are carried out. This station net is repeated 4 to 5 times during the 3 week investigation. The station grid is shifted when the expected drifting area leaves the grid.

Due to the limited capacity to analyze contaminants, these are only sampled at the central drift station. However, before beginning the drift experiment, contaminants are also sampled at a 20 nm interval on a first station grid. Sampling of sediments and benthic fauna is carried out before and after each experiment.

During the experiment, 5 moorings with current meters and turbidity sensors are anchored in the expected experimental area. In the autumn 1991 experiment, the movement of water masses will also be followed by CODAR measurements from stations in Heligoland and Eiderstedt, allowing a permanent estimation of surface current patterns (Schirmer et al., 1987). The area of CODAR information is restricted to a smaller part of the main experimental area which is limited by the water depth and frequently used shipping lanes in the southern part of the German Bight.

First results

During April 1991, the first experiment was performed, including 5 repetitions of the station grids measured by VALDIVIA and GAUSS and 3 drift experiments performed in the central northern part of the German Bight (Fig. 2).

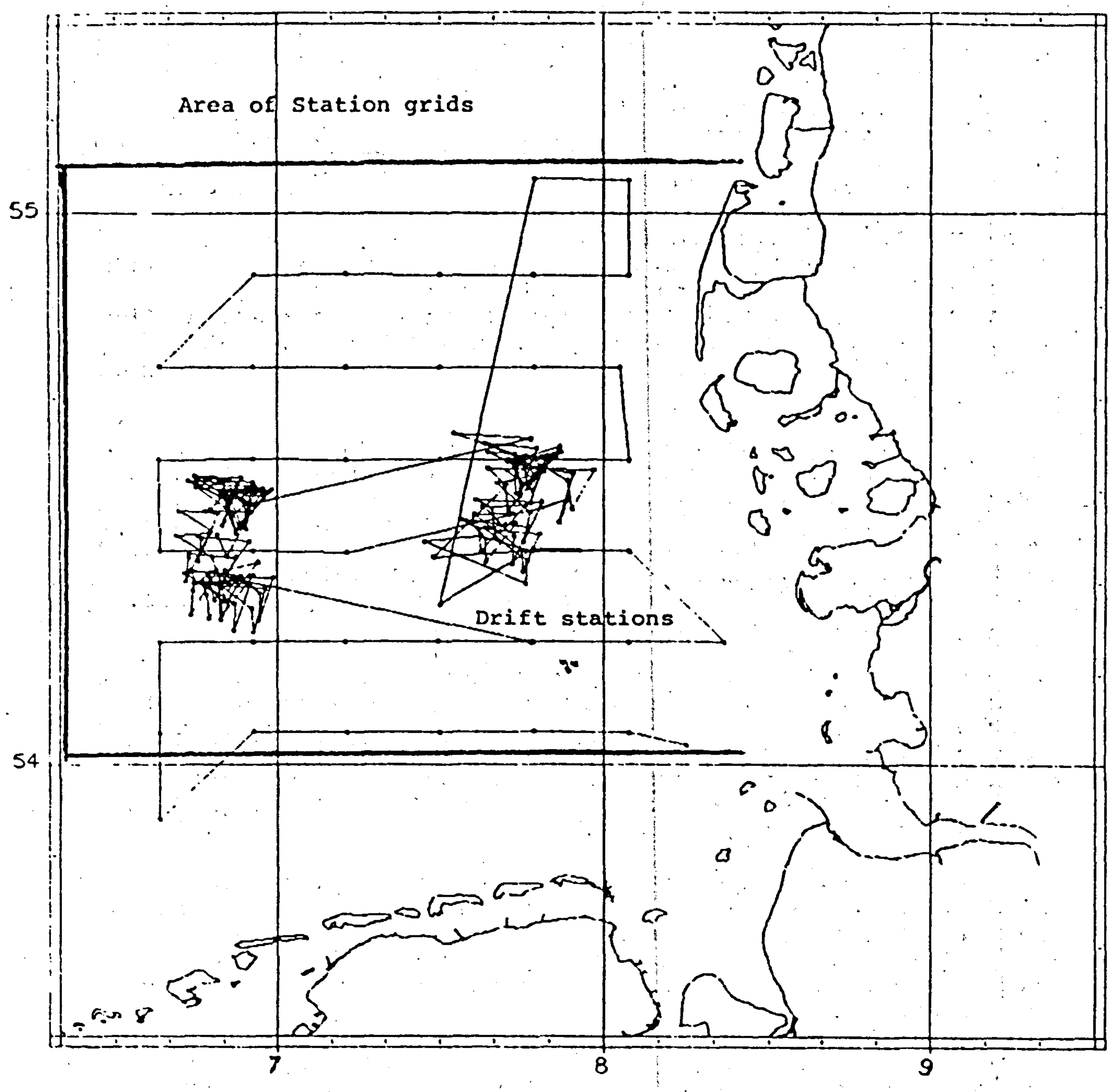

Fig. 2: German Bight with the tracks of the first drift experiment as well as the area where repeated station grids with 10 nm spacing were sampled in spring 1991 (M. Haarich, pers. comm.).

Predictive calculations of water mass transport were made available by the BSH. These were generally in agreement with the observed drift directions which - due to the low winds - were mainly determined by tidal currents.

During this experiment the Elbe River plume was spreading nitrate-rich water into the German Bight, in which most of the other nutrients were at very low concentrations, already limiting phytoplankton growth (Fig. 3). The river-plume water

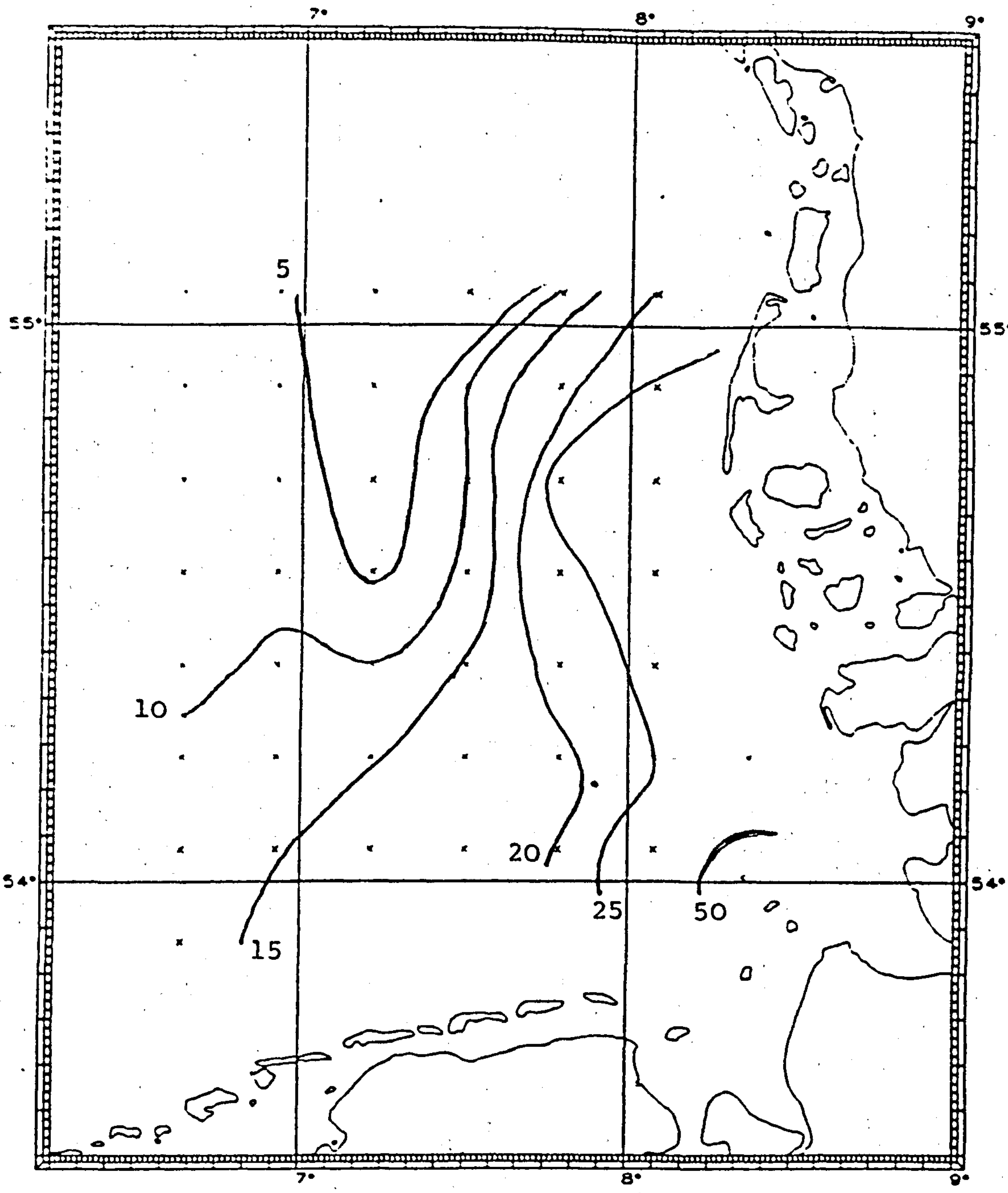

Fig. 3: Nitrate concentrations in the German Bight near the bottom during the period 17-21 April 1991.

was characterized by diatoms, presumably dominating here due to the still available silicate and the higher growth rate in comparison to flagellates (Fig. 4).

Mesocosm experiments

In order to exclude advection influences completely, mesocosm experiments are planned for spring in 1992 in the outer harbour of Heligoland using plastic bags with 3 m^3 volume

Fig. 4: Relative abundance of *Phaeocystis globosa*, diatoms and *Ceratium fusus* from net hauls (55 μm) in the German Bight (13 April - 1 May 1991 (H.J. Rick, pers. comm.). Qualitative data, analyzed on board the ship.

(Brockmann et al. 1977). During these experiments, parallel runs will be performed with combined algal cultures of phytoplankton species isolated in the same area in advance. Cultures of Thalassiosira rotula and Phaeocystis globosa will be used in order to study the effects of very different organisms on the phase-transfer and transformation of contaminants. Different concentrations of heavy metals (e.g. copper) and pesticides (e.g. HCH) will be added to parallel enclosures reaching at maximum the tenfold concentrations measured in the mouth of the Elbe River. Another series will be performed with synthetic pollutants like Anthracine or phenoxicarbonic acid. Finally, experiments will be carried out with a mixture of natural plankton to which some contaminants are to be added. In total, up to 10 parallel enclosures will be measured in each series.

Especially in the mesocosms the transfer of contaminants between the different phases will be followed closely. By incubation of stripes of the plastic material from the walls, adsorption processes will be analyzed in order to establish mass balances of contaminants as well as nitrogen and phosphorus. The conversion of contaminants will be another main point in the enclosure experiments by analysis, for instance, of the shift of enantiomeric relations of organic contaminants, which was also observed in the open water (Faller et al. 1991).

Measurements in the open water and mesocosms will be supplemented by laboratory experiments. These will include sorption experiments. Combining these results, we hope to be able to quantify transport processes - at least for some pathways of contaminant transfer and transformation in the German Bight. The results will be tested later in other areas.

Table 1 gives a timetable of the PRISMA field experiments.

Multiship cruise	13 April-1 May 1991	German Bight
Multiship cruise	6 Aug.-1 Sept. 1991	German Bight
Multiship cruise	7 April-1 May 1992	German Bight
CODAR-Measurements	August-Dec. 1991	N. Frisian Coast
Mesocosms	May-June 1992	Heligoland

Atmospheric contaminants

A relatively large proportion of certain contaminants reaching the North Sea enter via the atmosphere, and it is one of the main objectives of meteorologists and air chemists in the

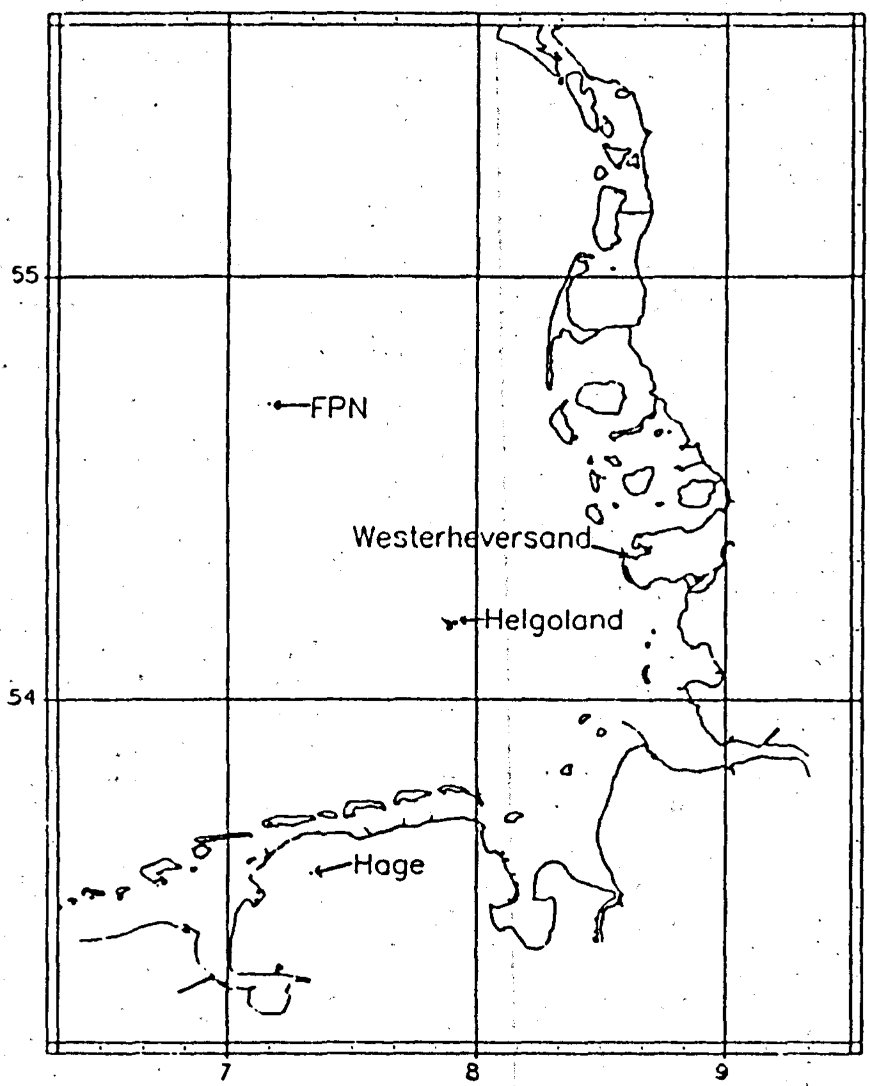

Fig. 5: Stations for continuous air chemistry measurements in the German Bight.

PRISMA-project to determine input quantities and transport pathways.

Concentrations of particle-bound heavy metals, sulphate and nitrate are being determined on a continuous basis at several stations on land and at sea (see Fig. 5), in addition to shipboard measurements carried out during the experiments. A combination of concentration measurements and deposition models allows calculation of total inputs. These input values are compared with data on total and wet deposition, which are measured separately. Sulphate, nitrate, ammonium and heavy metals are analyzed for both fractions. The measurement stations are confined to the German Bight at the moment but are being extended to the central and northern North Sea.

Methodological work is being done on measurement of halogenated hydrocarbons in aerosol, in precipitation and in the gaseous phase.

Meteorological measurements and models are used for interpretation of the distribution of airborne contaminants in the German Bight obtained by the air chemists. For example, analysis of air mass movements using backward trajectories gives insight into the origin and transport pathways of atmospheric contaminants. Basic information on the state of the atmosphere, e.g. with respect to dispersion conditions for contaminants, are obtained using an analytical model for several meteorological parameters based on observations from the German Weather Service (Luthardt, 1985). The model uses a 42 x 42 km grid net (Fig. 6). It produces water temperatures (every 24 h), wind fields and surface pressure fields (every 3 h), dating back to 1982. Furthermore, a mesoscale model (METRAS) is used to investigate local effects of the coastline on the atmospheric input as well as to perform case studies to determine extreme input situations. For example, METRAS has been implemented to study the dependence of the dry deposition of SO_2 on surface characteristics (Schlünzen and Pahl 1991). It will also be used to study the transport and deposition of several gases, e.g. NO, NO_2 and NH_3, and of particles.

Investigations on the vertical structure of the boundary layer are carried out from ship during the experiments. These are accompanied by land-based SODAR/sonic measurements on the coast (Eidersperrwerk) and inland (Itzehoe). In addition, the results of the meteorological models (friction velocity and pressure fields) are used for forcing the oceanographic models. Synoptic meteorological data go into the oceanographic circulation model for the entire North Sea. The mesoscale model results will be used for the mesoscale circulation model of the southern North Sea.

Oceanographic models

Numerical models of the dynamics and suspended matter and pollutant transport within the North Sea are under development. The 3D-circulation model (Backhaus and Hainbucher 1987) has been extended by a forcing by actual wind data and SST-fields, now allowing simulation of the depth of the thermocline (Pohlmann 1990). Fig. 7 shows the computed thermocline depth for the month of July 1988.

On the basis of velocity fields of the circulation model and wave data, simulations of suspended matter transport and concentrations have been carried out (Puls and Sündermann 1990, Sündermann and Puls 1990) as well as lead concentrations and accumulation rates of fine sediments (see Fig. 8 for an example).

Due to the importance of small scale hydrodynamic processes in the German Bight and due to the location in a coastal current

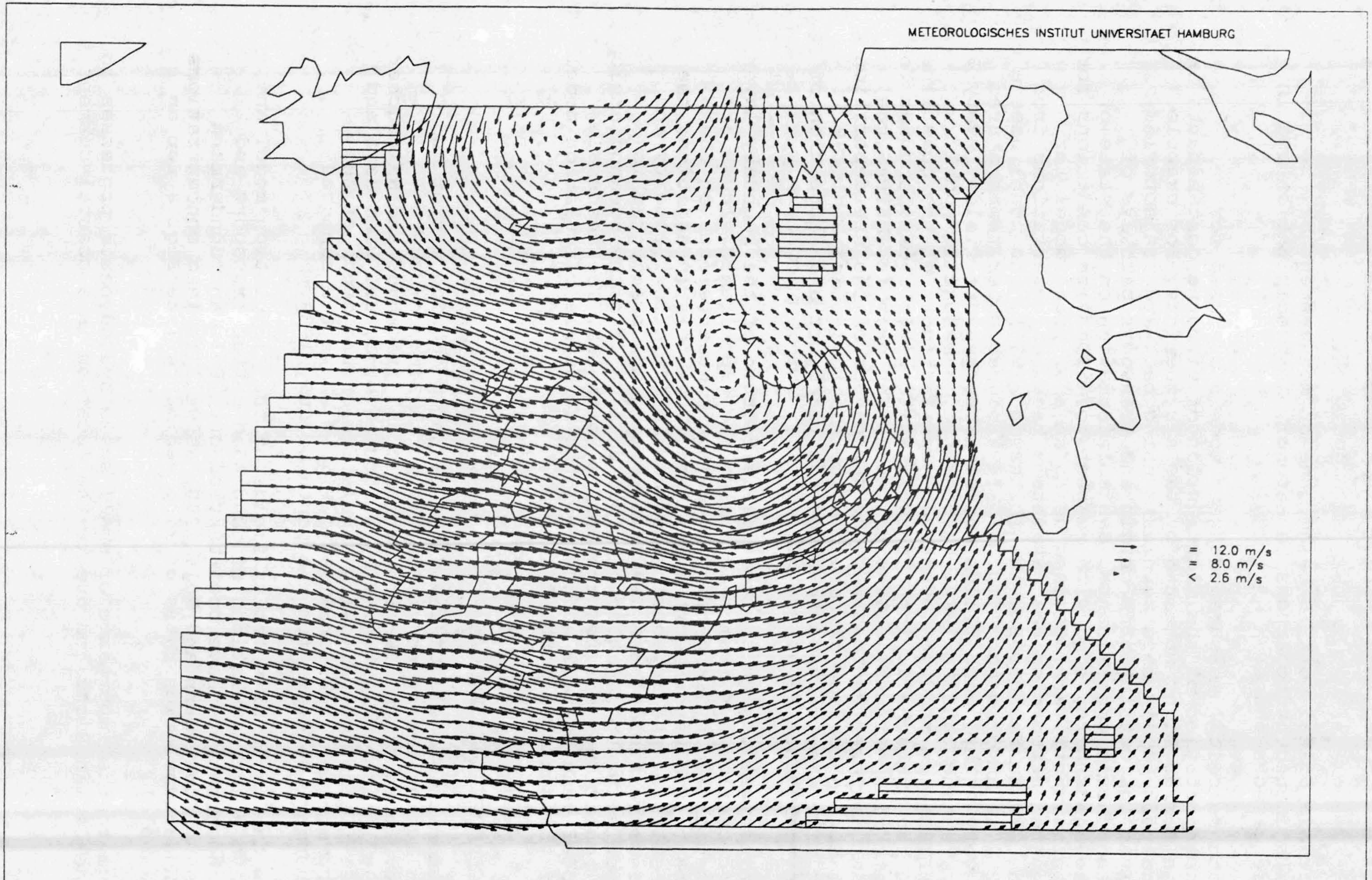

Fig. 6: Example of a wind field produced by the analytical meteorological model (Luthardt, 1985) for 26 Feb. 1990, 12.00 h UTC. The cyclone Viviane, recognizable off the southwest coast of Norway, caused extremely high wind speeds over the North Sea.

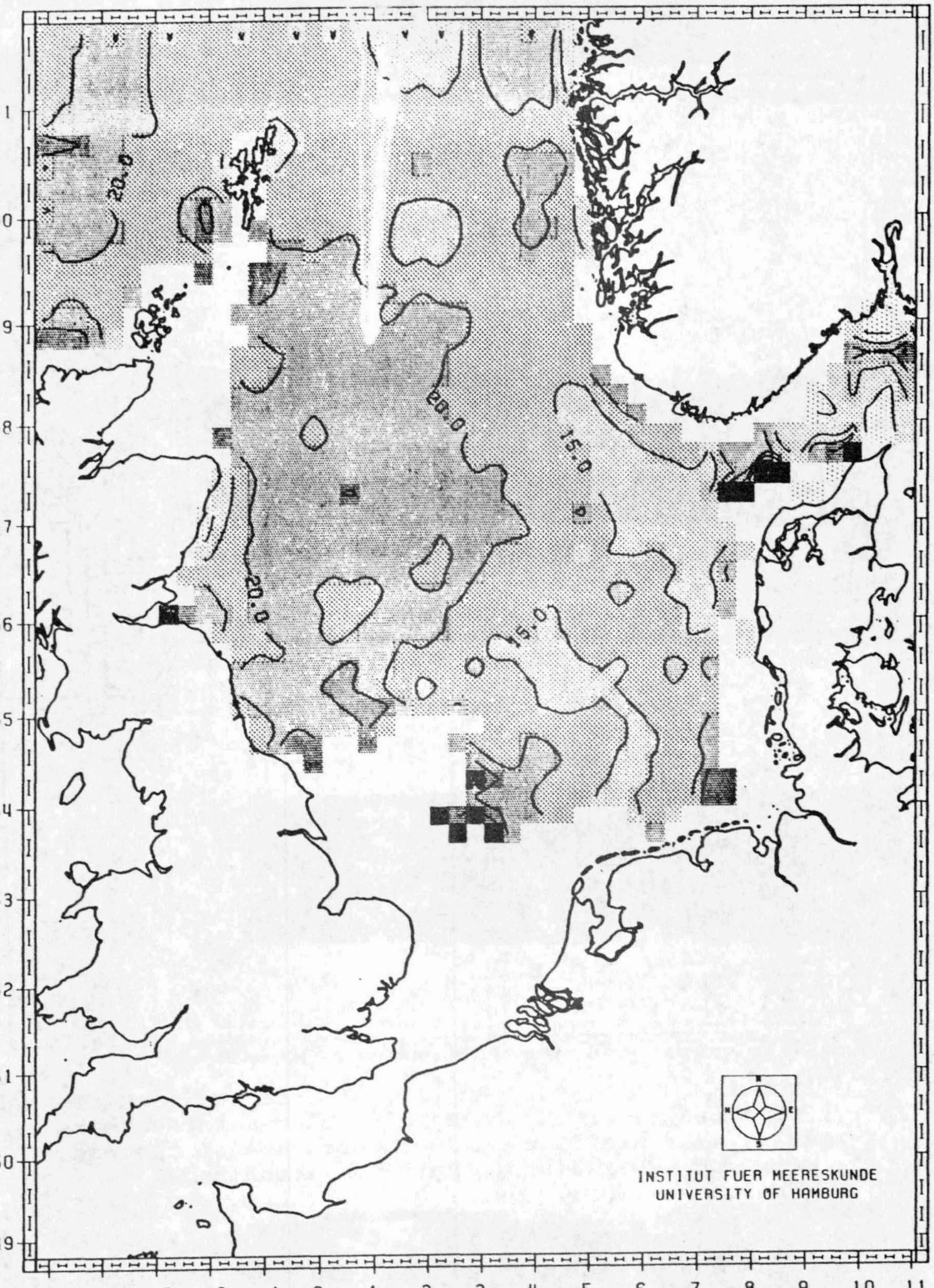

Fig. 7: Depth of the thermocline in meters, calculated as monthly means by a 3-D-circulation model (Pohlmann, 1990) for July, 1988.

0.00 - 1.00
1.00 - 2.00
2.00 - 3.00
3.00 - 10.00
10.00 - 15.00
15.00 - 20.00
20.00 - 25.00
25.00 - 30.00
30.00 - 40.00
40.00 - 50.00
> 50.00

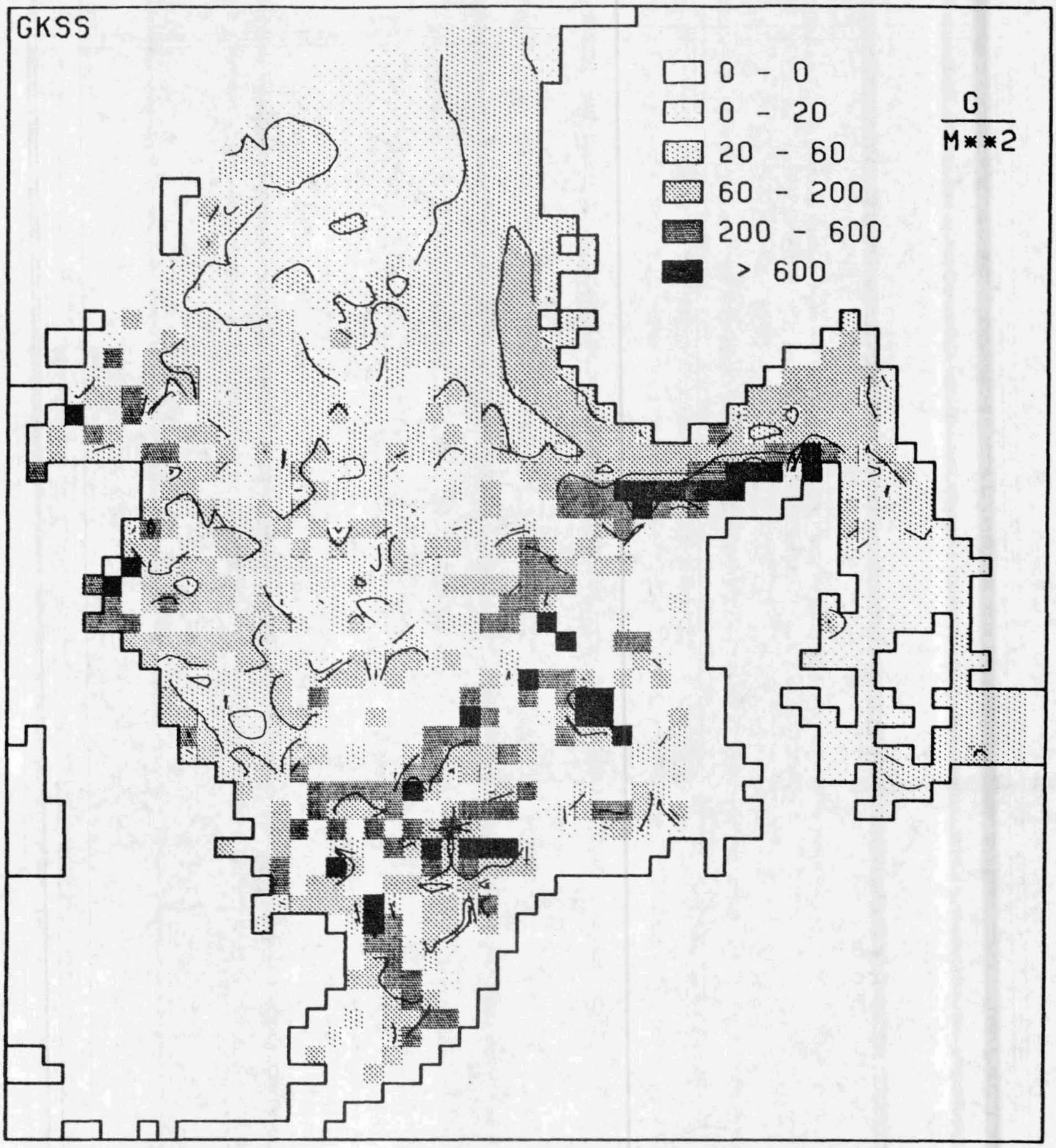

Fig. 8: Computed annual accumulation of fine sediment at the North Sea floor, average value of the three years 1979, 1985 and 1986. Calculations are on the basis of velocity fields of the circulation model (Pohlmann & Puls, 1992).

system in which contaminants from local and remote sources are mixed, transport models with a high resolution are necessary in order to distinguish the different pathways of transported pollutants. Such a model is currently under development for the southern North Sea. Numerical models are also being developed to simulate the transfer of contaminants within the ecosystem by plankton. On the basis of a 1-D phytoplankton-phosphate model (Moll, 1989), a 3-D model is under development in which advection and diffusion are included. The aim of this model is to interpret primary production in time and space as well as transport processes of pollutants within the ecosystem.

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