PROSJEKTRAPPORT

ISSN 0071-5638

HAVFORSKNINGSINSTITUTTET
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Forskningsstasjonen Flødevigen	Austevoll havbruksstasjon	Matre havbruksstasjon
4817 His	5392 Storebø	5984 Matredal
Tlf.: 37 05 90 00	Tlf.: 55 23 85 00	Tlf.: 55 23 85 00
Faks: 37 05 90 01	Faks: 56 18 22 22	Faks: 56 36 75 85

Distribusjon: ÅPEN

HI-prosjektnr.: 15.03.01

Oppdragsgiver(e): Nordisk Ministerråd

Oppdragsgivers referanse: NO COMMENTS

Rapport: FISKEN OG HAVET — NR. 3 - 2002

Tittel:
ENVIRONMENTAL STATUS OF THE SKAGERRAK AND NORTH SEA 2000

Senter: Marint miljø

Seksjon: Fysisk oseanografi

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Antall sider, vedlegg inkl.: 22

Dato: 20.03.2002

Sammendrag:

En koblet fysisk, kjemisk og biologisk havmodell (NORWECOM) er brukt for å simulere år 2000 i Nordsjøen og Skagerrak. Resultatene fra denne modellkjøringen er så brukt for å lage en miljøstatus for dette året. I statusen presenteres blant annet verdier for primærproduksjon, oxygen-nivå, sedimenteringsrate og vanntransport inn til Nordsjøen. Til slutt blir det gitt en vurdering av eutrofieringsgraden i Skagerrak og Kattegat basert på referanseverdier foreslått av svenske miljøstyresmakter.

Emneord - norsk:
1. Miljøstatus
2. Nordsjøen og Skagerrak
3. Numerisk modell

Emneord - engelsk:
1. Environmental status
2. North Sea and Skagerrak
3. Numerical model

Prosjektleder

Seksjonsleder

Environmental status of the Skagerrak and North Sea 2000

Morten D. Skogen Einar Svendsen Henrik Søiland

Abstract

An environmental status for year 2000 of the North Sea and Skagerrak has been done based on outputs from a biophysical model (NORWECOM). The model results suggests that in year 2000 the mean annual primary production in the North Sea was the highest in the period 1985-2000, and that the net inflow through the English Channel, due to an extreme strong influx in the fourth quarter, was the highest on an annual basis in the period 1955-2000. Also the oxygen levels and sedimentation rates in the North Sea and Skagerrak have been examined, and a eutrophication assessment conclude that, except for the winter values of nitrate, eutrophication is not a big problem in most of the Skagerrak and Kattegat area.

Key words : Skagerrak, North Sea, environmental status

1 Introduction

A project, NO COMMENTS (NOrdic COMmunity Model for ENvironmental Tasks in the Seas), supported by the Nordic Council of Ministers' Sea and Air Group, started out in 1999 with the main objective *to develop an operational modelling tool for environmental management and planning in the Baltic Sea and the North Sea.* One of the deliverables in the project is a yearly model run to give an environmental status of the areas of interest. Such a status should also include an overview of some of the last years events and possible calculation of source aportionment from different countries based on last years loads. The environmental status has been be carried out in two steps. In the first step a provisional status is produced based on available data at the start of the subsequent year, while a final environmental status is carried out at the end of that year including the best available observed input data for biogeochemical effluents. One status is made for Region West (North Sea and Skagerrak) based on the model runs performed at IMR/DNMI, and one for Region East (Baltic) from the model operated by SMHI.

The present report is the final year 2000 environmental status for Region West, and is a follow up of the provisional report for this region (Skogen *et al.*, 2001). Both reports are available at `http://www.imr.no/~morten/nocomments`.

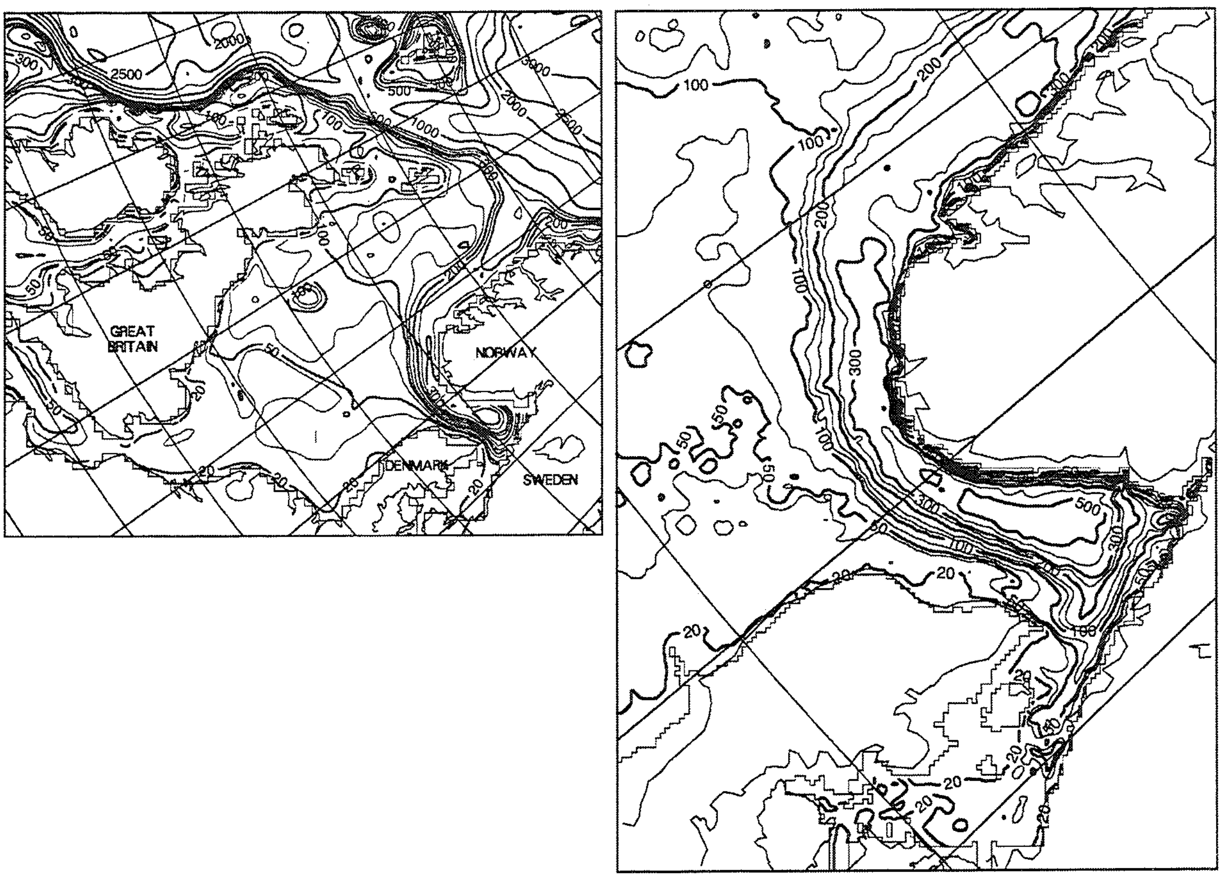

Figure 1: Model bathymetry. Coarse North Sea model domain (left) and fine Skagerrak model domain (right)

2 Material and methods

2.1 The model design

The NORWegian ECOlogical Model system (NORWECOM) is a coupled physical, chemical, biological model system (Aksnes *et al.*, 1995; Skogen *et al.*, 1995; Skogen & Søiland, 1998) applied to study primary production, nutrient budgets and dispersion of particles such as fish larvae and pollution. In the present study a nested version of the model is used, with a coarse 20 × 20 km. grid on an extended North Sea, and a fine 4 × 4 km. mesh in the Kattegat/Skagerrak area (see Figure 1). The coarse model was run initially, providing the necessary boundary and initial values for the fine grid. In the vertical 12 bottom-following sigma layers are used. The physical model is based on the primitive equation, wind and density driven Princeton Ocean Model (Blumberg & Mellor, 1987). The forcing variables are six-hourly hindcast atmospheric pressure fields and wind stress from the European Center for Medium Medium-Range Weather Forecasts (ECMWF), four tidal constituents at the lateral boundaries and freshwater runoff.

The chemical-biological model is coupled to the physical model through the subsurface light, the hydrography and the horizontal and the vertical movement of the water masses. The prognostic variables are dissolved inorganic nitrogen (DIN), phosphorous (PHO) and silicate (SI), two different types of phytoplankton (diatoms and flagellates), detritus (dead organic matter), diatom skeletals (biogenic silica), inorganic suspended particulate matter (ISPM), oxygen and light. The incident irradiation is modelled using a formulation based on Skartveit & Olseth (1986, 1987), with surface solar radiation data from ECMWF as input data. Nutrients (inorganic nitrogen, phosphorous and silicate) are added to the system from the rivers, from the atmosphere (only inorganic nitrogen) and through the open boundary. Particulate matter has a sinking speed relative to the water and may accumulate on the bottom if the bottom stress is below a certain threshold value and likewise resuspension takes place if the bottom stress is above a limit. Input data on suspended particulate matter, are taken from Pohlmann & Puls (1994). Regeneration of organic particulate matter takes place both in the water column and in the sediments. The bottom stress is due to both currents (including tides) and surface waves.

Surface heat fluxes (short and long wave radiation, sensible and latent heat fluxes), are calculated using data available from the ECMWF archive. Initial values for velocities, water elevation, temperature and salinity in the coarse model are taken from monthly climatologies (Martinsen *et al.*, 1992). Interpolation between monthly fields are used at all open boundaries, except at the inflow from the Baltic where the volume fluxes have been calculated from the modelled water elevation in the Kattegat and the climatological mean fresh water runoff to the Baltic, using an algorithm from Stigebrandt (1980). To absorb inconsistencies between the forced boundary conditions and the model results, a 7 grid cell "Flow Relaxation Scheme" (FRS) zone (Martinsen & Engedahl, 1987) is used around the open boundaries. To calculate the wave component of the bottom stress, data from DNMI's operational wave model, WINCH (SWAMP-Group, 1985; Reistad *et al.*, 1988), are used. The initial nutrient fields are derived from data obtained from ICES together with some small initial amounts of algae.

2.2 Experimental set-up

The 20km North Sea model was spun up by running 1998 three times and then 1998 through 2000 was run sequentially. The fine grid model was initialised with results from the coarse grid January 5, 1999. The 4 km model was run from January 5, 1999, through 2000 with boundary conditions from the 20 km North Sea model.

2.3 Limitations

The final 2000 environmental status has as far as possible been run with realistic forcing (wind, waves, light, heat fluxes, river runoffs, etc....). In Table 1 an overview of the forcing used in this simulation, and a comparison with the forcing used for the provisional run (Skogen *et al.*, 2001), is given.

	Final status	Provisional
Wind	ECMWF operational 2000	DNMI hindcast 2000
Waves	WINCH 2000	WINCH 1998
Irradiance	2D ECMWF 2000	Taastrup 1990
Heat flux	Radiation 2000 + relaxation	Relaxation towards climatology
SST relax.	30 days	10 days
SSS	Evap. - prec.	None
Rivers Belgium	Real/real	Clim/clim
Rivers Germany	Real/clim	Clim/clim
Rivers Denmark	Real/real	Clim/clim
Rivers United Kingdom	Clim/clim	Clim/clim
Rivers Norway	Real/clim	Clim/clim
Rivers Netherlands	Real/real	Clim/clim
Rivers Sweden	Real/real	Clim/clim
Baltic in/out	Clim	Clim

Table 1: Forcing used for the 2000 environemental status simulations. The river data should be read as *freshwater runoff/nutrient inputs*

The main improvements between the provisional and the final environmental status are: updated river inputs, updated wave data, implementation of a surface heat flux scheme and the use of realisitc two dimensional irradiance data in the light model. For reasons of stability, a weak relaxation towards climatological sea surface temperature is kept, but the time constant are increased from 10 days (provisional run) to 30 days. It was planned to use data for the Baltic inflow from the provisional run at SMHI, but since this simulation was not finished climatological data had to be used. For consistency, ECMWF data are used for all atmospheric forcings after the implementation of the radiation scheme. However, it should be noted that there might be significant differences between different wind fields (J.Ozer, MUMM, Brussels, pers.comm), and this might be reflected in the model outputs.

3 Results

3.1 Model validation: the Torungen-Hirtshals transect

One of the most important work in model development is to ensure and quantify the quality of the model implementation and results. This is also essential in respect to using the model as a tool for planning and decision. Therefore model validation (Dee, 1995) should go on continously through all modelling projects. For this purpose measurements from the Torungen-Hirtshals transect have been used for the validation of the outputs from the environemental status simulation.

Physical, chemical and biological state variables are measured along a section from

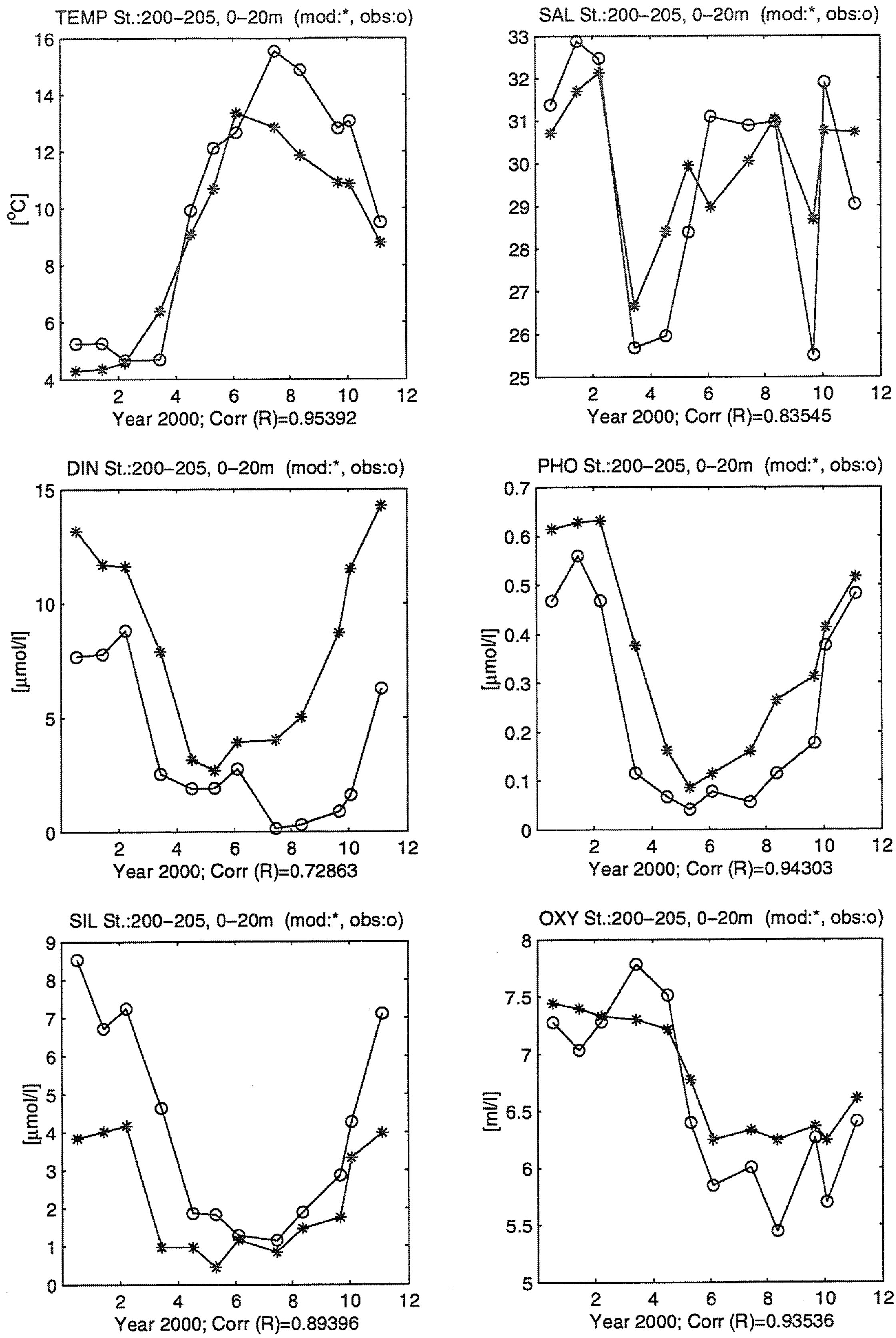

Figure 2: A comparison of measurements and model results in surface waters (0-20 m depth) on the Norwegian coast 0-5 nautical miles off Torungen

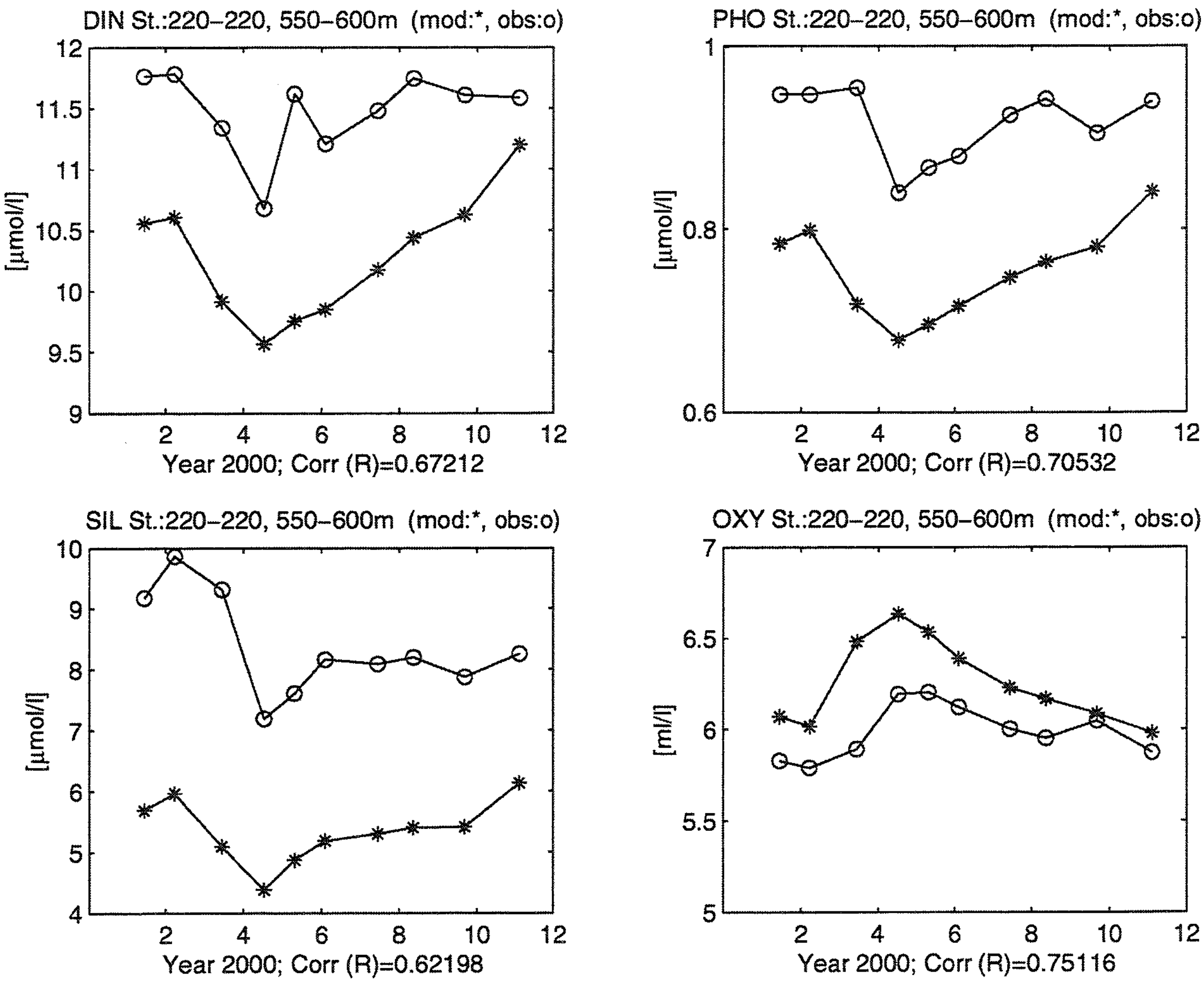

Figure 3: A comparison of measurements and model results in the deepest part of Skagerrak (550-600 m depth) 20 nautical miles off Torungen

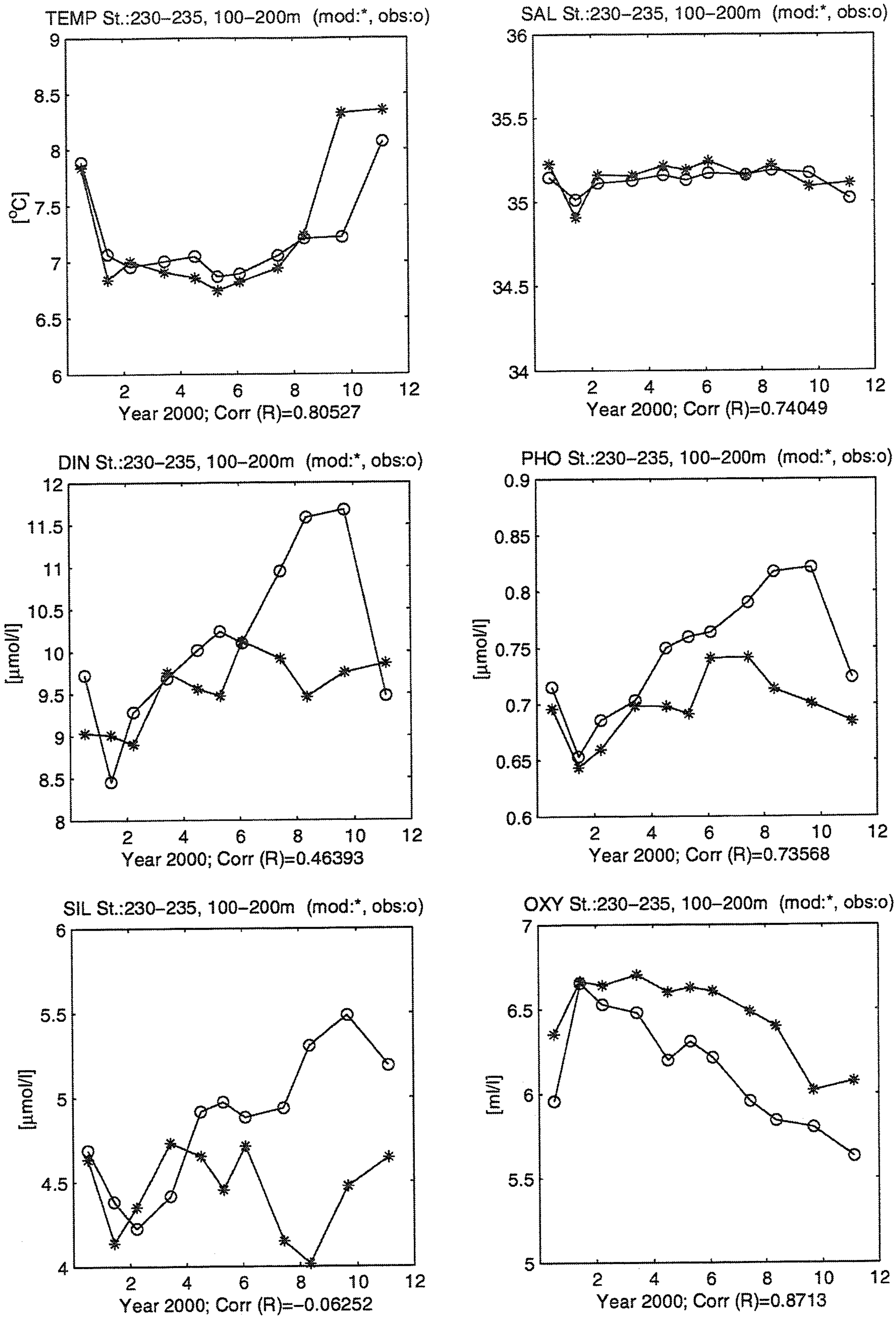

Figure 4: A comparison of measurements and model results in teh Atlantic inflow area (100-200 m depth) on the Danish shelf break 30-35 nautical miles off Torungen

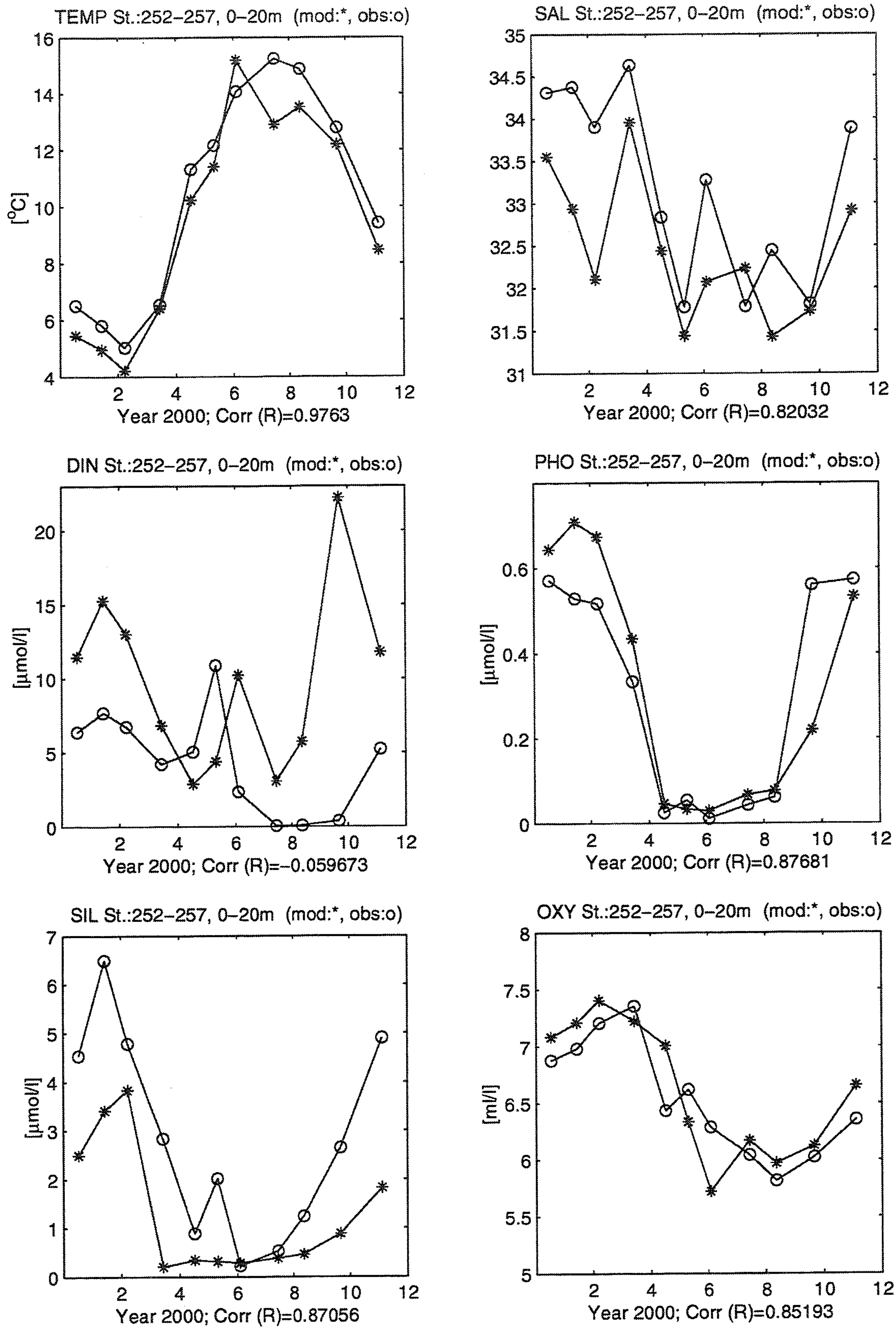

Figure 5: A comparison of measurements and model results in surface waters (0-20 m depth) on the Danish coast 52-57 nautical miles off Torungen

Torungen (outside Arendal, Norway) and Hirtshals (Denmark) approximately once every month days. Mean values from some of these stations over a certain depth interval are extracted and compared with similar spatial means from the model, using a 25 hourly mean for the same day as the measurements. It should be noted that the positions of the stations and model points will not have a perfect match. Four areas of comparison, each with different water masses present, have been selected. The first one with surface waters (0-20 m depth) close to the Norwegian coast (Figure 2), the second from the deepest station (550-600 m depth) of the transect (Figure 3), the third focus on the inflow of Atlantic water (100-200 m depth) on the shelf break on the Danish side of the transect (Figure 4), and the fourth one is the surface water (0-20 m depth) close to the Danish coast (Figure 5).

The figures show different degrees of agreement between model and measurements. There is a general high correlation between modeled and measured salinity, temperature and oxygen. The results for silicate, phosphate and dissolved inorganic nitrogen varies between the different water masses.

3.2 Algae and primary production

The annual depth integrated primary production ($gC/m^2/year$) for both the 20 kilometer North Sea model and the 4 kilometer Skagerrak model are shown in Figure 6. For the North Sea the highest modelled production is along the southern North Sea continental coast with an annual production of more than $200 gC/m^2/year$. This is more than 3 times the values in the central and northern North Sea. In the Skagerrak (except for the Danish coast), the coarse model gives production estimates between 100 and 150 $gC/m^2/year$, while the production outside the Norwegian west coast is around 100 $gC/m^2/year$.

These general patterns are also seen in the fine scale model. Inside Skagerrak the 4 kilometer model suggests values between 120 and 150 $gC/m^2/year$, with an elevated production (above 150 $gC/m^2/year$) along the Norwegian coast. This higher production is mainly diatoms, and is caused by new supplies of silicate during coastal upwelling events. The higher production in the central Skagerrak is probably related to the well known upwelling of nutrients associated with the typical cyclonic circulation in the Skagerrak.

Year 2000 is the first NO COMMENTS year, thus it is hard to tell how these values compare to a *mean* production level. However, Skogen & Moll (2000); Skogen(pers.comm), have modelled the primary production in the North Sea (20 kilometer resolution) from 1985 to 2001 using version 1.0 of NORWECOM (Skogen, 1993). Comparing those year 2000 results with the long term mean, indicates that year 2000 has the highest (together with 1990) mean annual production in the period, almost two standard deviations above the mean. Except for the areas along the English and continental coast, the production in 2000 appears to be higher than normal in the whole North Sea, with the highest positive anomali of more than 10 % above the mean in the whole Atlantic inflowing area. In the Skagerrak the model gives values between 0 and 10 % above the mean, while in the Kattegat the production were lower than normal.

To get an idea about the day to day variability in the primary production, the spatial averaged modelled daily production ($gC/m2/day$) in Skagerrak are shown in Figure 7.

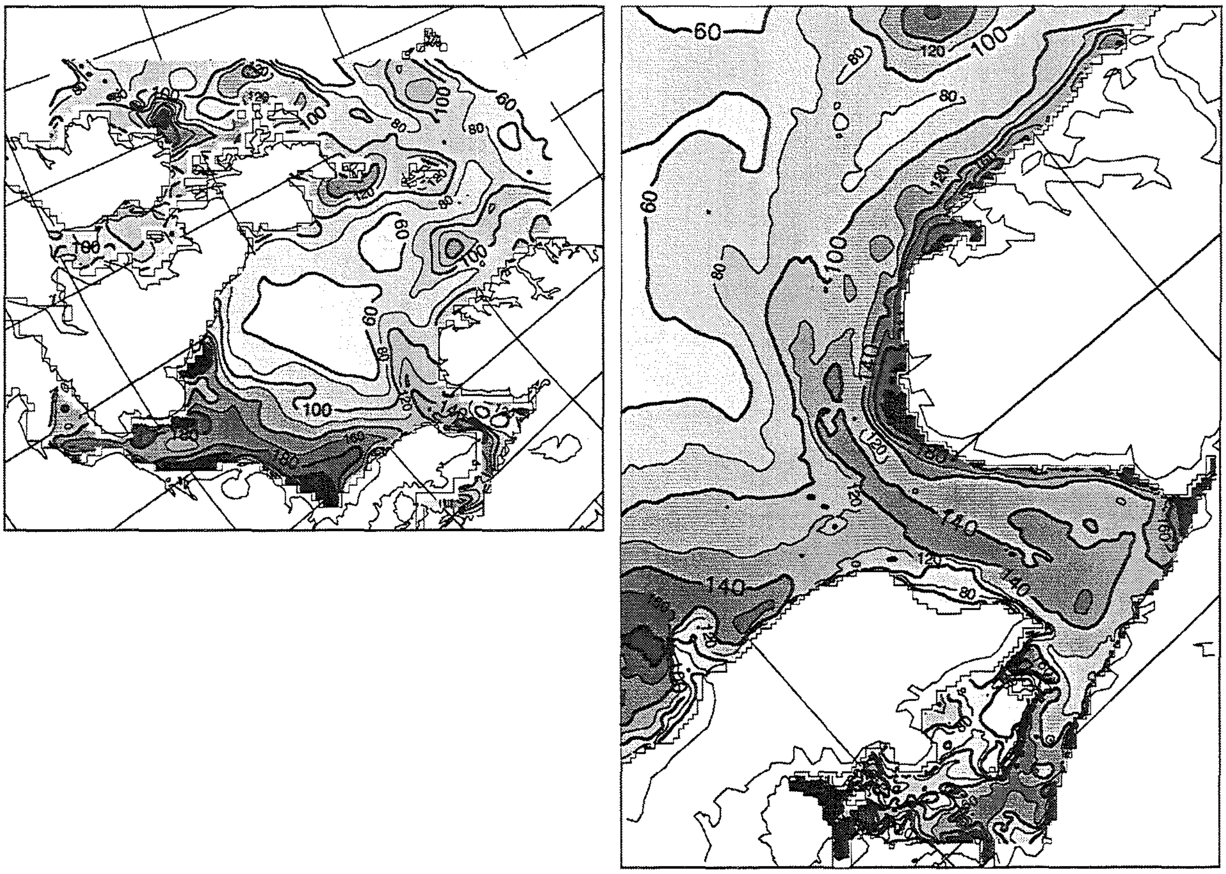

Figure 6: Modelled annual depth integrated primary production ($gC/m^2/year$) for the coarse North Sea model (left) and the fine Skagerrak model (right)

The production has an average of 0.36 and a maximum level of 1.45 $gC/m2/day$. The production shows large day to day variations. In the figure an early spring diatom bloom with a maximum in the end of March, followed by a bloom of flagellates with a maximum in early May can clearly be seen. The flagellate production decreases as the nutrients are depleted, but several production maximas are seen both in the late summer and fall.

In early May 2000 a bloom of the harmful algae *Chatonella* was observed along the Danish west coast. This algae was registered for the first time in Scandinavian waters in 1998, when it caused death in fish farms in an area close to the southern tip of Norway. After that, the *Chatonella* disappeared and was not seen blooming along the Norwegian coast later that year. However, it was observed in very high concentrations on the west coast of Denmark resulting in dead garfish, herring, sandeel and mackerel (Aure *et al.*, 2001). It was feared that also in the May 2000 bloom, a wave of *Chatonella* might follow the prevailing cyclonic circulation in the Skagerrak, and result in a new situation with death in Norwegian fish farms.

An operational model run (Skogen & Søiland, pers.comm.), with less updated forcing

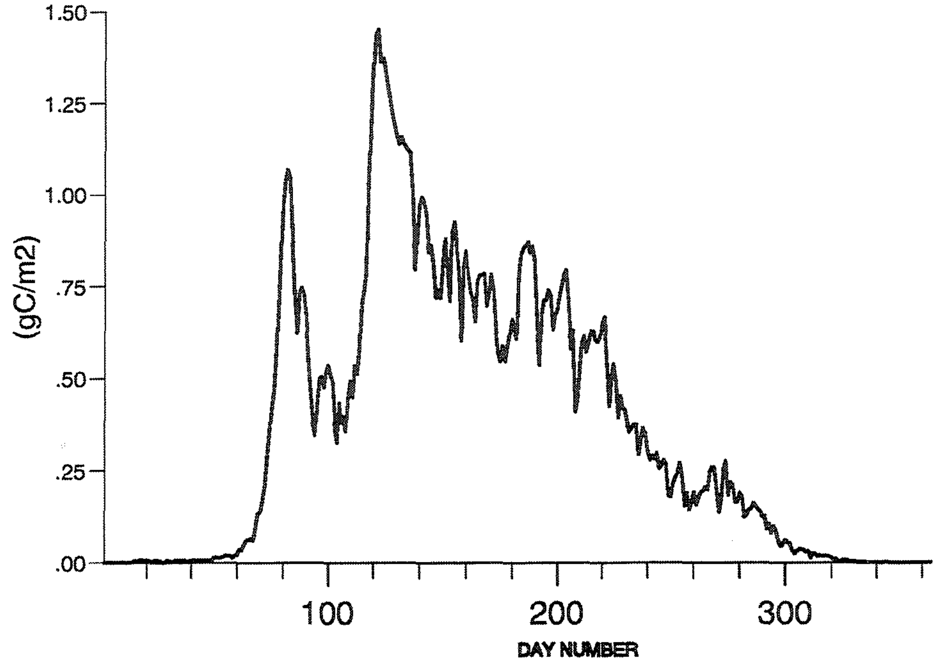

Figure 7: Modelled daily primary production ($gC/m2/day$) in Skagerrak from the fine scale model

than for the present environmental status, were used to forecast the growth and advection of these algae. From this operational simulation, the modelled flagellate distribution at 3 m depth for May 8 and May 16 are shown in Figure 8. On May 8 very high algae concentrations are seen on the Danish west coast, while the model gives much lower concentrations a week later. The *Chatonella* did not recover after this, and it was not reported on any death of fish due to the bloom. This decay of the bloom was also confirmed by satellite imagery as reported in the DeciDe-HAB project (`http://www.nrsc.no/Decide-HAB/`). The modeled decay of the bloom was caused by a lack of nutrients. Since also the predicted circulation was not in favor of rapid transports of the blooming algae to the Norwegian and Swedish coasts, it was used operationally to forecast that this bloom would not make any harm for the fish farms around the Skagerrak and west coast of Norway.

3.3 Oxygen and sedimentation

One of the main concerns related to eutrophication is oxygen depletion. High production, sinking of dead organic matter and biochemical decomposition of organic matter, can locally give rise to low oxygen values in stagnant water. In Figure 9 the modelled oxygen concentration in the lowermost model level (within 2.5 % above the sea bottom) are shown. The situations are from week 1 (early January) and week 37 (mid September).

In the beginning of the year the oxygen conditions are good in most of the North Sea. Except for the Norwegian trench and two local mimimas east of Scotland (coincides with

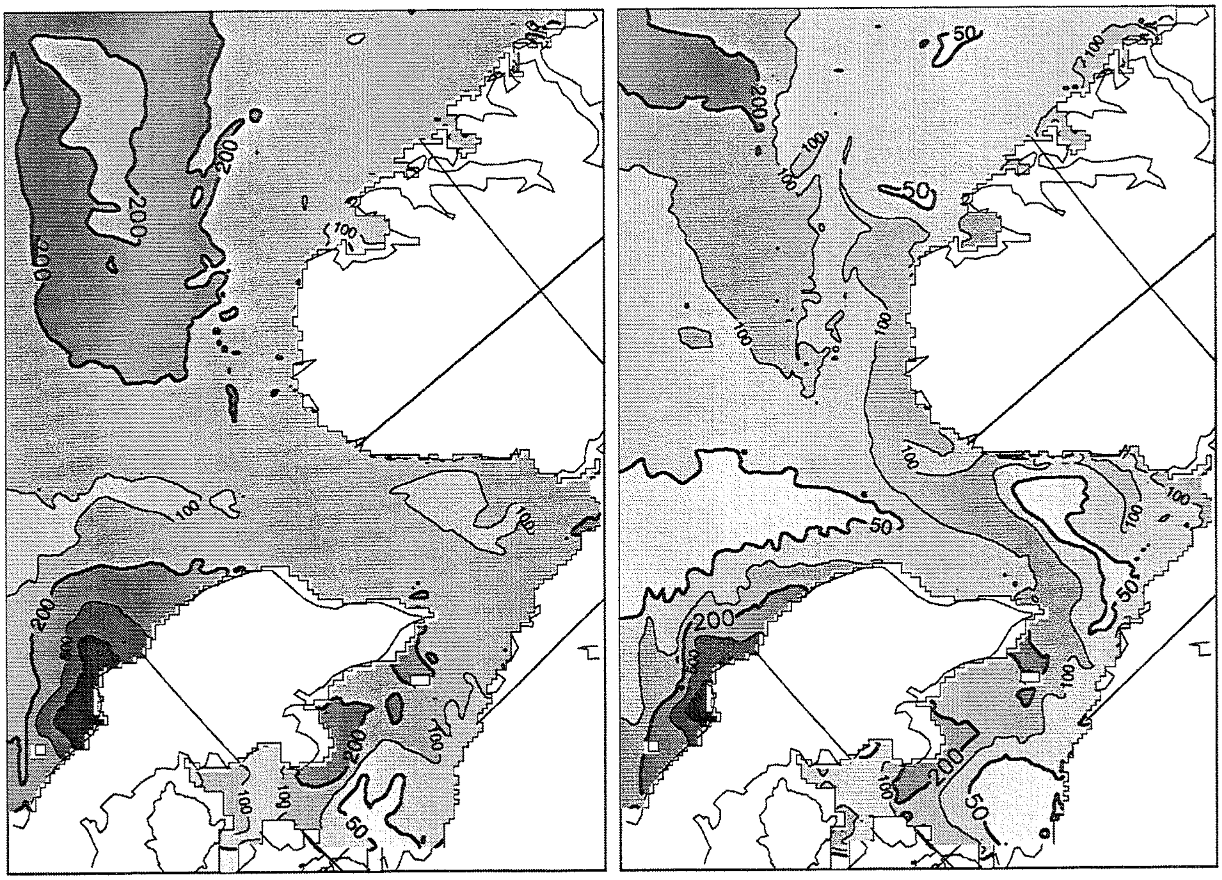

Figure 8: Modelled flagellate distribution (mgC/m^3) at 3 m depth for May 8 (left) and May 16 (right)

local minimas in the topography), the modelled oxygen levels are higher than $6.5ml/l$. During summer, an oxygen minimum are developing south and east of the Dogger Bank, and in week 37 two local oxygen minimas (extending towards the Skagerrak) are seen in this area. They are both connected to local mimimas in the topography, where stagnant waters are appearant. At this time the modelled minimum oxygen levels are just below $3ml/l$. One of these minimas extends into the 4 km domain, where a plume of low oxygen water are following the shelf break into Skagerrak. The model shows the appearance of this low oxygen water during a three weeks period in mid September. Measurements on September 11 along the Torungen - Hirtshals transect (measured approximately once every month), indicates the appearance of a oxygen minimum on the shelf break on the Danish side (30-75 m depth). On the Norwegian coast a similar minimum is seen, with a second extreme minima 15 nm. off the Norwegian coast at the same depth. The oxygen level at the second point off the Norwegian coast, is the lowest measured at this position in the period 1990-2000 (D.Danielssen, Flødevigen, pers.comm.). An oxygen minimum is also seen outside Hirtshals August 14, and the corresponding salinity values indicates

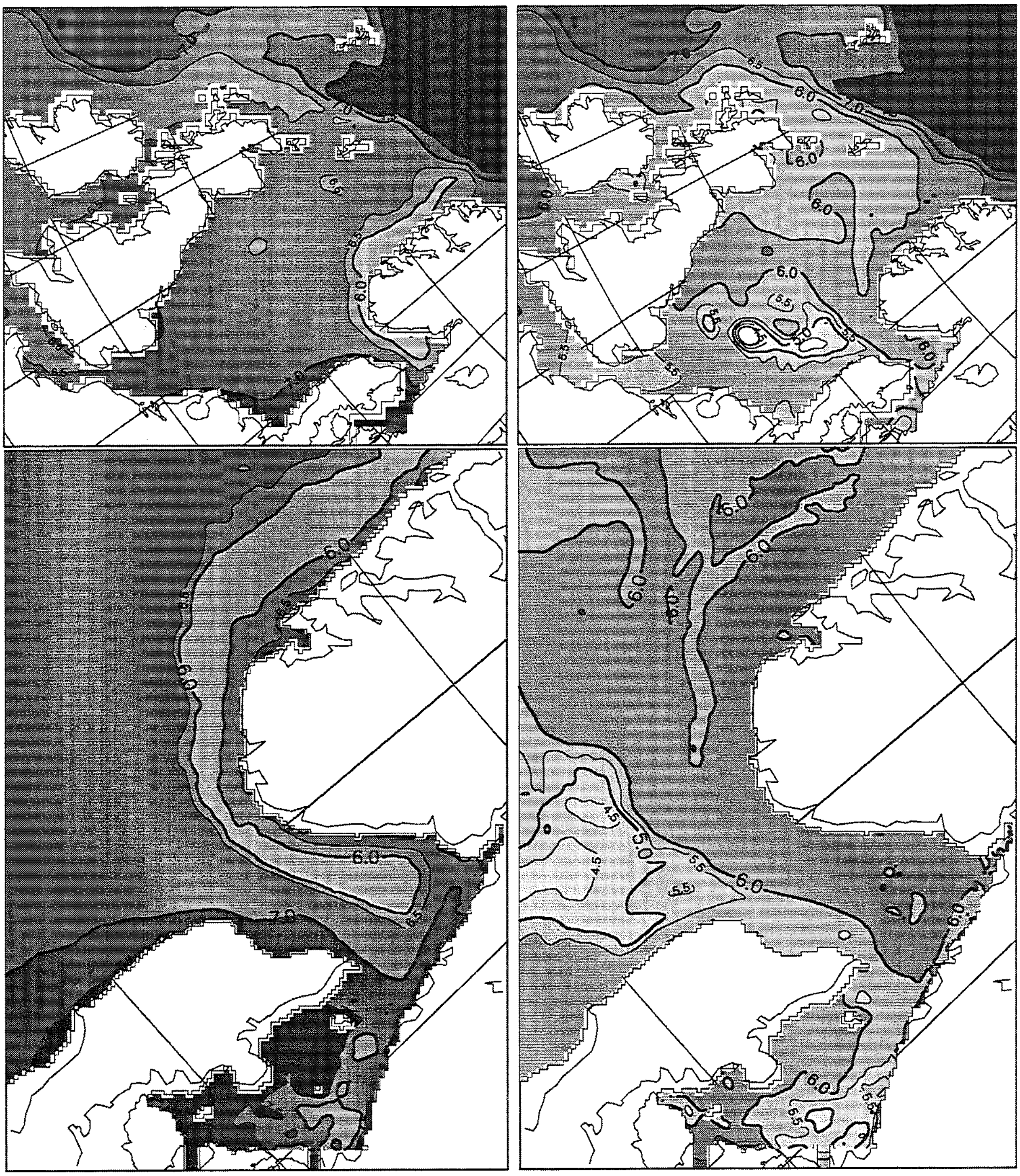

Figure 9: Modelled oxygen, ml/l, (left) in the lowermost model level (2.5 % above bottom) from the coarse North Sea model (upper) and the fine Skagerrak model in December (lower). Week 1 (early January) in the left panels and week 37 (mid September) in the right panels

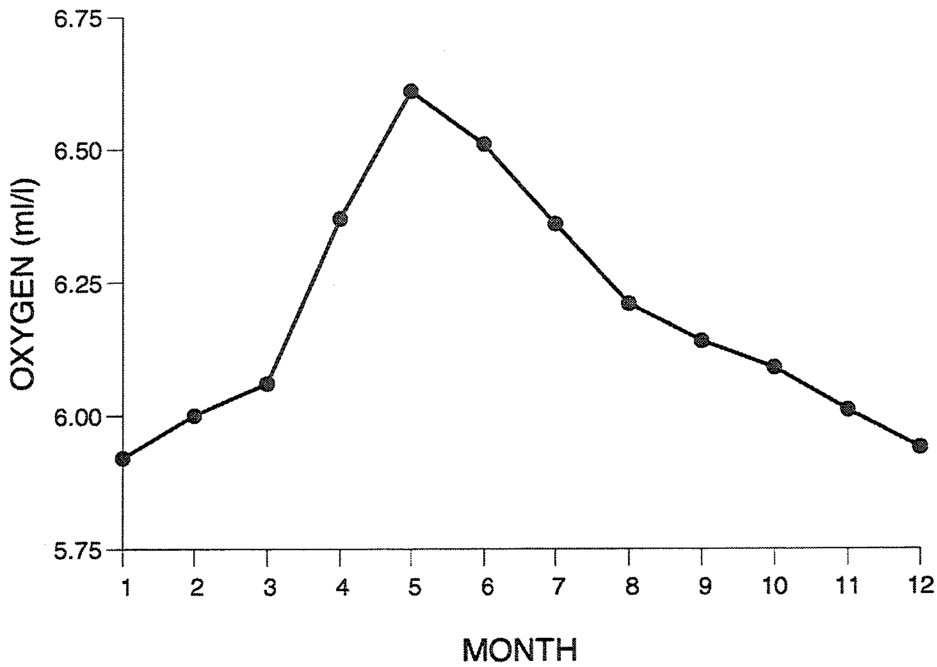

Figure 10: Modelled mean monthly oxygen level (ml/l) in Skagerrak below 500 m depth from the fine scale model

that the low oxygen water originates from the North Sea. The oxygen minimum outside Norway is never seen in the model, we assume this is due to too much mixing in the model. Nevertheless, the model reproduces the observed advection of low oxygen North Sea water into the Skagerrak.

Except for this low oxygen plume, the bottom water in most of Skagerrak and Kattegat has oxygen levels higher than 5.5 ml/l. In December (not shown) the model gives a similar picture as January with no oxygen depleted areas in the North Sea due to the strong winds causing vertical mixing to the bottom, except for the low oxygen levels in the Norwegian trench and Skagerrak being too deep and stratified for surface wind mixing to reach the bottom. During summer and fall the model shows a continuous decrease in the oxygen levels in the Norwegian trench This trend is shown in Figure 10, where the mean oxygen concentration below 500 m in Skagerrak are plotted. Both data and previous model experiments (Søiland *et al.*, 2001), indicates an oxygen minimum in winter, with a renewal of the bottom waters in spring (see also Figure 3).

The net sedimentation results (Figure 11) for December show that except for a few small areas east of Scotland, the only sedimentation area in the North Sea are in the Norwegian trench, Skagerrak and partly eastern Kattegat. However, the results for September show that there is a large area south and east of Dogger Bank where net sedimentation occurs during summer, but that these sediments are resuspended during fall. The modelled mean sedimentation rate inside Skagerrak is approximately $300g/m^2/year$, but there are large spatial differences with the highest net sedimentation in the deepest part. The coarse

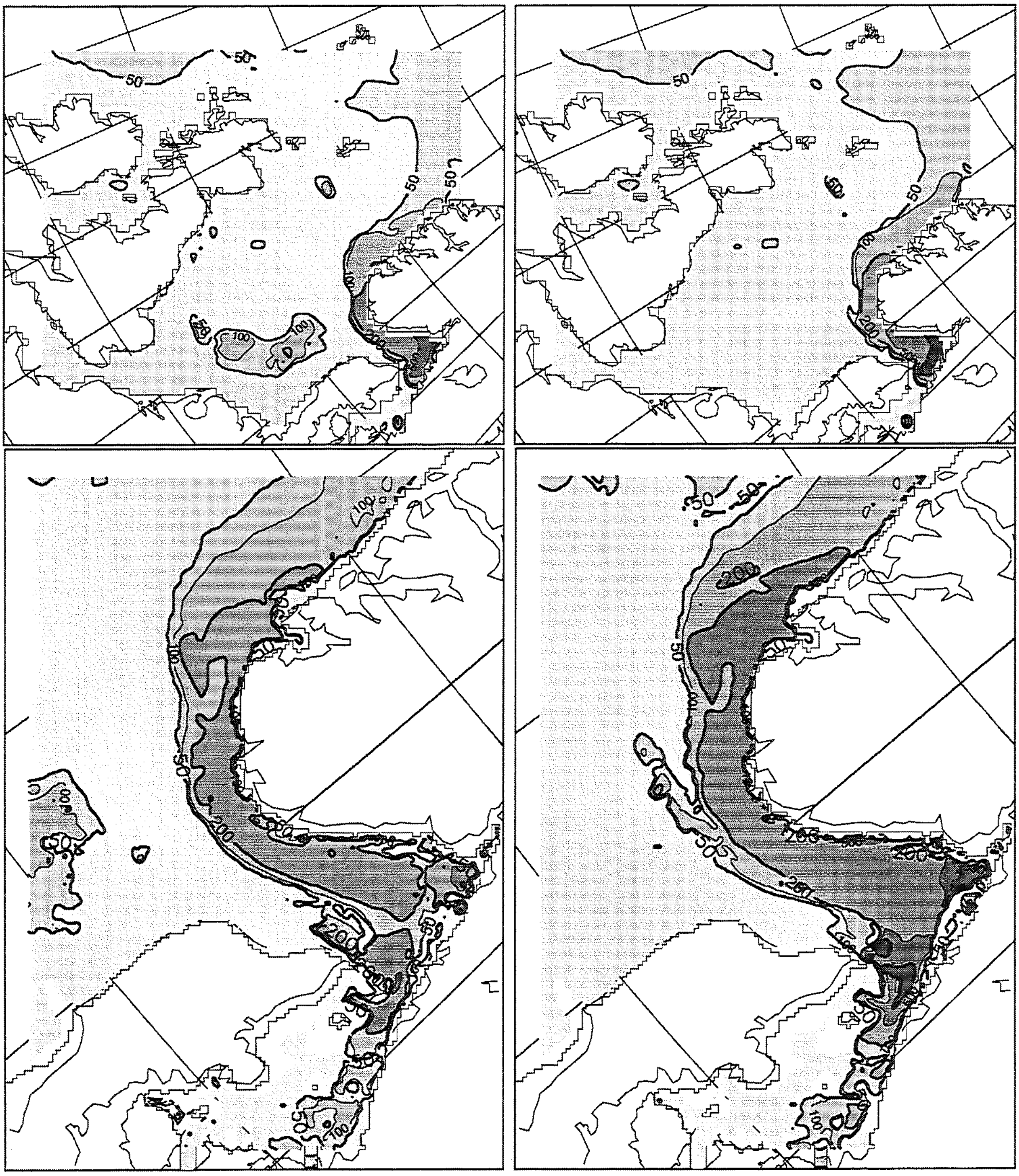

Figure 11: Accumulated net sedimentation (g/m^2) the last model year in the coarse and fine simulation. September (left) and December (right)

model has a local maxima in the eastern part of Skagerrak of $1250 g/m^2/year$, while the fine scale model has a maximum of more than $1.6 kg/m^2/year$ in the same area.

3.4 Circulation

The modelled year 2000 North Sea circulation are shown in Figure 12, both as an annual and a fourth quarter mean. The model reproduces the well known cyclonic circulation pattern, with a well defined Norwegian Coastal Current, Atlantic and English Channel inflow and the eastward Dooley current at about 58°N. Using a similar approach as for the modelled primary production, year 2000 can be classified from a long term modelling experiment. The physical part of NORWECOM has been run for an area covering the whole shelf area from Portugal to Norway (including the North Sea) for all years back to 1955 (Iversen *et al.* (2002); Skogen(pers.comm)). Focusing on the North Sea inflow, the flux through an east-west section going from Norway (Utsira) to Orkneys (along 59.17°N) are approximately 20 % above the mean in the first quarter, while the flux is approximately 10 % below the mean the rest of the year. The southern inflow through the English Channel have a quite normal values in the three first quarters, but for the last quarter there is a dramatic change. The net inflow is about 6 times higher than the long term mean for this quarter, and has the maximum fourth quarter value through the whole 45 year model period. It is also interesting to observe that this makes year 2000 the highest year (of the 45 years) of annual mean net inflow through the English Channel, and continues a trend back to 1996 with very high inflows to the North Sea through the English Channel.

Comparing both the 20 kilometer and 4 kilometer model (Figure 12), it is interesting to observe how the origin of the Skagerrak surface waters changes to mainly Central and Southern North Sea waters in the fourth quarter of year 2000.

3.5 Eutrophication assessment

The supply of nutrients and the possible eutrophication of the open sea and coastal waters (e.g. extensive algal blooms, oxygen depletion in bottom waters, extinction of bottom living species) can be studied with various types of measurements and observations. Accordingly, a number of parameters are needed as an assessment criteria for eutrophication. Among others, the Eutrophication Task Group (ETG) under the OSPAR Convention have done an extensive work on the definition of such Ecological Quality Objectives for assessing nutrient and eutrophication effects to be used within the whole North East Atlantic. Also the Swedish Environmental Protection Agency has made a set of assessment criterias for Swedish and adjacent waters which can highlight the effect of eutrophication. Based on levels of several state variables (chlorophyll$_a$, bottom oxygen, nutrients, water transparency) measured along the Swedish coast around 1990, the level of eutrophication are classified is five classes as: very low, low, moderate, high and very high. These levels have been used in the present assessment for reference. Further information are available on `http://www.internat.environ.se`.

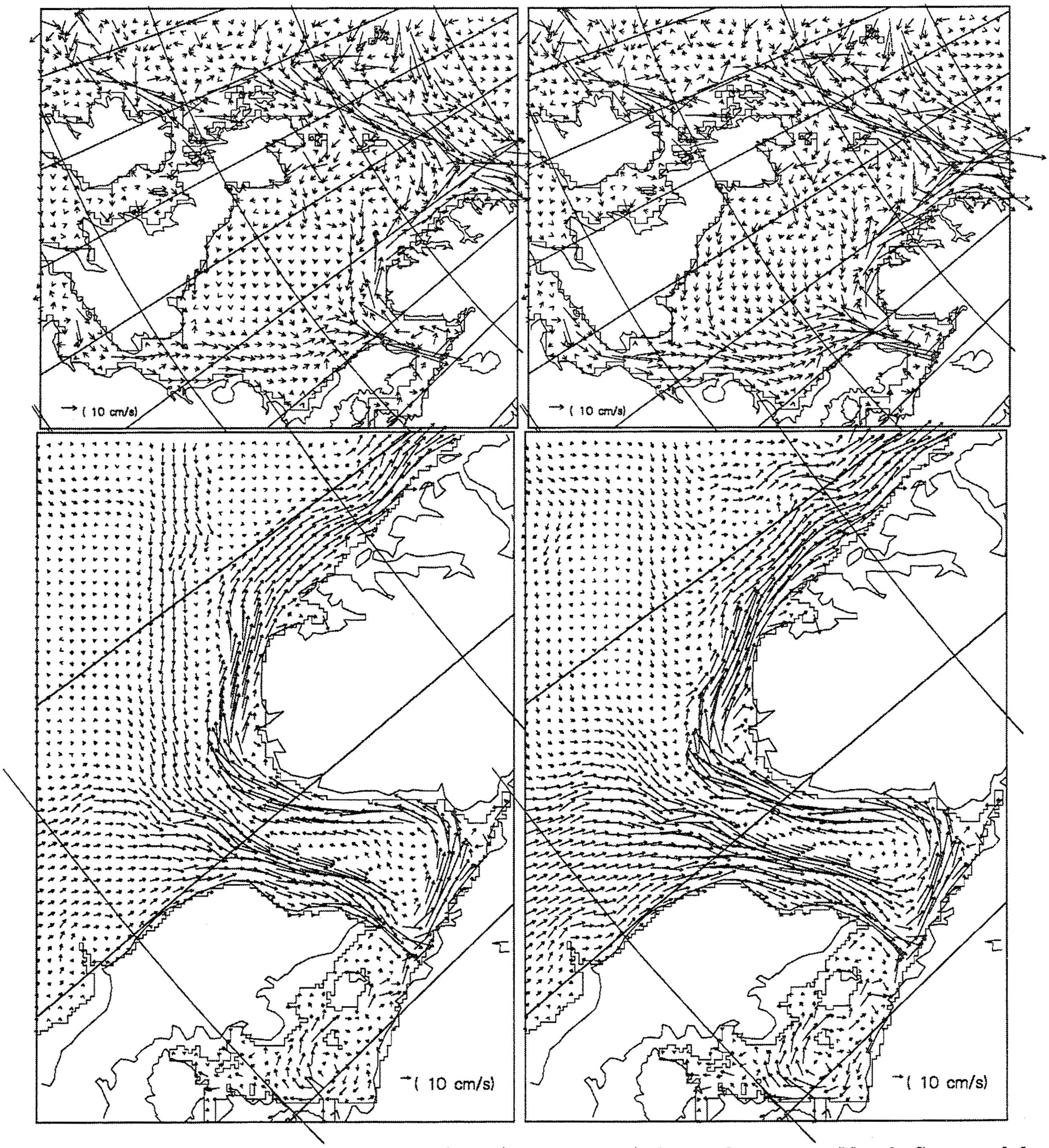

Figure 12: Modelled mean velocity field (10 m depth) from the coarse North Sea model (upper) and fine Skagerrak model (lower). Annual mean (left) and fourth quarter (October-December, right)

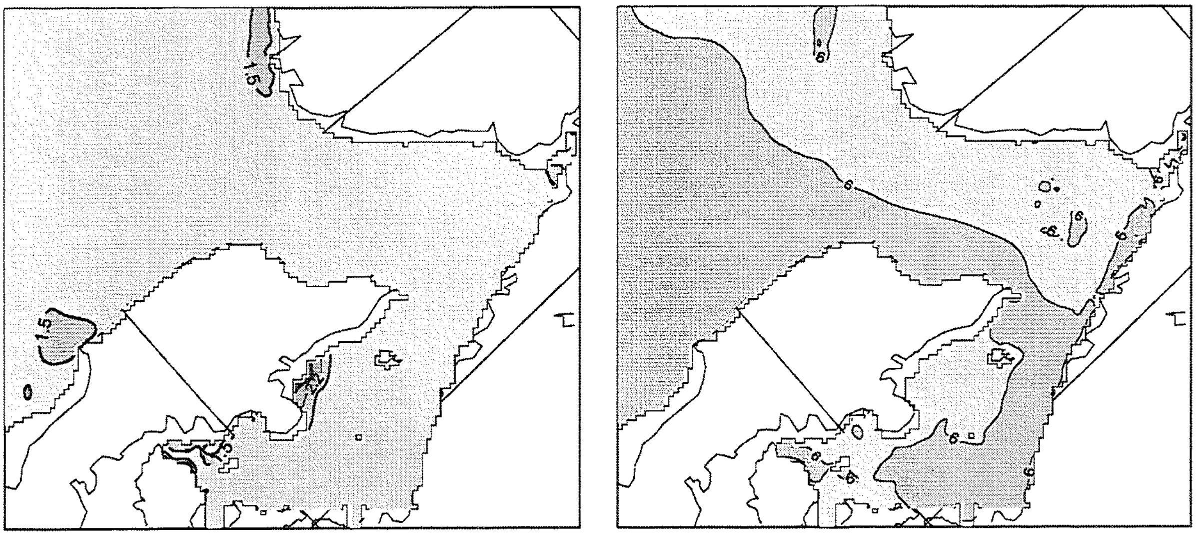

Figure 13: Modelled eutrophication assessment levels of Chlorophyll$_a$ in August (left) and oxygen in mid September (right). The colors, referring to the eutrophication levels, should be read as: very high (red), high, moderatly high, low and very low (blue)

3.5.1 Chlorophyll

The amount of the coloured substance, chlorophyll$_a$, provides an indirect measure of phytoplankton concentration in water. The level of chlorophyll$_a$ is thus related to the concentrations of nutrients in the water and to the degree of eutrophication. Chlorophyll$_a$ levels can vary widely in time and space, therefore measurements should be carried out in August when temporal variations are comparatively small.

The mean modelled chlorophyll$_a$ concentration at 5 m depth have been used to assess the level of eutrophication from chlorophyll. The results from the fine scale model in Skagerrak and Kattegat (note the somewhat reduced view) is shown in Figure 13. The model gives very low levels ($< 1.5\mu g/l$) in most of Skagerrak and Kattegat. In the Oslofjord and west of Jutland there are areas with Low values (1.5-2.2 $\mu g/l$), while there are some areas along the Danish east coast which are classified as Moderate and High ($> 3.2\mu g/l$).

3.5.2 Bottom level oxygen

Eutrophication implies an increased risk of oxygen depletion in bottom-level waters. The lowest level of oxygen during the course of the year is decisive for the survival of the bottom fauna. That annual minimum may therefore be used to indicate the negative consequences of eutrophication.

The oxygen content of the bottom waters is determined by the balance between supply and consumption. Oxygen is transported to the bottom areas primarily through mixing with surface waters, or via inflow of bottom waters from other areas. Oxygen is consumed in the respiration of living organisms and the decomposition of organic matter.

During periods of limited supply and large consumption, oxygen depletion may occur. Eutrophication leads to increased oxygen consumption, and therefore increases the risk of oxygen depletion. If the oxygen is completely exhausted, hydrogen sulphide is formed. Oxygen depletion and, even more so, the presence of hydrogen sulphide constitute a serious threat to the bottom fauna. The risk is usually greatest in the deepest sections of a water body.

The lowest oxygen levels during the year usually occur during late summer and autumn. But such episodes are usually brief, and may thus go undetected if samples are not taken frequently enough during the critical seasons of the year. Data on oxygen concentrations should thus be compared with the conditions for the soft-bottom fauna, which may be affected by even very short periods of oxygen deficiency.

The week averaged oxygen in the bottom layer of the model have been examined in late summer and fall to search for episodes of low oxygen levels. The situation from week 37 (mid September) is shown in Figure 13. The modelled bottom layer show high (=very low eutrophication level) ($> 6ml/l$) or moderatley high ($4 - 6ml/l$) oxygen levels in all areas except for the Oslofjord where a small area of low oxygen levels ($2 - 4ml/l$) occurs.

3.5.3 Winter nutrients

Assessments of nutrient levels in coastal and marine waters can be based partly on the supply of total nitrogen and phosphorus during both summer and winter, and partly on winter levels of phosphates and of nitrogen in ammonium, nitrates and nitrites.

Levels of total nitrogen and phosphorus in sea water include not only dissolved inorganic nutrients, but also the amounts that are bound in plankton and suspended particles. Those levels vary widely during the course of the year. During summer and winter, they can serve as measures of the total amounts of nutrients in the marine ecosystem. They can also be used throughout the year as indicators of eutrophication. However, measurements taken during massive algal blooms should not be used, since surface waters may contain abnormally high levels of the nutrients that are bound in plankton on such occasions.

The portion of total nutrients which is present in the form of dissolved nutrients, ammonium, nitrites, nitrates and phosphates - is readily available to aquatic vegetation. As a result, concentrations of those substances vary widely during the year. Their levels drop in the spring, when plankton algae (phytoplankton) and other plants bind nutrients. During winter, when there is little plant growth, levels of nutrients rise again, due to the decomposition of organic matter and additions from various sources on land and from the atmosphere.

This means that winter levels of nutrients provide an indication of how large the production of plankton algae and other vegetation is likely to be during the following season of primary production. Summer levels, on the other hand, primarily indicate which nutrient is in short supply and thus is the limiting factor on plant production. Therefore the winter values of the nutrients should be assessed in this context (measured before the spring

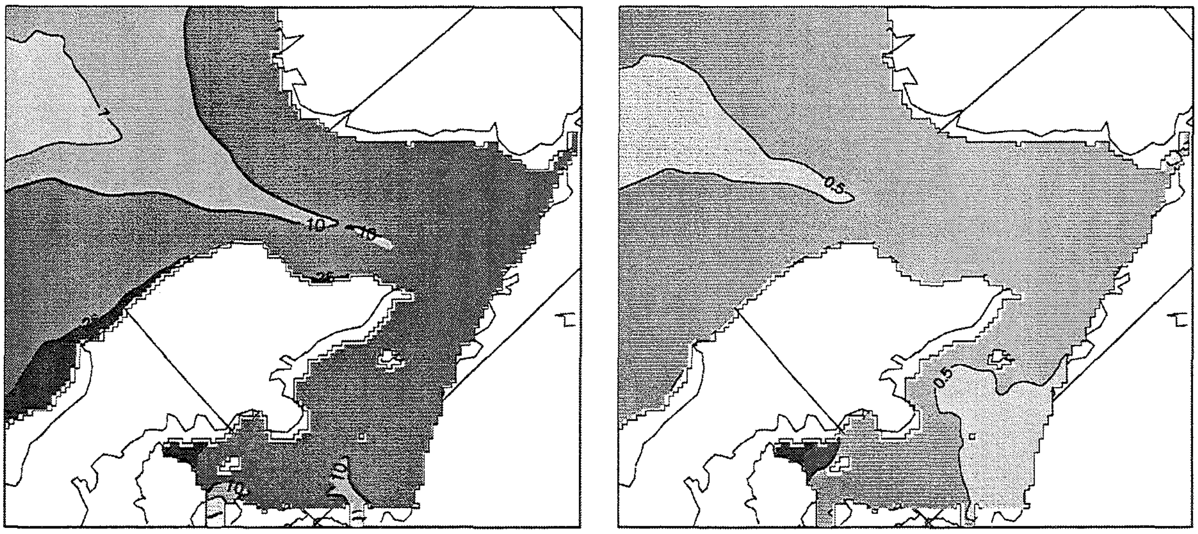

Figure 14: Modelled eutrophication assessment levels of nitrate (left) and phosphate (right) in January. The colors, referring to the eutrophication levels, should be read as: very high (red), high, moderatly high, low and very low (blue)

bloom of the plankton algae).

The mean modelled nitrate and phosphate concentrations in January at 5 m depth have been used to assess the level of winter nutrients. These results are shown in Figure 14. The model shows high ($> 10\mu mol$) nitrate levels in most of Skagerrak and Kattegat, and very high ($> 26\mu mol$) along the Danish west and close to Lillebælt. The Atlantic inflowing water are classified as low ($< 7\mu mol$) and moderatly high. For phosphate the model gives (except for Lillebælt) no areas of high levels ($> 0.77\mu mol$), indicating that the primary production in the model mainly is phosphate limited.

4 Summary

An environmental status for year 2000 of the North Sea and Skagerrak based on outputs from a biophysical model (NORWECOM) has been performed. The simulation has as far as possible included real forcing data (meteorological fields and river runoffs). After a model validation using monthly data from the Torungen-Hirtshals transect, the focus of the status have been on primary production, oxygen, sedimentation and circulation. In addition an assessment of eutrophication levels in Skagerrak and Kattegat have been performed based on a classification of such levels from the Swedish Environmental Protection Agency.

Several findings characterizing the year 2000 simulation have been reported. The annual depth integrated primary production for the whole North Sea is the largest since 1990, almost two standard deviations above a long term (modelled) mean. The circulation is characterized by an extremely high net inflow through the English Channel. Due to a high inflow in the fourth quarter, this inflow is the highest throughout a period of 45 years with model simulations. A bloom of the harmful algae *Chatonella* were observed west of Denmark in early May. The modelled flagellate distribution showed that the bloom did not follow the prevailing cyclonic circulation in the Skagerrak. Instead the concentrations decayed, in agreement with satellite imagery. In August/September an inflow of water characterized by very low oxygen levels to the Skagerrak were measured. Except for a delayed timing, this special event were reproduced by the model.

The modelled eutrophication assessment, concludes that (except for high values of winter values of inorganic dissolved nitrogen) the eutrophication level in the Skagerrak and Kattegat is low. The only exception to this is the Oslofjord and some areas along the Danish east coast. However, when interpreting this, one should be aware of the limitations in the simulation. The Baltic exchange is only based on climatological values, and the horizontal resolution, including bottom topography and the coastline, is a limiting factor with respect to correct simulation of, for example, near-shore and mesoscale processes. For the present application this limitation is of special importance in the Kattegat area.

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