ISSN 0071 - 5638

PROSJEKTRAPPORT

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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

Dato:
9/12-02

Senter:
Senter for marint miljø

Seksjon:
Fysisk oseanografi

Antall sider totalt:
20

Rapport:
FISKEN OG HAVET

Nr.
3-2003

Tittel (norsk/engelsk):
Environmental status of the Skagerrak and North Sea 2001

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Sammendrag:
En koblet fysisk, kjemisk og biologisk havmodell (NORWECOM), er brukt for å simulere år 2001 i Nordsjøen og Skagerrak.Resultatene fra denne modellkjøringen er deretter brukt for å lage en miljøstatus for dette året. I statusen presenteres blant annet verdier for primærproduksjon, oxygen 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. Resultatene er sammenlignet med en tilsvarende rapport for år 2000.

Summary:
A coupled physical, chemical and biological ocean model (NORWECOM) is used to simulate 2001 in the North Sea and Skagerrak. The results from this simulation is used to make an environmental status for that year. In the status estimates of primary production, oxygen level and water transport in the North Sea are given. Finally, an assessment of eutrophication in the Skagerrak and Kattegat is given based on reference levels suggested by Swedish environmental authorities. All results are compared with a similar status for 2000.

Emneord:	Subject heading:
1. Miljøstatus	1. Environmental status
2. Nordsjøen og Skagerrak	2. North Sea and Skagerrak
3. Numerisk modell	3. Numerical model

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prosjektleder

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seksjonsleder

Environmental status of the Skagerrak and North Sea 2001

Morten D. Skogen Henrik Søiland Einar Svendsen

Abstract

An environmental status for year 2001 of the North Sea and Skagerrak has been done based on outputs from a biophysical model (NORWECOM). The results show that the annual depth integrated primary production in the whole North Sea is higher in 2001 than in 2000, but with large spatial differences. Oxygen in Skagerrak deep water were somewhat lower in 2001 than in 2000, but nothing like the very low oxygen levels found in the North Sea from the 2000 simulation, were seen in 2001. Both the Atlantic inflow and the inflow through the English Channel were lower in 2001 than in 2000. Estimates from a long term modelling experiment, rank the Atlantic inflow in 2001 among the lowest since 1955. The eutrophication assessment give significant higher values of winter phosphate along than Danish west coast in 2001 than in 2000, while the winter nitrate values in the same area are somewhat lower. The assessment also give some high values of chlorophyll$_a$ on the Danish east coast. Except for these areas and state variables, the simulation gives no areas of high eutrophication in 2001.

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 first environmental status was made for the year 2000 Skogen *et al.* (2001, 2002a). The present report is the final year 2001 environmental status for Region West, and is a follow up of the provisional report for this region (Skogen *et al.*, 2002b). All reports are available at `http://www.imr.no/~morten/nocomments`.

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

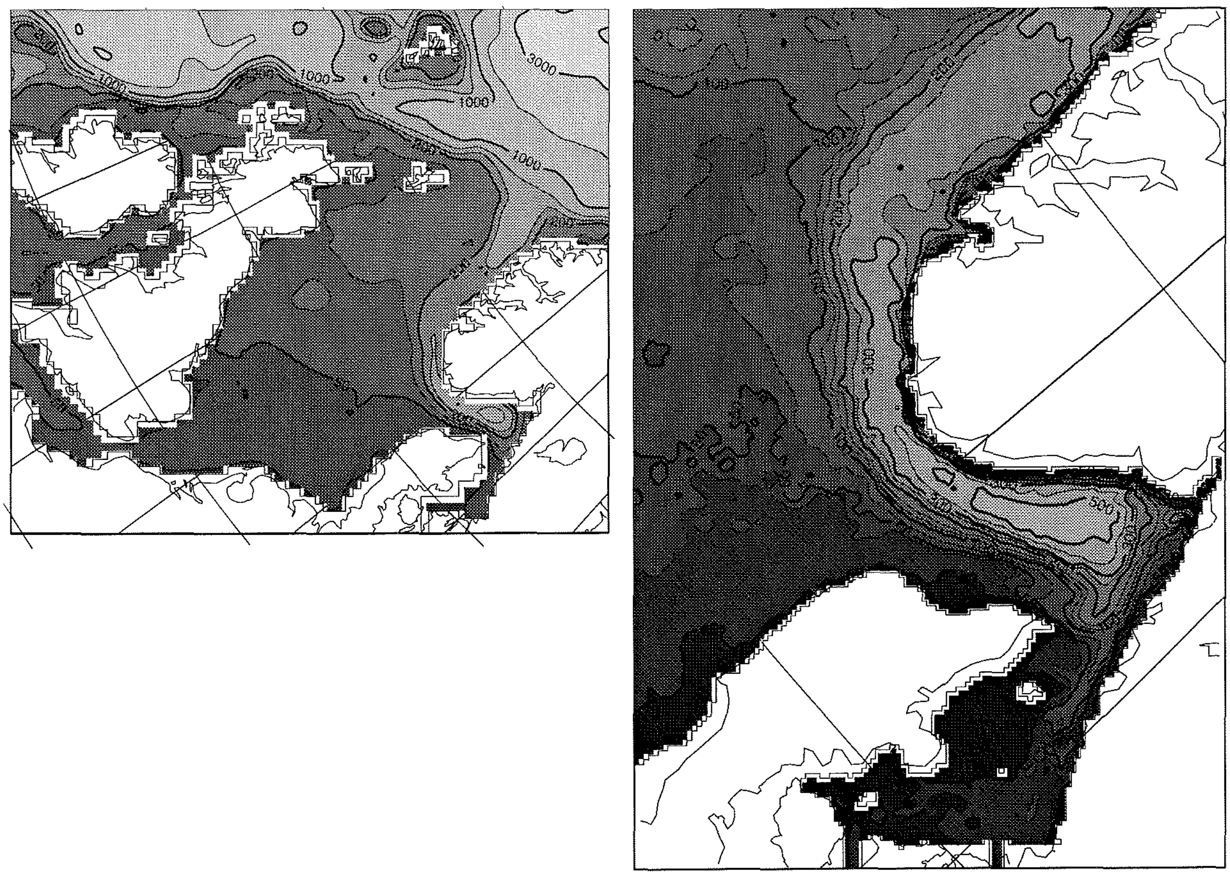

Figure 1: Model bathymetry. Coarse North Sea model domain (left) and fine Skagerrak model domain (right)

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 1999 three times and then 1999 through 2001 was run sequentially. The fine grid model was initialised with results from the coarse grid January 5, 2000. The 4 km model was run from January 5, 2000, through 2001 with boundary conditions from the 20 km North Sea model.

2.3 Limitations

The final 2001 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.*, 2002b), is given.

	Final status	Provisional
Wind	ECMWF operational 2001	DNMI hindcast 2001
Waves	WINCH 2001	WINCH 1998
Irradiance	2D ECMWF 2001	Taastrup 1990
Heat flux	Radiation 2001 + relaxation	Relaxation towards climatology
SST relax.	30 days	10 days
SSS	Evap. - prec.	None
Rivers Belgium	Clim/clim	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 2001 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 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 the coarse model gives production estimates between 100 and 200 $gC/m^2/year$, while the production outside the Norwegian west coast is just above 100 $gC/m^2/year$.

These general patterns are also seen in the fine scale model. However, inside Skagerrak the 4 kilometer model suggests lower values (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 production in the central Skagerrak is dominated by flagellates.

Comparing the annual production with 2000 (Skogen *et al.*, 2002a), the mean North Sea production in 2001 is somewhat higher (116 compared to 107 $gC/m^2/year$). However, there are large spatial differences (see Figure 6, right panels). In 2001 there was a higher

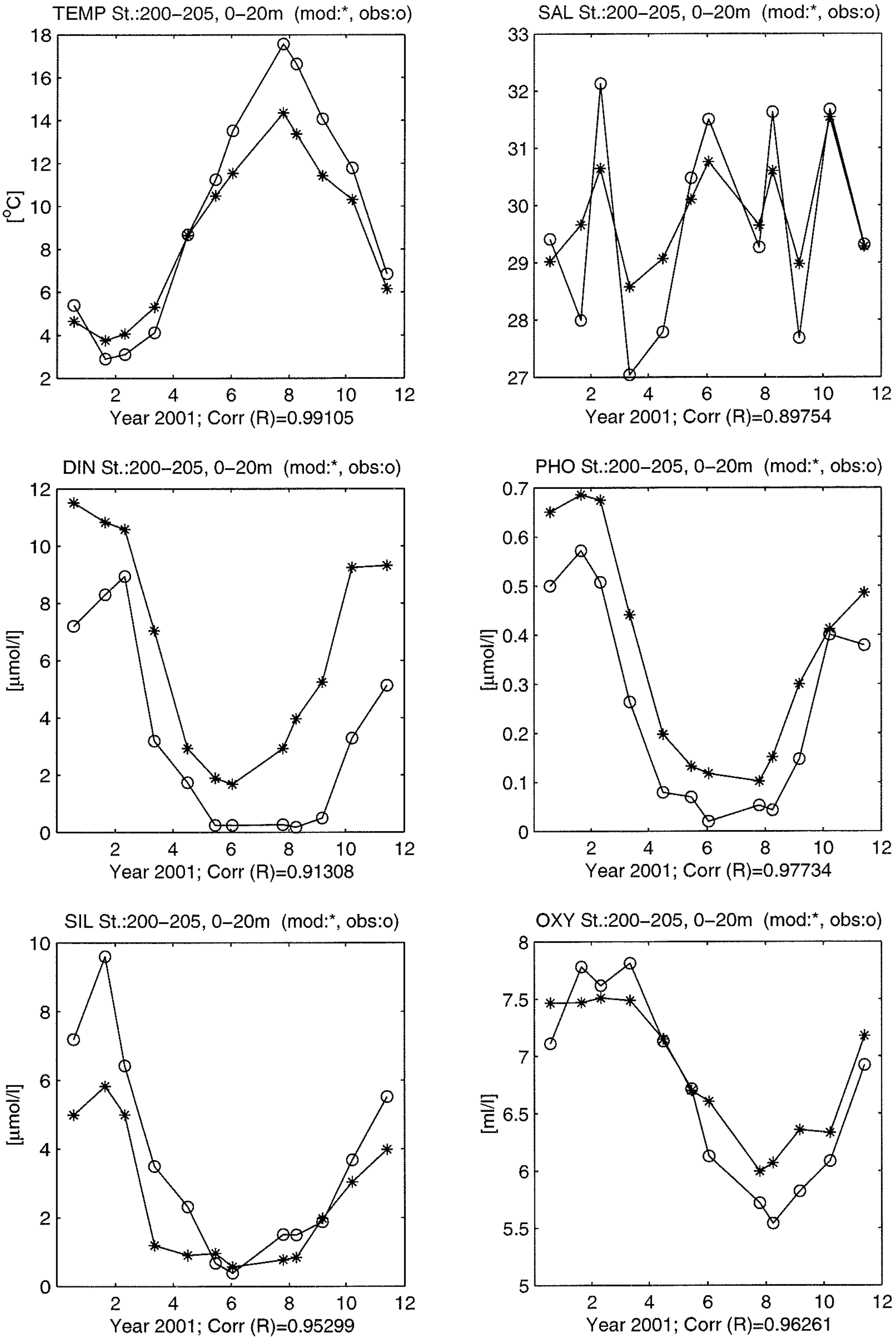

Figure 2: A comparison of measurements and model results in surface waters (0-20 m depth) on the Norwegian coast 0-5 nautical miles off Torungen

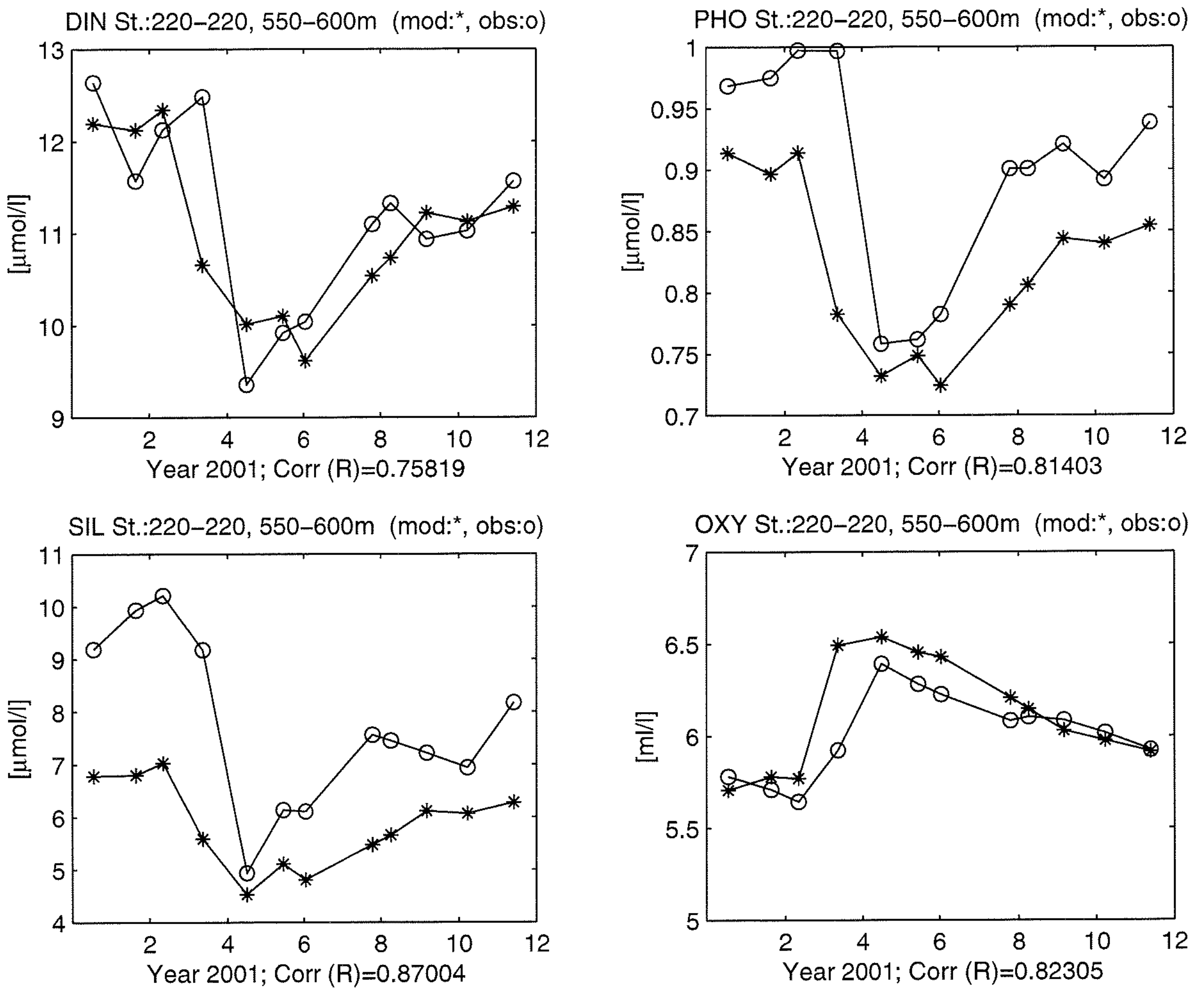

Figure 3: A comparison of measurements and model results in the deepest part of Skagerrak (550-600 m depth) 20 nautical miles off Torungen

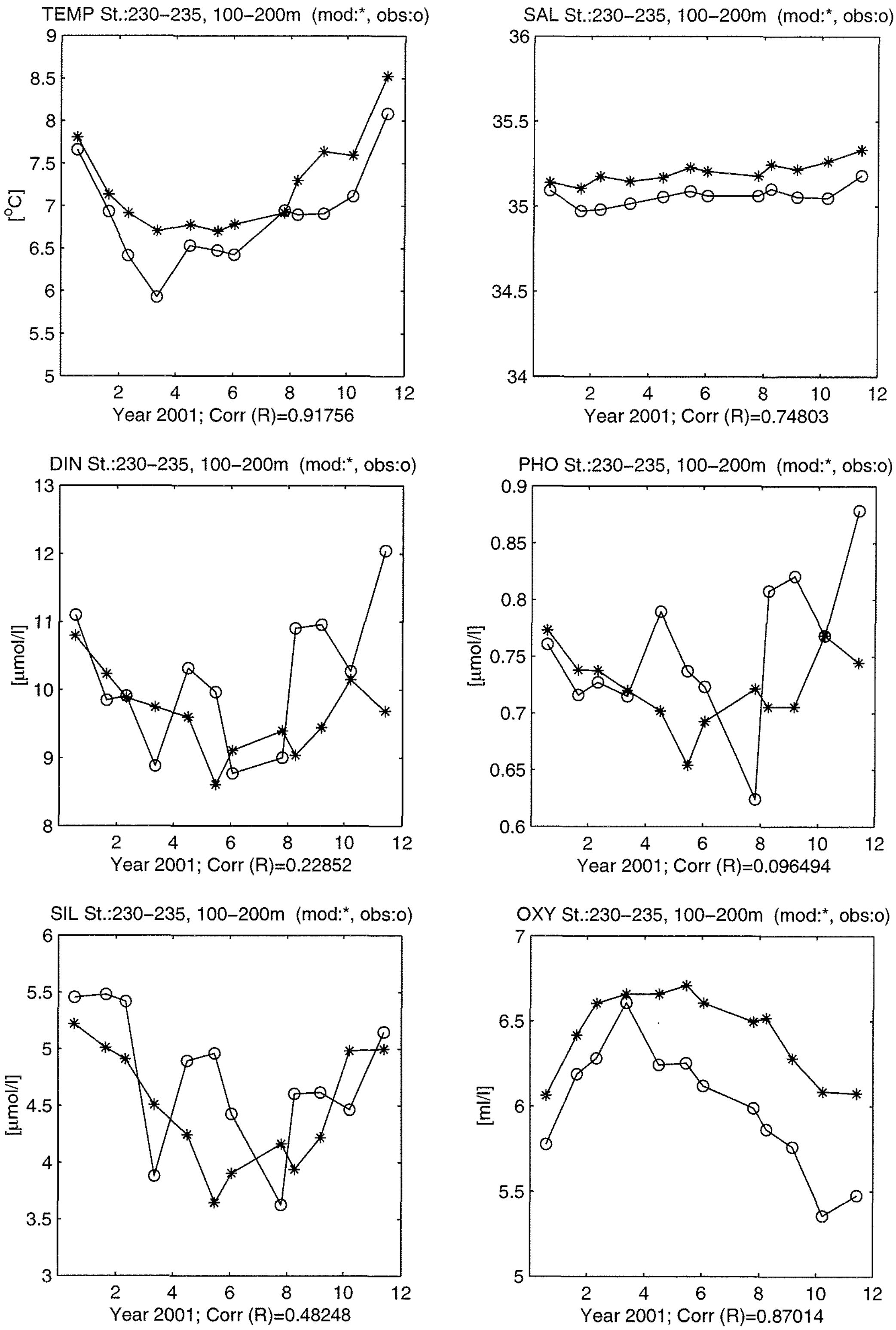

Figure 4: A comparison of measurements and model results in teh Atlantic inflow area (100-200 m depth) on the Danish shelf break 30-35 nautical miles off Torungen

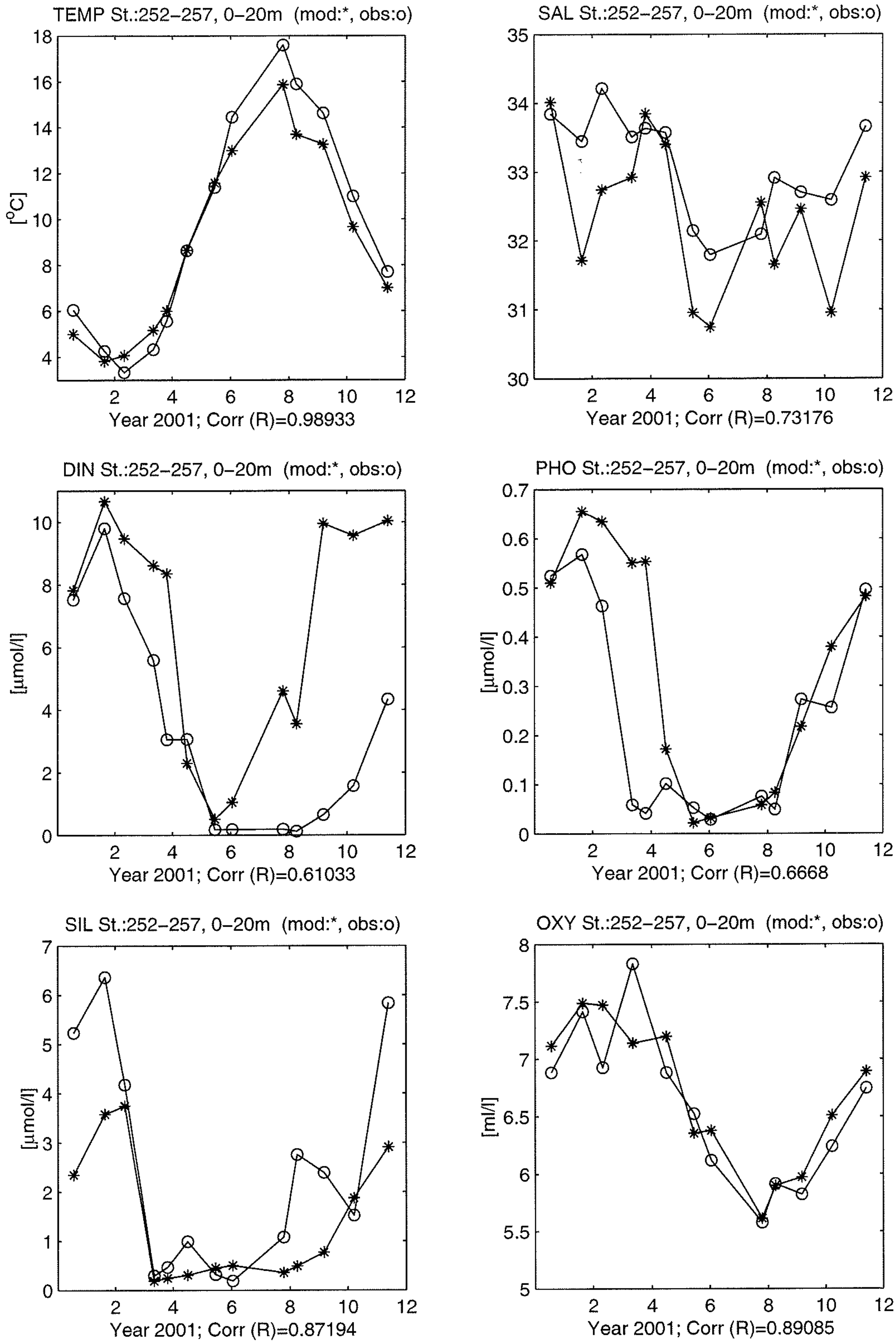

Figure 5: A comparison of measurements and model results in surface waters (0-20 m depth) on the Danish coast 52-57 nautical miles off Torungen

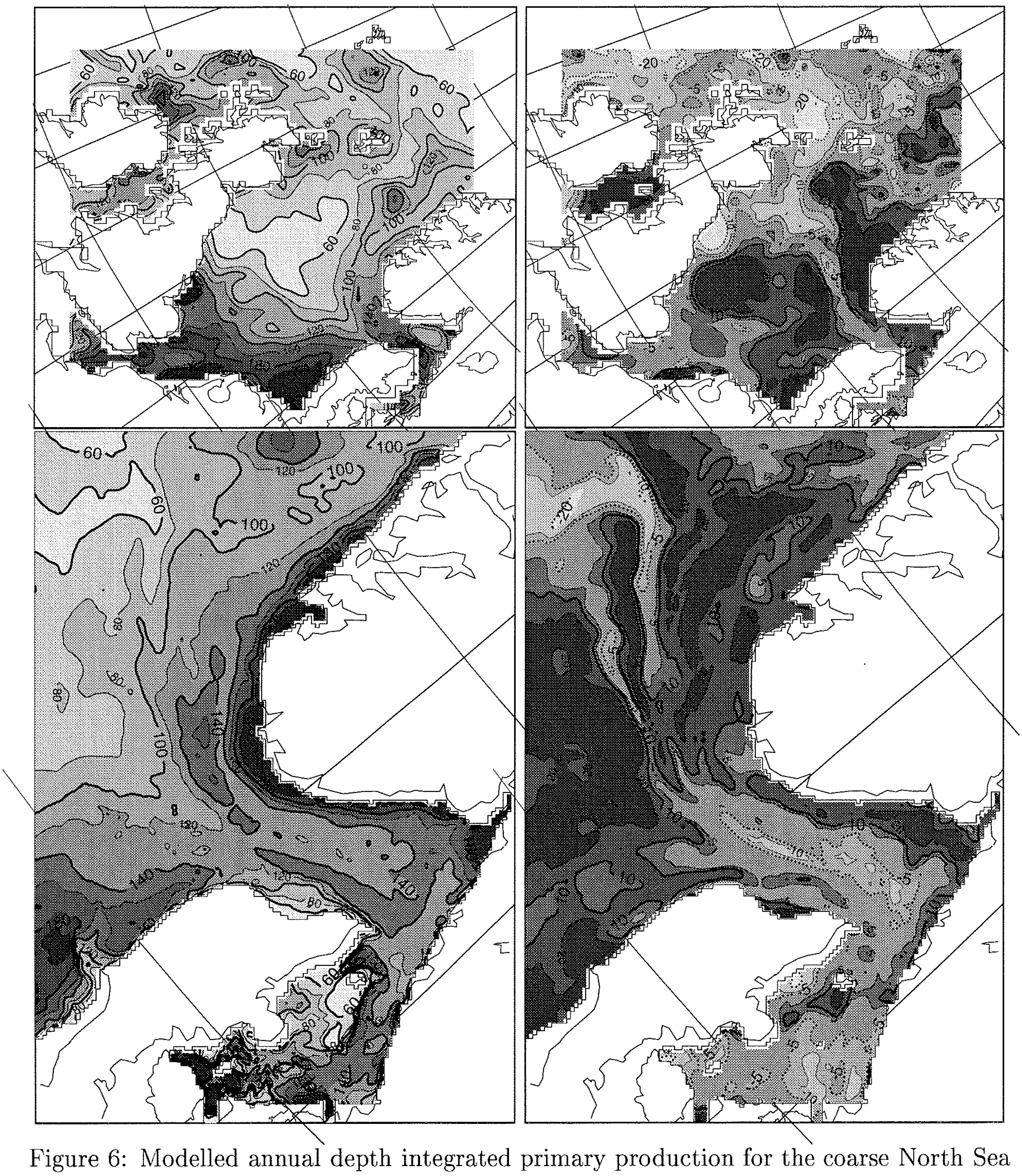

Figure 6: Modelled annual depth integrated primary production for the coarse North Sea model (upper) and the fine Skagerrak model (lower). In the left panels the absolute values ($gC/m^2/year$) and in the right panels the change (in percentage) compared with 2000 (Skogen *et al.*, 2002a)

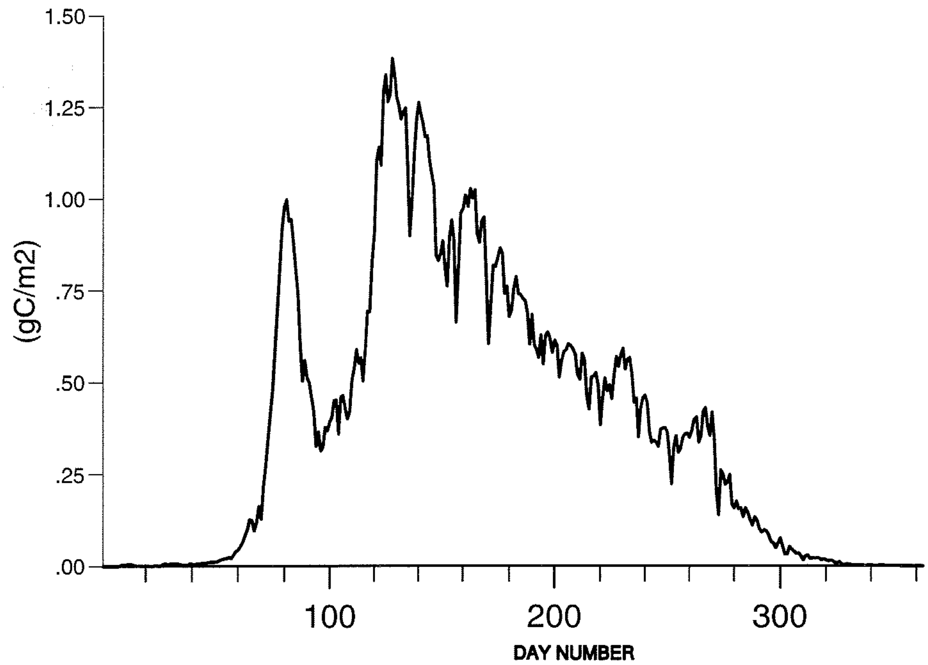

Figure 7: Modelled daily primary production ($gC/m2/day$) in Skagerrak from the fine scale model

production in the central North Sea and along the Norwegian coast, while the production was lower than 2000 in the northwestern North Sea. The fine scale model indicates an increased production along the Norwegian coast and the Danish east coast, while the production are somewhat lower in 2001 than in 2000 in the central Skagerrak basin.

To get an idea about the day to day variability in the primary production, the spatial averaged modelled daily production ($gC/m^2/day$) in Skagerrak are shown in Figure 7. The production has an average of 0.38 and a maximum level of 1.38 $gC/m^2/day$ (in 2000 the numbers were 0.36 and 1.45 $gC/m^2/day$). 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 two maximas in early May can clearly be seen. The flagellate production decreases as the nutrients are depleted, but several production maximas of both diatoms and flagellates are seen both in the late summer and fall.

3.3 Oxygen

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 8 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 35 (late August).

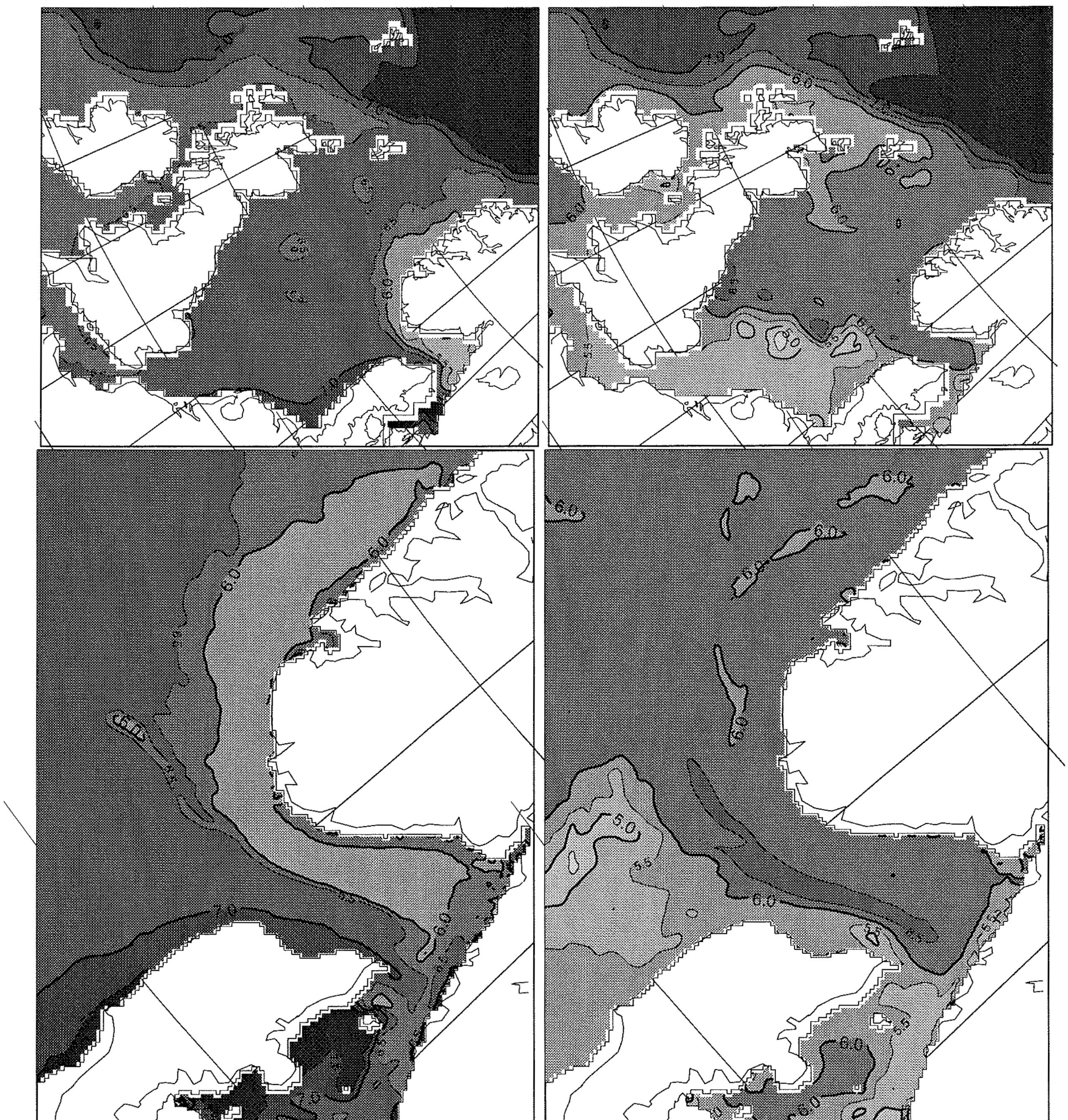

Figure 8: Modelled oxygen, ml/l, (left) in the lowermost model level (2.5 % above bottom) from the coarse North Sea model (upper) and the fine Skagerrak model (lower). Week 1 (early January) in the left panels and week 35 (late August) in the right panels

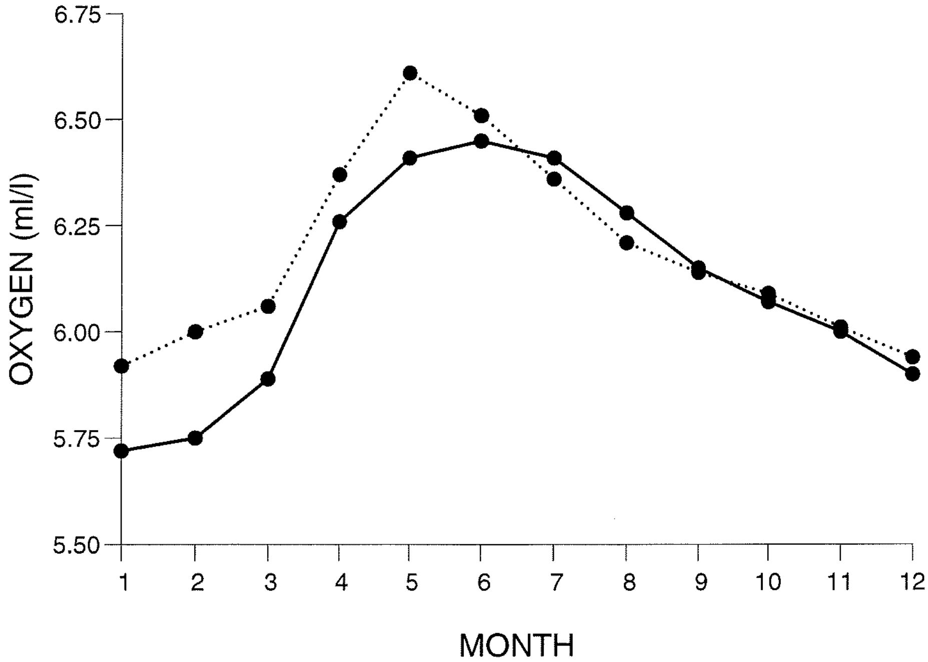

Figure 9: Modelled mean monthly oxygen level (ml/l) in Skagerrak below 500 m depth from the fine scale model. 2001 (solid line) and 2000 (dotted line)

In the beginning of the year the oxygen conditions are good in most of the North Sea. Except for the Norwegian trench and some local mimimas east of Scotland (coincides with local minimas in the topography), the modelled oxygen levels are higher than $6.5ml/l$. During summer, oxygen are depleted in the whole North Sea, especially south and east of the Dogger Bank. In late August and early September (week 35 and 36) the minimum mean modelled North Sea oxygen level in the North Sea are found with oxygen levels between 4.5 and $5.5ml/l$ in the southern North Sea (minimum value just below $4ml/l$). This situation is dramatically different from 2000 (Skogen *et al.*, 2002a), when the model gave oxygen levels of less than $3ml/l$ in stagnant waters in mid September south of Dogger bank.

The modelled bottom water in most of Skagerrak and Kattegat has oxygen levels all through the year higher than 5.0 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 9, where the mean oxygen concentration below 500 m in Skagerrak are plotted, together with the results from the status in 2000 (Skogen *et al.*, 2002a). The model show a clear annual cycle in oxygen concentrations, with an oxygen maximum in May and a minimum in January in agreement with measurements (see Figure 3). These data also confirms the modelled renewal of the

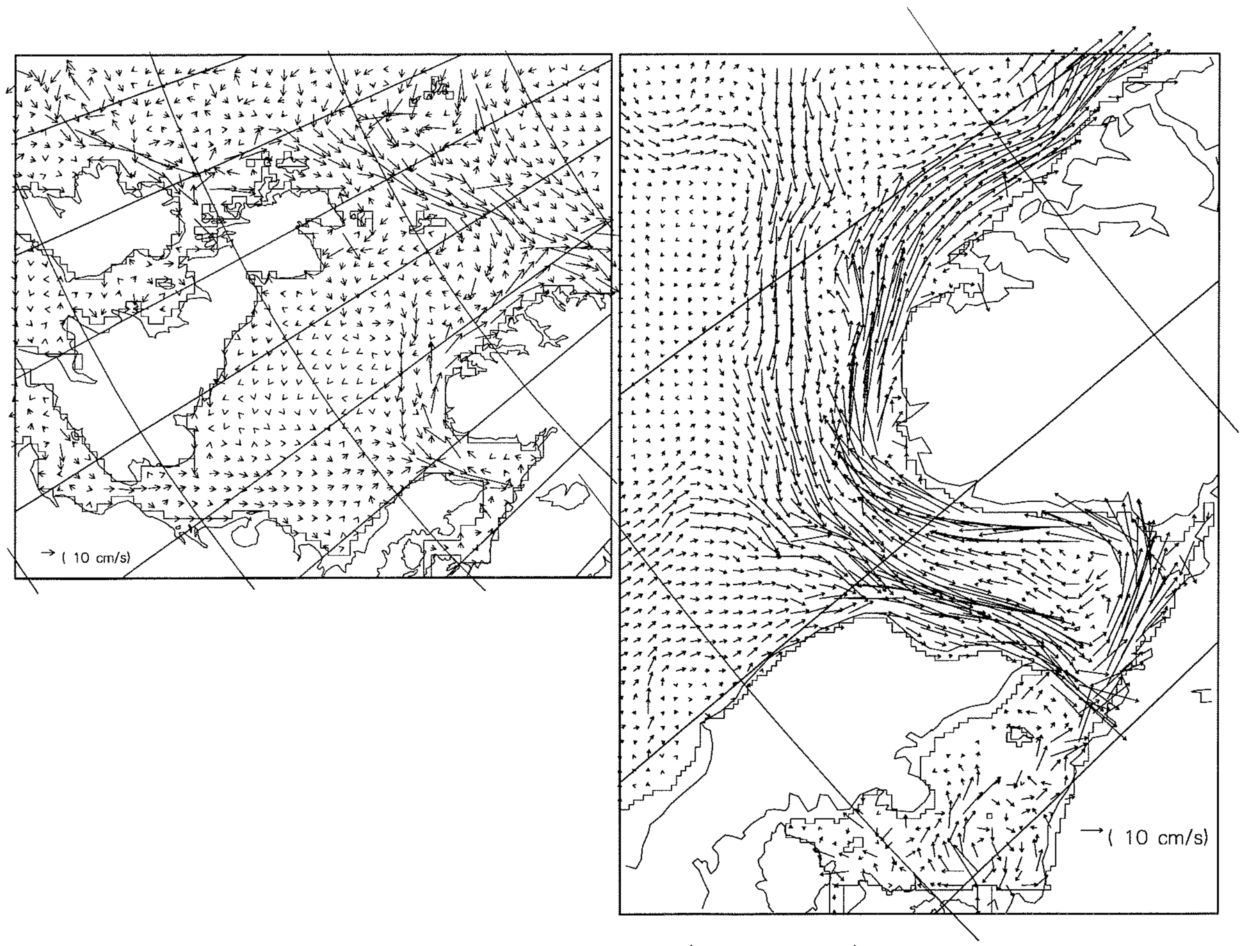

Figure 10: Modelled annual mean velocity field (10 m depth) from the coarse North Sea model (left) and fine Skagerrak model (right)

bottom waters in spring. Compared with 2000, the oxygen levels in 2001 are somewhat lower throughout the year. This is mainly due to a somewhat higher modelled oxygen level in January 2000 than in January 2001.

3.4 Circulation and transports

The modelled annual mean year 2001 North Sea circulation are shown in Figure 10. 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.

By comparing the North Sea inflows between 2000 and 2001 through one transect from Orkney to Utsira and one crossing the English Channel (Figure 11) large differences are seen. The Atlantic inflow through the east-west section from the Orkney to Utsira (along 59.17 °N) are much lower in the first quarter and somewhat higher in the fourth. The net transport through the English Channel is more equal between the years, except for the

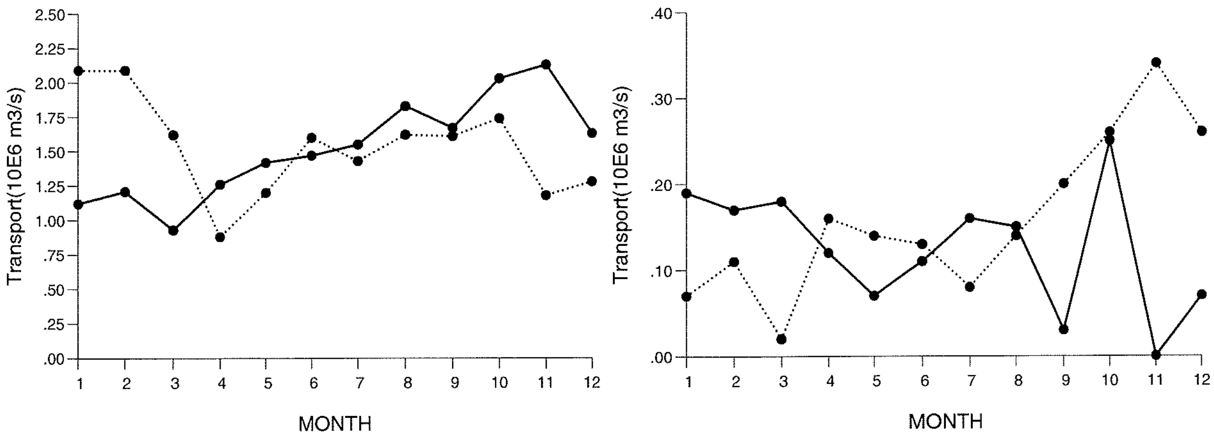

Figure 11: Modelled monthly mean inflow through the Orkney-Utsira transect (left), and net flow through the English Channel (right). 2001 (solid line) and 2000 (dotted line)

very high inflow in the end of 2000 which was the highest modelled since 1955 (Skogen *et al.*, 2002a).

The transports from 2001 can also be classified from a long time 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(unpubl.data)). This experiment puts 2001 with the second lowest first quarter inflow, and the lowest first half of the year Atlantic inflow through the Orkney-Utsira transect. Altogether this ranks 2001 the fourth lowest annual Atlantic inflow. The English Channel inflow is above the mean in the first quarter, but the mean annual net inflow is ranked as 35 out of 47.

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`.

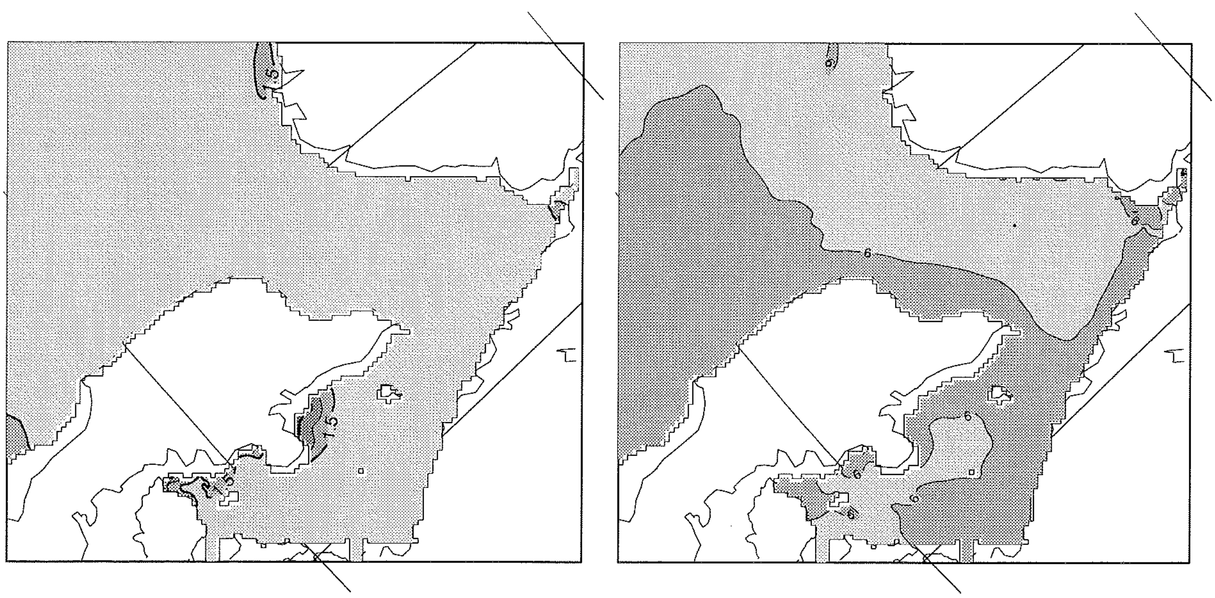

Figure 12: Modelled eutrophication assessment levels of Chlorophyll$_a$ in August (left) and oxygen in mid September (right). The colors, referring to the eutrophication levels, should be read as: very high (red), high, moderatly high, low and very low (blue)

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 12. 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 large areas along the Danish east coast which are classified as Moderate to High ($2.2 - 5.0\mu g/l$). Compared with the 2000 simulation (Skogen *et al.*, 2002a), the chlorophyll values on the Danish east coast, are almost equal.

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 35 (late August) is shown in Figure 12. 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 some small areas outside the Belts where 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

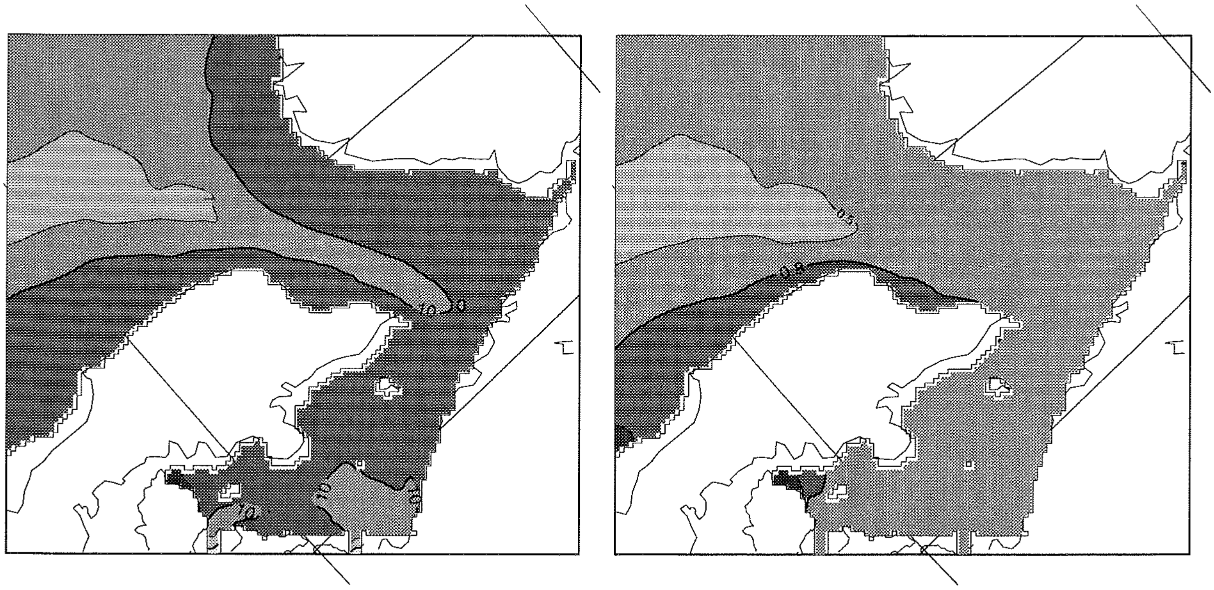

Figure 13: Modelled eutrophication assessment levels of nitrate (left) and phosphate (right) in January. The colors, referring to the eutrophication levels, should be read as: very high (red), high, moderatly high, low and very low (blue)

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 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 13. The model shows high ($> 10\mu mol$) nitrate levels in most of Skagerrak and Kattegat. The Atlantic inflowing water are classified as low ($< 7\mu mol$) and moderatly high. The only area with very high levels ($> 26\mu mol$) in 2001 is outside the Belts. This is very different from 2000 (Skogen *et al.*, 2002a) when very high nitrate levels, originating form the southern North Sea, were found along most of the Danish west coast. For phosphate there is an opposite situation. In 2000 there were no areas of high levels, while 2001 gives high phosphate levels ($> 0.8\mu mol$) along the whole Danish west coast. In the rest of the areas the phosphate levels are comparable between the two years (low to moderately high).

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 statushave 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 year 2001 can be reported. Compared to the status for 2000 (Skogen *et al.*, 2002a), the mean North Sea annual primary production is higher in 2001, but with large spatial differences. While 2000 showed areas of very low oxygen levels in the North Sea in late summer, such low oxygen levels was not seen in 2001. The North Sea inflow both through the English Channel and through the Orkney-Utsira transect was lower in 2001 than in 2000. Results from a long term modelling experiment (1955-2001) rank 2001 among the very lowest with respect to Atlantic inflow through the Orkney-Utsira transect. Eutrophication assessment levels in 2001 indicates high chlorophyll levels along the Danish east coast, and high winter nitrate and phosphate levels on the Danish west coast. Compared with the environmental status 2000 (Skogen *et al.*, 2002a), the winter phosphate levels are higher, the chlorophyll levels are similar, while the winter nitrate levels are lower.

References

AKSNES, D.L., ULVESTAD, K.B., BALIÑO, B., BERNTSEN, J., EGGE, J., & SVENDSEN, E. 1995. Ecological modelling in coastal waters : Towards predictive Physical-Chemical-Biological simulation models. *Ophelia*, **41**, 5–36.

BLUMBERG, A.F., & MELLOR, G.L. 1987. A description of a three-dimensional coastal ocean circulation model. *In:* HEAPS, N. (ed), *Three-Dimensional Coastal Ocean Models, Vol.4*. American Geophysical Union.

DEE, DICK P. 1995. A pragmatic approach to model validation. *Pages 1–14 of:* LYNCH, D.R., & DAVIES, A.M. (eds), *Quantitative Skill Assessment for Coastal Ocean Models.* American Geophysical Union. ISBN 0-87590-261-8.

IVERSEN, S.A., SKOGEN, M.D., & SVENDSEN, E. 2002. Availability of horse mackerel *Trachurus trachurus* in the north eastern North Sea, predicted by the transport of Atlantic water. *Fisheries Oceanography*, **11**(4), 245–250.

MARTINSEN, E. A., ENGEDAHL, H., OTTERSEN, G., ÅDLANDSVIK, B., LOENG, H., & BALIÑO, B. 1992. *MetOcean MOdeling Project, Climatological and hydrographical data for hindcast of ocean currents.* Tech. rept. 100. The Norwegian Meteorological Institute, Oslo, Norway. 93pp.

MARTINSEN, E.A., & ENGEDAHL, H. 1987. Implementation and testing of a lateral boundary scheme as an open boundary condition in a barotropic ocean model. *Coastal Engineering*, **11**, 603–627.

POHLMANN, T., & PULS, W. 1994. Currents and transport in water. *Pages 345–402 of:* SÜNDERMANN, J. (ed), *Circulation and contaminant fluxes in the North Sea.* Berlin: Springer Verlag.

REISTAD, M., EIDE, L.I., GUDDAL, J., & MAGNUSSON, A.K. 1988. *Wave model sensitivity study.* The Norwegian Meteorolgical Institute.

SKARTVEIT, A., & OLSETH, J. A. 1986. Modelling slope irradiance at high lattitudes. *Solar Energy*, **36**(4), 333–344.

SKARTVEIT, A., & OLSETH, J. A. 1987. A model for the diffuse fraction of hourly global radiation. *Solar Energy*, **37**, 271–274.

SKOGEN, M.D., & SØILAND, H. 1998. *A User's guide to NORWECOM v2.0. The NORWegian ECOlogical Model system.* Tech. rept. Fisken og Havet 18/98. Institute of Marine Research, Pb.1870, N-5024 Bergen. 42pp.

SKOGEN, M.D., SVENDSEN, E., BERNTSEN, J., AKSNES, D., & ULVESTAD, K.B. 1995. Modelling the primary production in the North Sea using a coupled 3 dimensional Physical Chemical Biological Ocean model. *Estuarine, Coastal and Shelf Science*, **41**, 545–565.

SKOGEN, M.D., SVENDSEN, E., & SØILAND, H. 2001. *A provisional year 2000 environmental status of the Skagerrak and North Sea.* Internal report IMR, 12pp.

SKOGEN, M.D., SVENDSEN, E., & SØILAND, H. 2002a. *Environmental status of the Skagerrak and North Sea 2000.* Tech. rept. Fisken og Havet 3/2002. Institute of Marine Research, Pb.1870, N-5024 Bergen. 22pp.

SKOGEN, M.D., SVENDSEN, E., & SØILAND, H. 2002b. *A provisional year 2001 environmental status of the Skagerrak and North Sea.* Internal report IMR, 15pp.

STIGEBRANDT, A. 1980. Barotropic and baroclinic response of a semi-enclosed basin to barotropic forcing of the sea. *Pages 141–164 of:* FREELAND, H.J., FARMER, D.M., & LEVINGS, C.D. (eds), *Proceeding of the NATO Conference on Fjord Oceanography.* Plenum Press, New York.

SWAMP-GROUP. 1985. *Ocean wave modelling.* Plenum Press.