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Environmental status of the Skagerrak and North Sea 2004

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Sammendrag (norsk):
En koblet fysisk, kjemisk og biologisk havmodell(NORWECOM), er brukt for åsimulere år 2004 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 nivå 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 tilsvarende verdier for årene 2002 og 2003.

Summary (English):
A coupled physical, chemical and biological ocean model(NORWECOM) is used to simulate 2004 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 values for 2002 and 2003.

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

.... prosjektleder

.... forskningsgruppeleder

Environmental status of the Skagerrak and North Sea 2004

Morten D. Skogen Henrik Søiland

Abstract

An environmental status for year 2004 of the North Sea and Skagerrak has been done based on outputs from a biophysical model, NORWECOM. The results have been compared to results from 2002 and 2003.

The results show that the annual depth integrated primary production in the whole North Sea is lower in 2004 than in 2002 and 2003, but with large spatial differences. The oxygen conditions in the southern North Sea is much better in 2004 than in both 2002 and 2003, while oxygen in Skagerrak deep water are similar in all three years. Both the Atlantic inflow and the inflow through the English Channel are close to the long-term mean. The inflow through the Orkney-Utsira section is higher than in 2002 but lower than in 2003. For the net inflow through the English Channel it is higher than 2003 but lower than 2002. Only the winter nutrient assessment show any significant indications of eutrophication in the Skagerrak and Kattegat area. The model show high values in most of Kattegat and Skagerrak and an area of very high level of eutrophication on the Danish west coast. The situation are comparable to that in 2002, while the situation generally was worse in 2003. For the other variables, chlorophyll$_a$ and oxygen, the assessment only show moderate or high values in very limited areas on the Danish east coast.

Key words : Skagerrak, North Sea, environmental status

1 Introduction

A project, BANSAI (The BAltic and North Sea marine environmental modeling Assessment Initiative), supported by the Nordic Council of Ministers' Sea and Air Group, started out in 2005 with the main objective *to develop an integrated model system to calculate the environmental status including source apportionment, transport, dispersion, transformation and removal in the coastal and open sea marine waters of nutrients inputs to the North and Baltic Sea*. The main deliverable 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 apportionment from different countries based on last years loads. The present report is the status of 2004. Using model output the environmental status is assessed and compared to the situation in 2002-2003. This report presenting the status for the North Sea and Skagerrak, is one out of a total of four BANSAI reports describing 2004. In addition the Swedish Meteorlogical and Hydrological Institute (SMHI) is making one report for the Baltic, the Finnish Institute of Marine Research (FIMR) is making another report for the Baltic and finally Danish Hydrological Institute (DHI) is making a report for the transition zone between the Baltic and the Skagerrak. All these reports are available from the BANSAI web page: `http://www.imr.no/~morten/bansai`.

As part of another project (NO COMMENTS) funded by the Nordic Council of Ministers' Sea and Air Group, similar reports were made for 2000 and 2001 Skogen *et al.* (2002, 2003). These reports are available from: `http://www.imr.no/~morten/nocomments`.

2 Material and methods

2.1 The model design

The NORWegian ECOlogical Model system (NORWECOM, for additional information see also `http://www.imr.no/~morten/norwecom.html`) 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. The model has been validated by comparison with field data in the North Sea/Skagerrak in e.g. Svendsen *et al.* (1996); Skogen *et al.* (1997); Søiland & Skogen (2000); Skogen *et al.* (2004). In the present study a nested version of the model is used, with a coarse 20 $\times$ 20 km. grid on an extended North Sea, and a fine 4 $\times$ 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 processes included are primary production, respiration, algae death, remineralization of inorganic nutrients from dead organic matter, self shading, turbidity, sedimentation, resuspension, sedimental burial and denitrification. Phytoplankton mortality is given as a constant fraction, and is assumed to account also for zooplankton grazing which in this context is included as a forcing function.

The incident irradiation is modeled 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

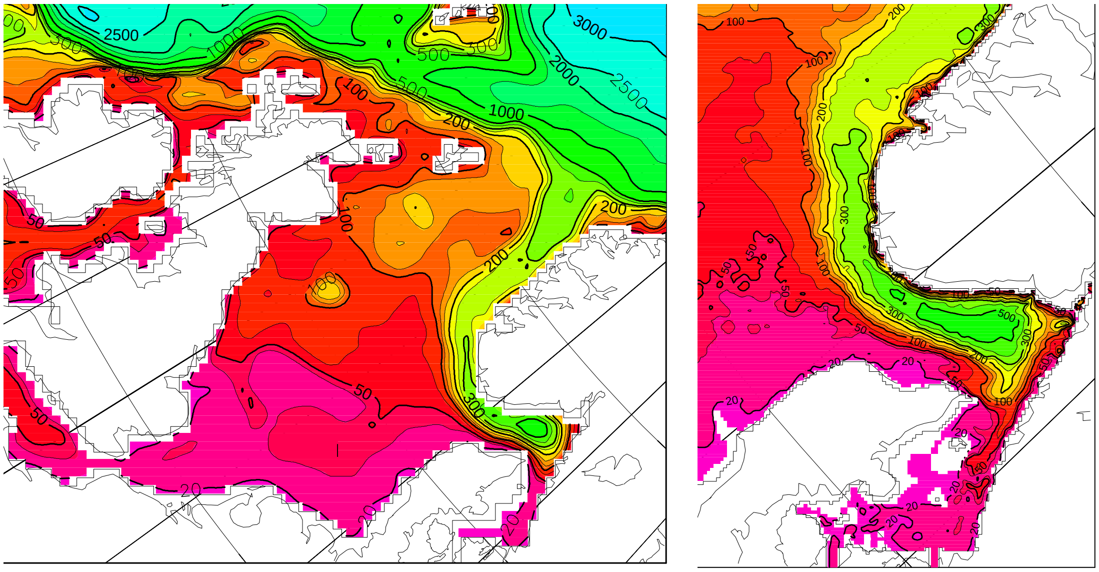

Figure 1: Model bathymetry. Coarse North Sea model domain (left) and fine Skagerrak model domain (right)

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. 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. Parameterization of the biochemical processes is taken from literature based on experiments in laboratories and mesocosms, or deduced from field measurements (Aksnes *et al.*, 1995; Pohlmann & Puls, 1994; Mayer, 1995; Gehlen *et al.*, 1995; Lohse *et al.*, 1995, 1996).

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 modeled 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. 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 2000 two times, and then 2001 through 2004 was run sequentially. The fine grid model was initialized with results from the coarse grid January 5, 2001. The 4 km model was run from January 5, 2001, through 2004 with boundary conditions from the 20 km North Sea model. This approach ensure that the models are in equilibrium with the boundary conditions and river loads, thereby eliminating the effect of the initial condition.

2.3 Limitations

The 2004 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.

	Final status	Remark
Wind	ECMWF operational	
Waves	WINCH	
Irradiance	2D ECMWF	
Surface heat flux	Radiation ECMWF	
SST relax	30 days	
Sea Surface Salinity	Evap. prec. ECMWF	
SSS relax	30 days	
Rivers Belgium	Real/real (flow/nutrients)	Clim. flow + NIT in 2004
Rivers Denmark	Real/real	
Rivers Germany	Real/clim	
Rivers Netherlands	Real/real	Clim. NIT in 2004
Rivers Norway	Real/real	Clim nutrients in 2004
Rivers Sweden	Real/real	
Rivers U.K.	Real/real	Only 2001-2002, clim. other years
Baltic in/out	Clim + Stigebrandt	

Table 1: Forcing used for the 2004 environmental status simulation. The river data should be read as *freshwater runoff/nutrient inputs*

For reasons of stability (to avoid drift in multi year simulations), a weak relaxation toward climatological sea surface temperature (SST) and sea surface salinity (SSS) is kept, but the time constant are very low (30 days). The main limitation in the forcing is the Baltic in and outflow. A possible improvement would be to use in and outflow through the Øresund and the Danish Belts from other models.

3 Results

3.1 Model validation: the Torungen-Hirtshals transect

One of the most important tasks 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 continuously through all modeling projects.

The set-up has been validated using data from the Torungen (outside Arendal on the south-east coast of Norway) to Hirtshals (Denmark) transect (Figure 1) in the Skagerrak. The Institute of Marine Research measure physical, chemical and biological state variables along this transect monthly. To compare model and data, mean values from some of these stations over a certain depth interval are extracted and compared with similar spatial means from the model in an attempt to identify and describe the different water masses in the area. It should be noted that the positions of the stations and model points will not have a perfect match, and that instantaneous measurements are compared to daily mean (25-hourly) model results for the date of observation.

In Figure 2 values (temperature, salinity, dissolved inorganic nitrogen, phosphate, silicate and chlorophyll) from the surface waters on the Norwegian coast (0-5 nautical miles off Torungen and upper 20 meters) are compared. The comparison is done for all years (2002-2004). Despite the smaller amplitudes, both the temperature and salinity results (timing and levels) demonstrates the model's ability to transport the correct water masses in the Norwegian Coastal Waters. The modeled summer temperature is clearly too low. One reason for this is probably that there is too much mixing in the model, especially in deep areas where the vertical resolution is reduced. In addition it is known that in areas with steep topography the sigma coordinates cause enhanced vertical mixing. There seems to be a bias in the modeled nutrient fields with generally too high levels of nitrogen, while the winter values of silicate is too low. The differences in the summer nitrogen minimum may be ascribed to the fact that modeled DIN is compared to measured nitrate. Nitrate is completely depleted in summer, while DIN (NO_3+NO_2+NH_4) does not become depleted. In general the timing of the spring bloom is equal in model and observations, but the peak chlorophyll levels are a factor 2 higher in the observations. However, the rest of the year, the model levels are comparable to the observed ones.

In Figure 3 values at the bottom (550-600m) of the Norwegian trench are shown. The data are dominated by a renewal of the bottom water every spring, which can easily be identified from the oxygen values and to some extent also in the nutrient levels. The same renewal is seen in the model. There is a bias toward lower levels in the modeled nutrient levels. The modeled oxygen level is clearly too high the first year when no renewal of the bottom water are seen in the data, while the results are close in the other two years.

Water from the central and northern North Sea, mainly of Atlantic origin with high salinity around 35, flows into the Skagerrak on the southern flank of the trench. Two stations (230 and 235, 30 and 35 nautical miles off Torungen) are located in the core of the inflowing water above 180-400 m bottom depth. In Figure 4 modeled and measured values from 100-200 m are plotted. Except for the first half of 2002 when the modeled salinity are clearly too high, salinity and temperature are generally in agreement with observations. The picture for nutrients are mixed.

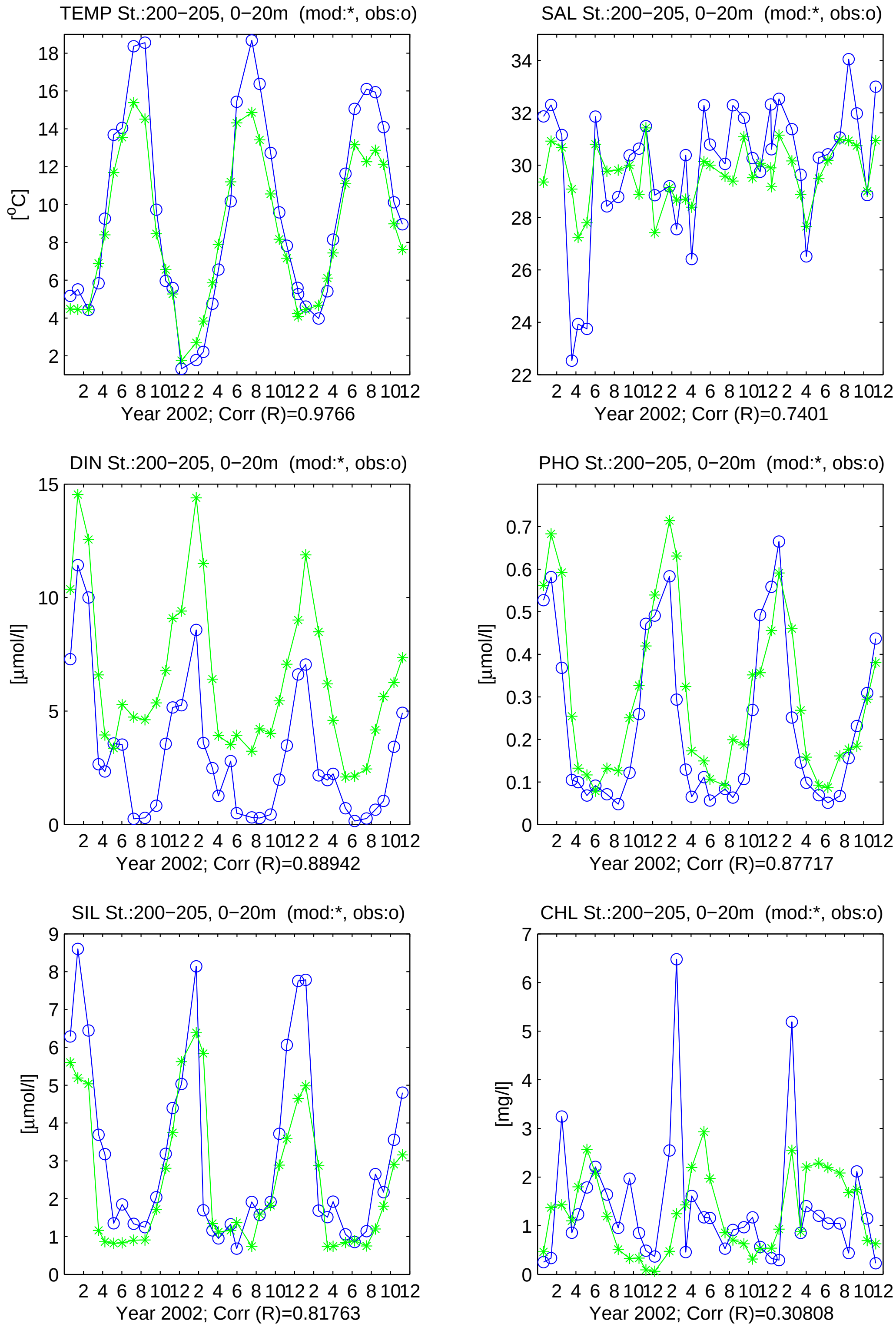

Figure 2: A comparison of measurements and model results in surface waters (0-20 m depth) on the Norwegian coast 0-5 nautical miles off Torungen

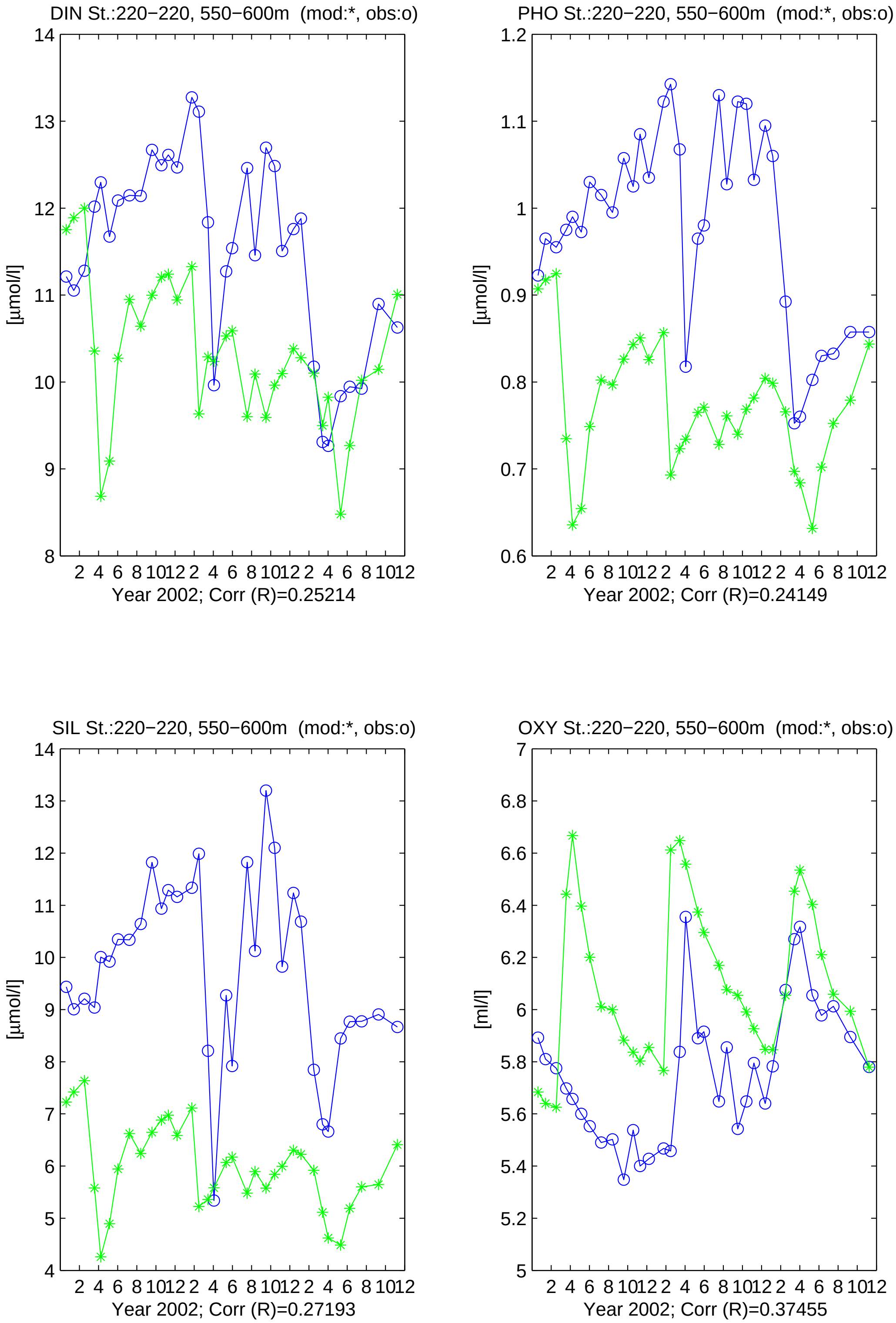

Figure 3: A comparison of measurements and model results in the deepest part of Skagerrak (550-600 m depth) 20 nautical miles off Torungen

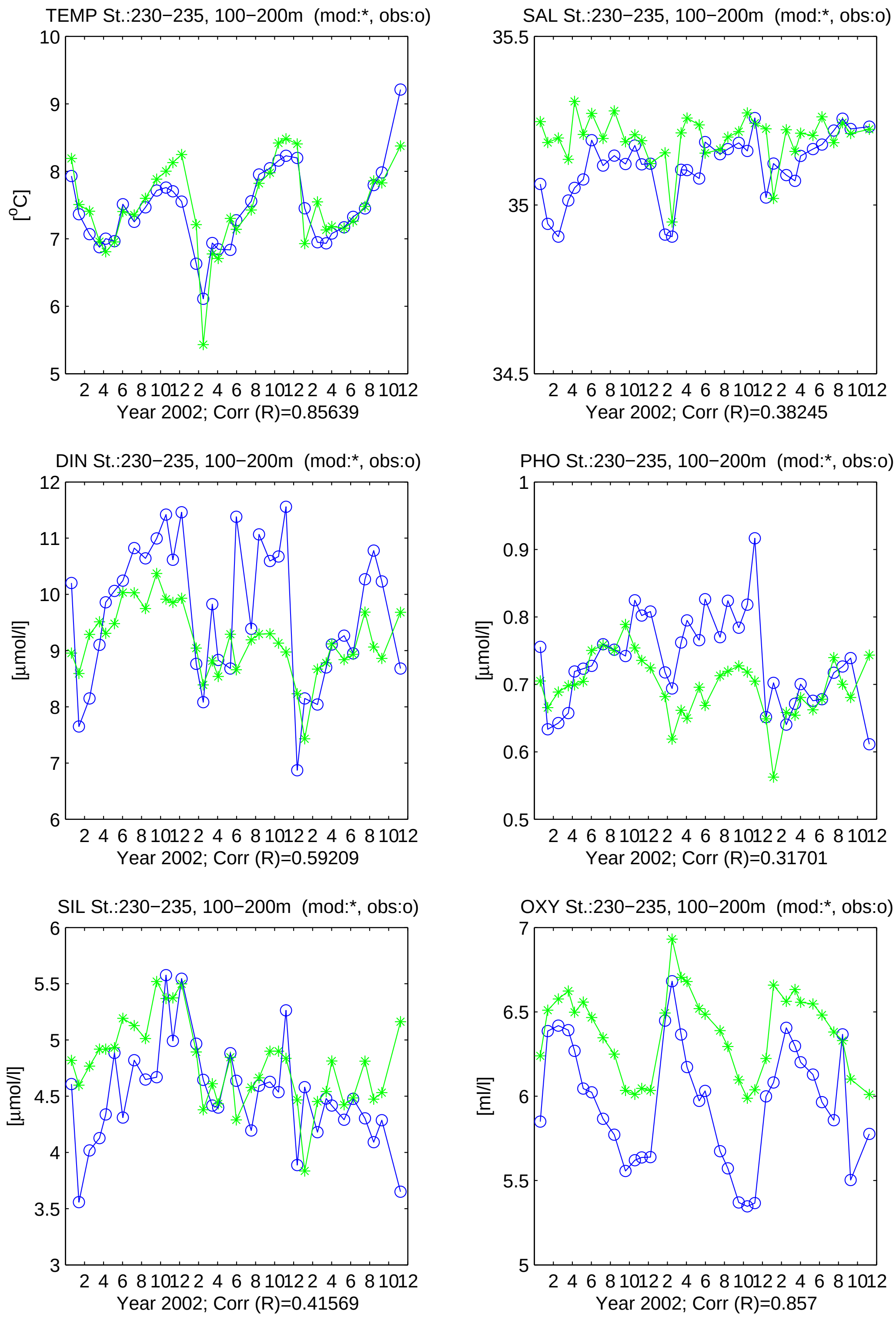

Figure 4: A comparison of measurements and model results in the Atlantic inflow area (100-200 m depth) on the Danish shelf break 30-35 nautical miles off Torungen

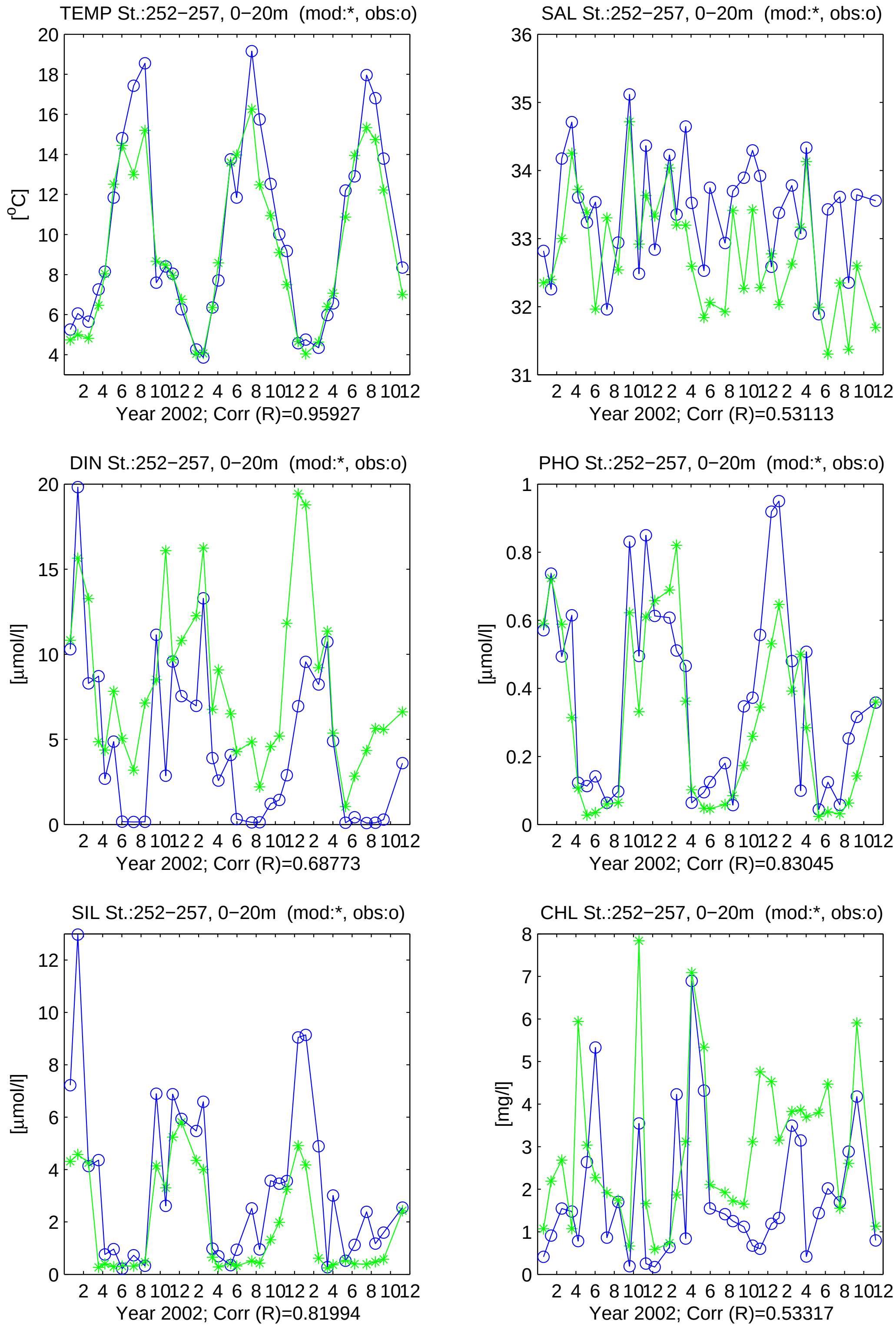

Figure 5: A comparison of measurements and model results in surface waters (0-20 m depth) on the Danish coast 52-57 nautical miles off Torungen

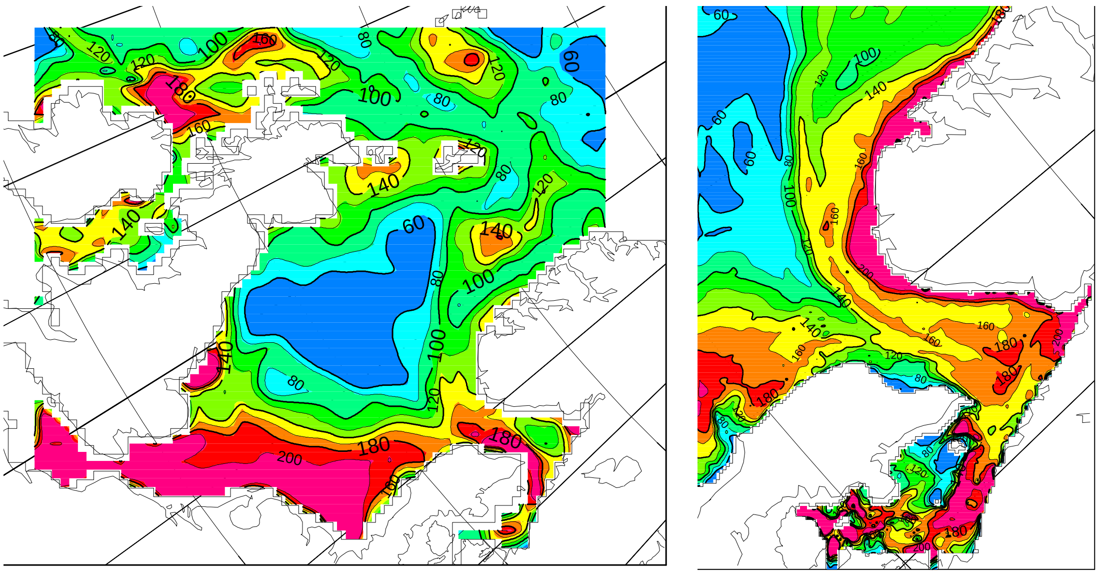

Figure 6: Modeled annual depth integrated primary production for the coarse North Sea model (left) and the fine Skagerrak model (right)

Inorganic nitrogen are generally too low in the 2nd half of the year. This is probably due to the boundary conditions used outside the North Sea. In this area very few data are available. Phosphorous is well represented in the first and third year, while the values are clearly too low in 2003. A clear annual cycle in oxygen values are seen in both model and observations. The timings are similar, but there is a bias in the model with generally too high levels.

Finally in Figure 5 values in the surface water (0-20 meters) on the Danish coast are seen. As for the Norwegian coastal waters, summer tempertures are clearly too low. There is a bias towards lower salinities in 2003 and 2004, while the timings are similar. The modelled inorganic nitrogen levels are too high, while both silicate and phosphate values are in good agreement with observations. An interesting observation in the modelled chlorophyll are the blooms in late fall (October/November) all years. These are confirmed by observations in both 2002 and 2004.

3.2 Algae and primary production

The annual depth integrated primary production $(gC/m^2/year)$ in 2004 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 modeled production is along the southern North Sea continental coast with an annual production of more than $200gC/m^2/year$. 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

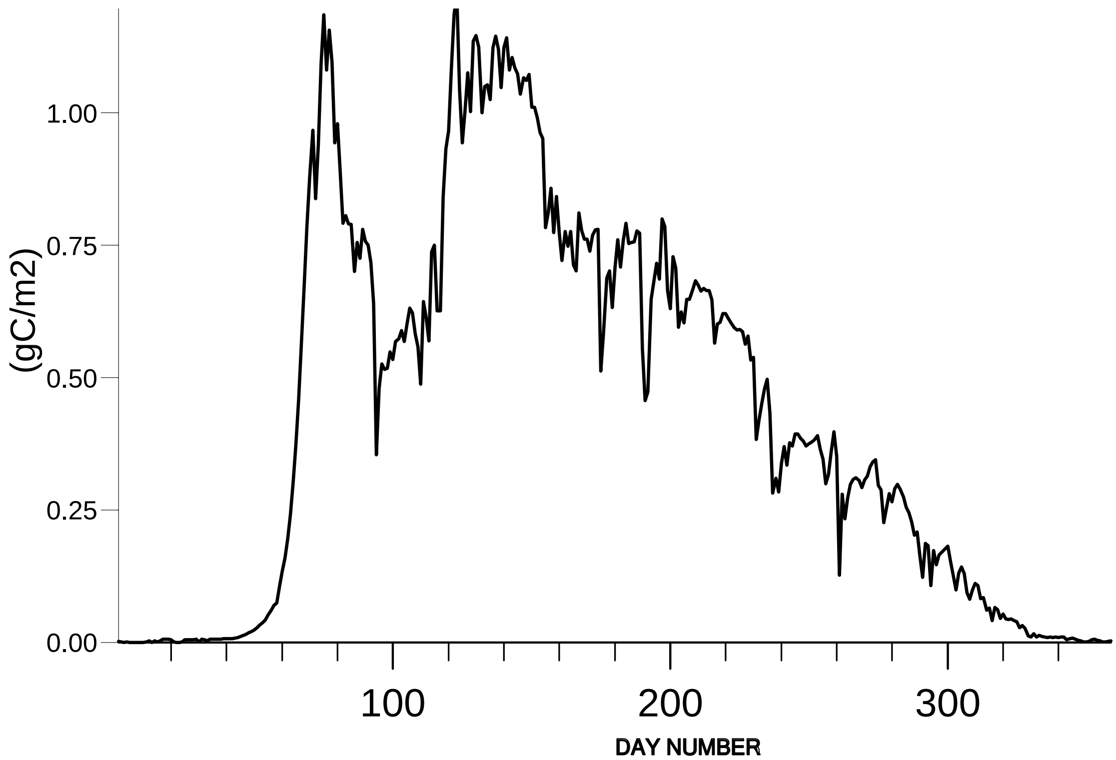

Figure 7: Modeled daily primary production $(gC/m2/day)$ in Skagerrak from the fine scale model

(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 between the years, the mean North Sea production in 2004 is close to that in 2002, but somewhat lower than the production in 2003 (122 compared to 123 and 130 $gC/m^2/year$). However, there are large spatial differences. In 2004 there was a higher production in the northern North Sea, and along the Norwegian west coast, while the production along the British and continental coasts were low.

To get an idea about the day to day variability in the primary production, the spatial averaged modeled daily production $(gC/m^2/day)$ in Skagerrak are shown in Figure 7. The production has an average of 0.43 and a maximum level of 1.22 $gC/m^2/day$ (in 2003 and 2002 the numbers were 0.39, 0.39 and 1.49, 1.63 $gC/m^2/day$ respectively). The production shows large day to day variations. In the figure an early spring diatom bloom with a maximum in mid March, followed by a bloom of flagellates with maximum 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 modeled oxygen concentration in the lowermost model level (within 2.5 % above the sea bottom) are shown. The figure shows the situations from week 1 (early January) and the annual minimum oxygen level in each point.

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 modeled oxygen levels are higher than $6.5ml/l$. During summer, oxygen are lowered in the whole North Sea, especially south and east of the Dogger Bank. In late August and early September the minimum modeled North Sea oxygen level in the North Sea are found. The mean level is $5.6ml/l$. The lowest oxygen levels between 4.5 and $5.5ml/l$ are found in the southern North Sea (minimum value is $4.7ml/l$). The modeled oxygen conditions in 2004 are in general much better than those in 2002 and 2003 when the minimum value in the same area south of Dogger bank was found to be 3.0 and 2.7 ml/l respectively.

The modeled 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 from the 4km model are plotted for all three years (2002-2004). The model show a clear annual cycle in oxygen concentrations, with an oxygen maximum in May and a minimum in January/February in agreement with measurements (see Figure 3). These data also confirms the modeled renewal of the bottom waters in spring. The values in spring 2002 seems low, and this is probably an effect of a shorter spin-up for this year. This is also confirmed in Figure 3, where the model seems to adjust to more correct oxygen values with time.

3.4 Circulation and transports

The modeled annual mean year 2004 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 $58\,^oN$.

By comparing the North Sea inflows between the years 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 $59.17\,^oN$) are lower in the first half of 2004 then in the second due to strong winds from south and west at the end of the year. The mean annual 2004 inflow is 1.57 Sv. This is slightly higher than in 2002, but lower than 2003. Also the net transport through the English Channel is higher in the second than in the first half of the year, with high variations between the months, especially in the fourth quarter. The net inflow in 2004 is slightly higher than in 2003, but 30% below that in 2002.

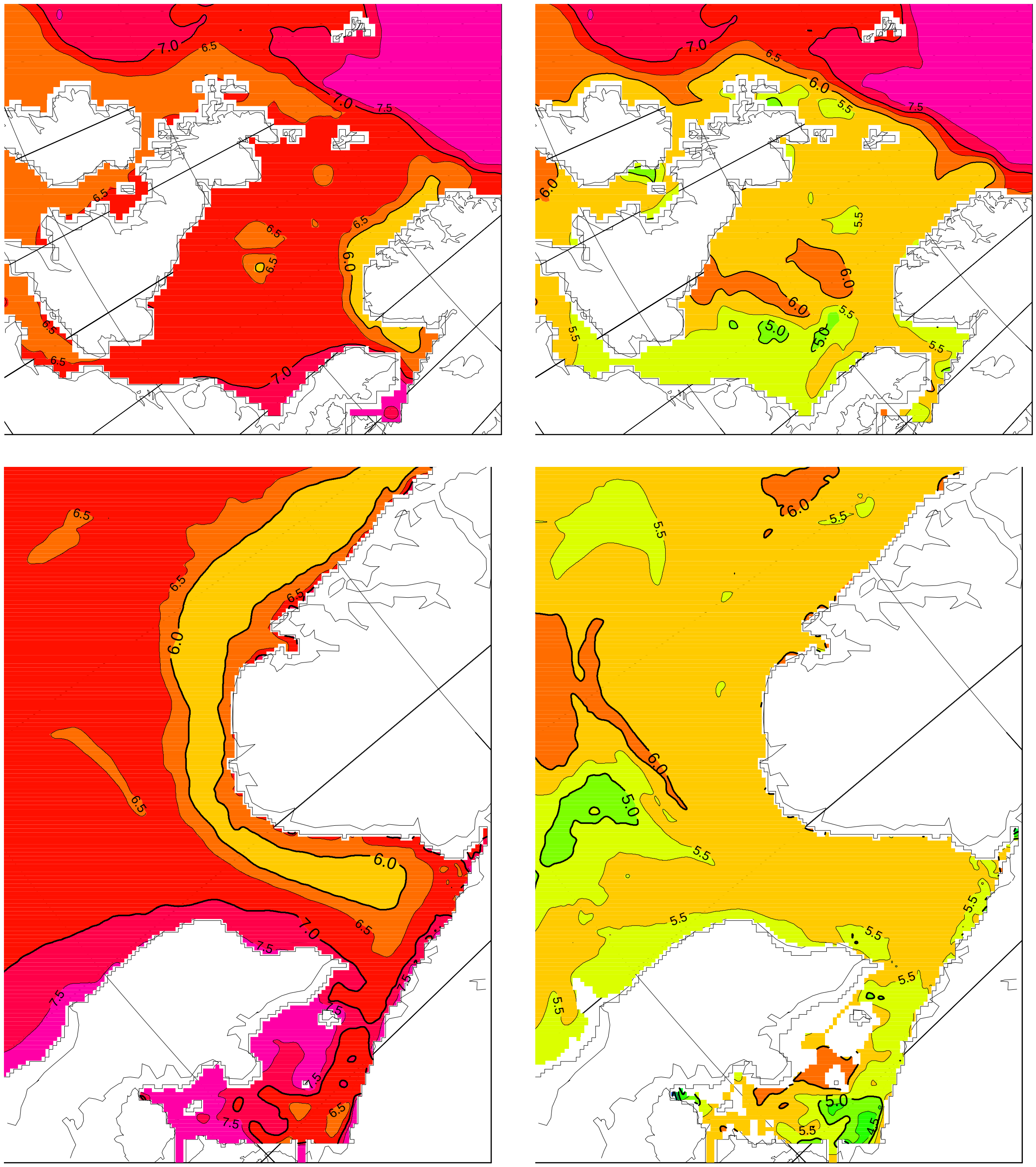

Figure 8: Modeled oxygen, ml/l, (left) in the lowermost model level (2.5 % above bottom) from the coarse North Sea model (upper) and the fine Skagerrak model (lower). Week 1 (early January) in the left panels and the annual minimum level in the right panels

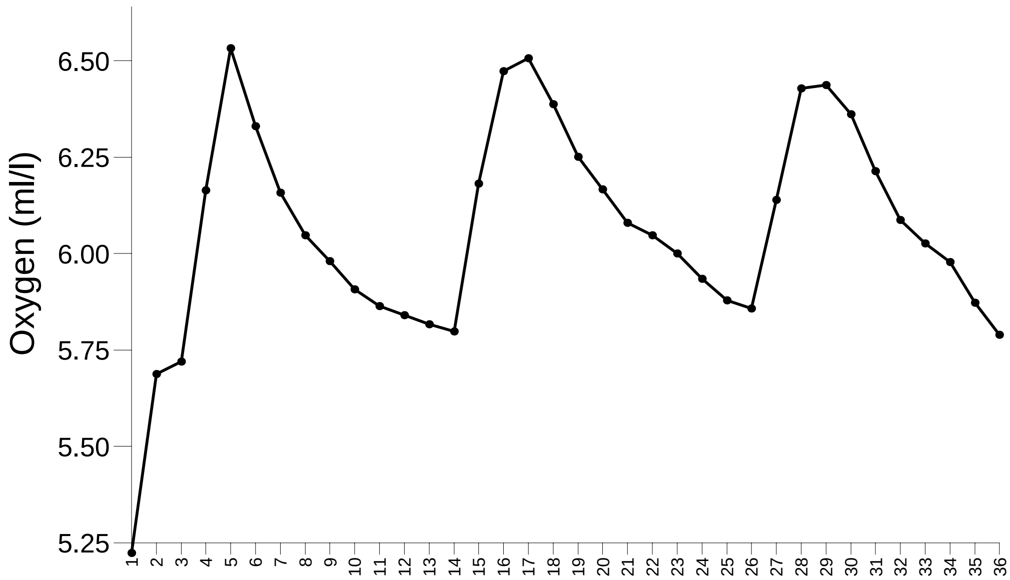

Figure 9: Modeled mean monthly oxygen level (ml/l) in Skagerrak below 500 m depth from the fine scale model. Months are notated long the x-axis, starting with January 2002

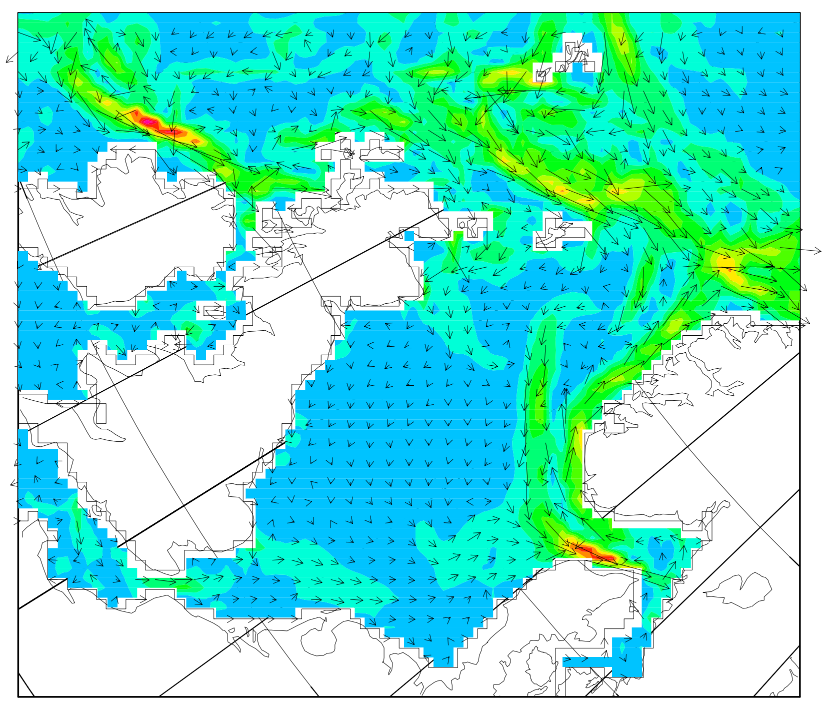

Figure 10: Modeled annual mean velocity field (10 m depth) and speed (in colors) from the coarse North Sea model

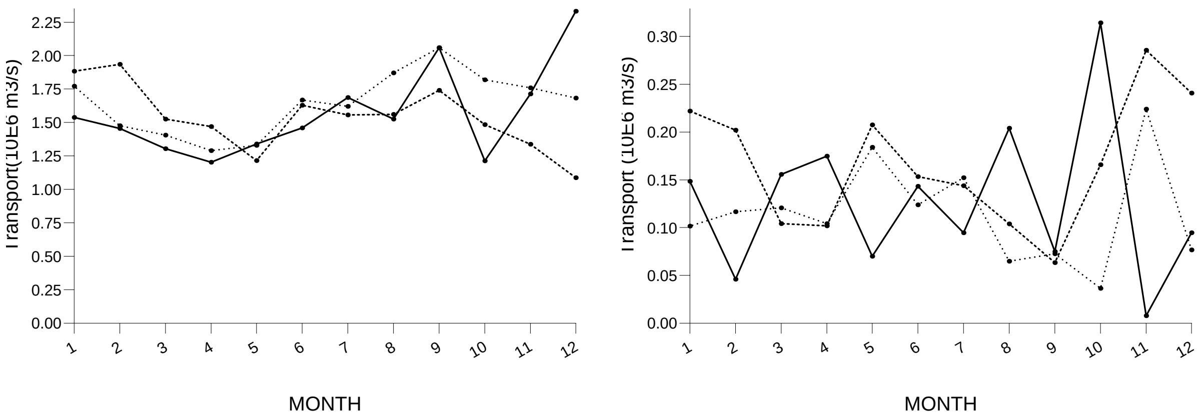

Figure 11: Modeled monthly mean inflow through the Orkney-Utsira transect (left), and net flow through the English Channel (right). 2004 (solid line), 2003 (dotted line) and 2002 (dashed line)

The transports from 2004 can also be classified from a long time modeling 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 both the 2004 Orkney-Utsira inflow and the English Channel net-flow close to the long term mean.

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 criteria 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.`

3.5.1 Chlorophyll

The amount of the colored 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

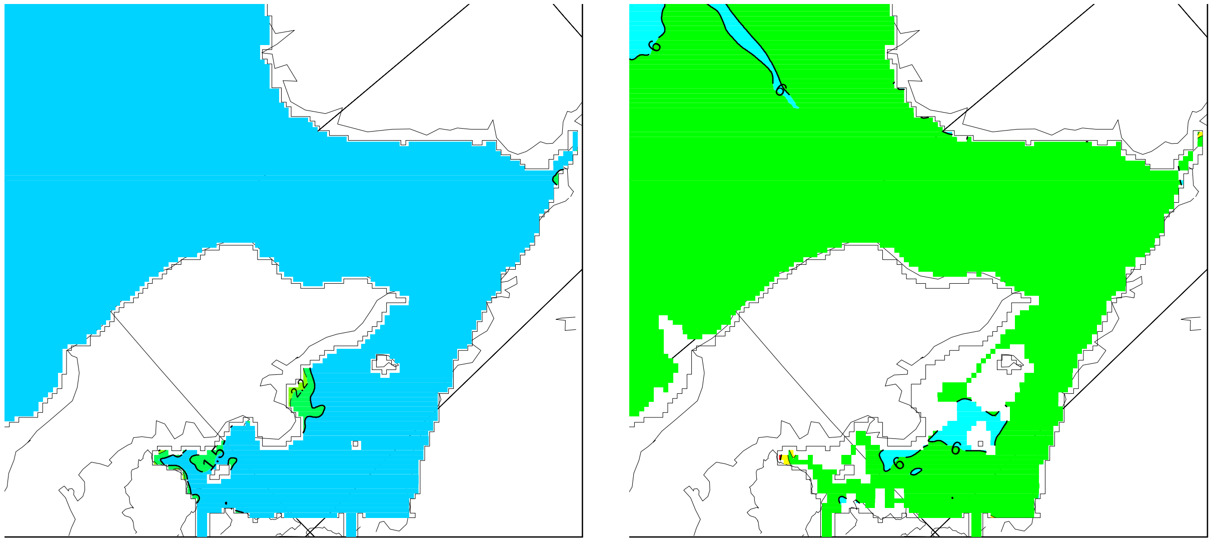

Figure 12: Modeled eutrophication assessment levels of Chlorophyll$_a$ in August (left) and point wise annual minimum oxygen (right). The colors, referring to the eutrophication levels, should be read as: very high (red), high, moderately high, low and very low (blue)

in time and space, therefore measurements should be carried out in August when temporal variations are comparatively small.

The mean modeled 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 (close to the river Glomma outlet) there is a small area classified as low (1.5-2.2 $\mu g/l$), while there are larger areas along the Danish east coast which are classified as Moderate to High $(2.2 - 5.0\mu g/l)$. Compared with 2003 and 2002, the picture is almost identical, but the extent of the Moderate to High areas, are slightly smaller in 2004.

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 point wise annual minimum oxygen in the bottom layer have been taken from week averages to search for episodes of low oxygen levels. The situation is shown in Figure 12. The modeled bottom layer show high (=very low eutrophication level) $(> 6ml/l)$ or moderately high $(4 - 6ml/l)$ oxygen levels in all areas except for some small areas outside Lille Belt where low oxygen levels $(2 - 4ml/l)$ occurs. The situation is very similar to that in 2003, while there are several isolated areas in the southern Kattegat in 2002 with low oxygen levels. In addition there is a larger area in the Central North Sea with low levels in 2002.

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, nitrate and nitrite.

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, nitrite, nitrate and phosphate - 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 bloom of the plankton algae).

The mean modeled 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

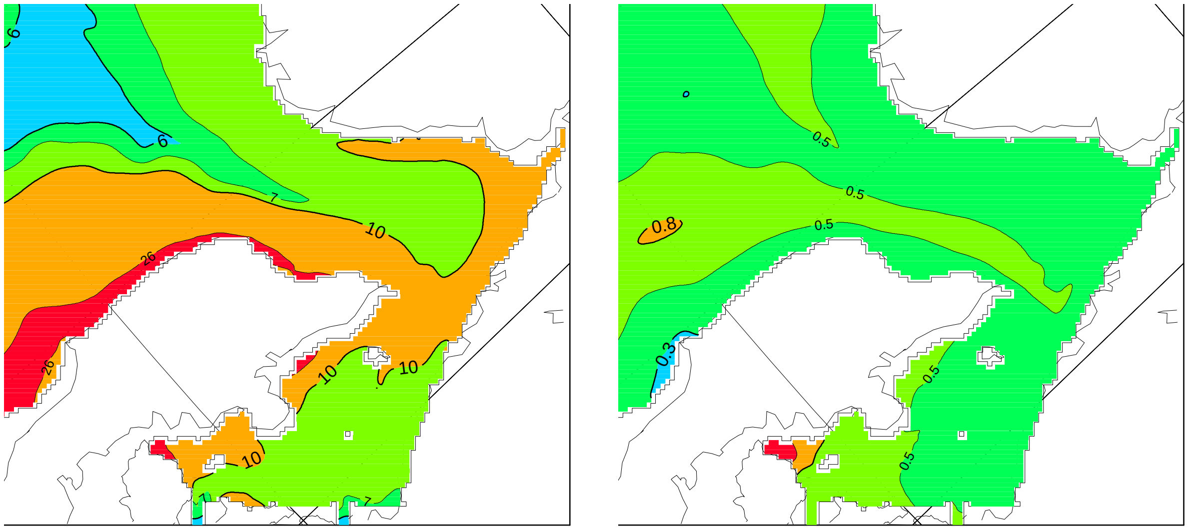

Figure 13: Modeled eutrophication assessment levels of nitrate (left) and phosphate (right) in January. The colors, referring to the eutrophication levels, should be read as: very high (red), high, moderately high, low and very low (blue)

water are classified as low $(< 7\mu mol)$ and moderately high. The only area with very high levels $(> 26\mu mol)$ in 2004 is along the Danish west coast, and some small areas on the Danish east coast. This picture are very similar to that in 2002, while the levels in 2003 generally were higher both in the Skagerrak and North Sea. For phosphate there is a similar situation. Except for some small areas the levels are Low or Moderate in 2004. The only area with High levels are outside the Danish Belts. In 2002 the levels are slightly higher, while in 2003 the levels are Moderate in most of Skagerrak and Kattegat, with a tongue of High phosphate levels $(> 0.8\mu mol)$ stretching from the German Bight and along the Danish west coast as far north as Hanstholm.

4 Summary

An environmental status for year 2004 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, circulation and transports. 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 2004 have been reported and compared to the situation in 2002 and 2003. The annual depth integrated primary production in the whole North Sea is lower in 2004 than in 2002 and 2003, but with large spatial differences. The oxygen conditions in the southern North Sea is much better in 2004 than in both 2002 and 2003, while oxygen in Skagerrak deep water are similar in all three years. Both the Atlantic inflow and the inflow through the English Channel are close to the long-term mean. The inflow through the Orkney-Utsira section is higher than in 2002 but lower than in 2003. For the net inflow through the English Channel it is higher than 2003 but lower than 2002. Only the winter nutrient assessment show any significant indications of eutrophication in the Skagerrak and Kattegat area. The model show high values in most of Kattegat and Skagerrak and an area of very high level of eutrophication on the Danish west coast. The situation are comparable to that in 2002, while the situation generally was worse in 2003. For the other variables, chlorophyll$_a$ and oxygen, the assessment only show moderate or high values in very limited areas on the Danish east coast.

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