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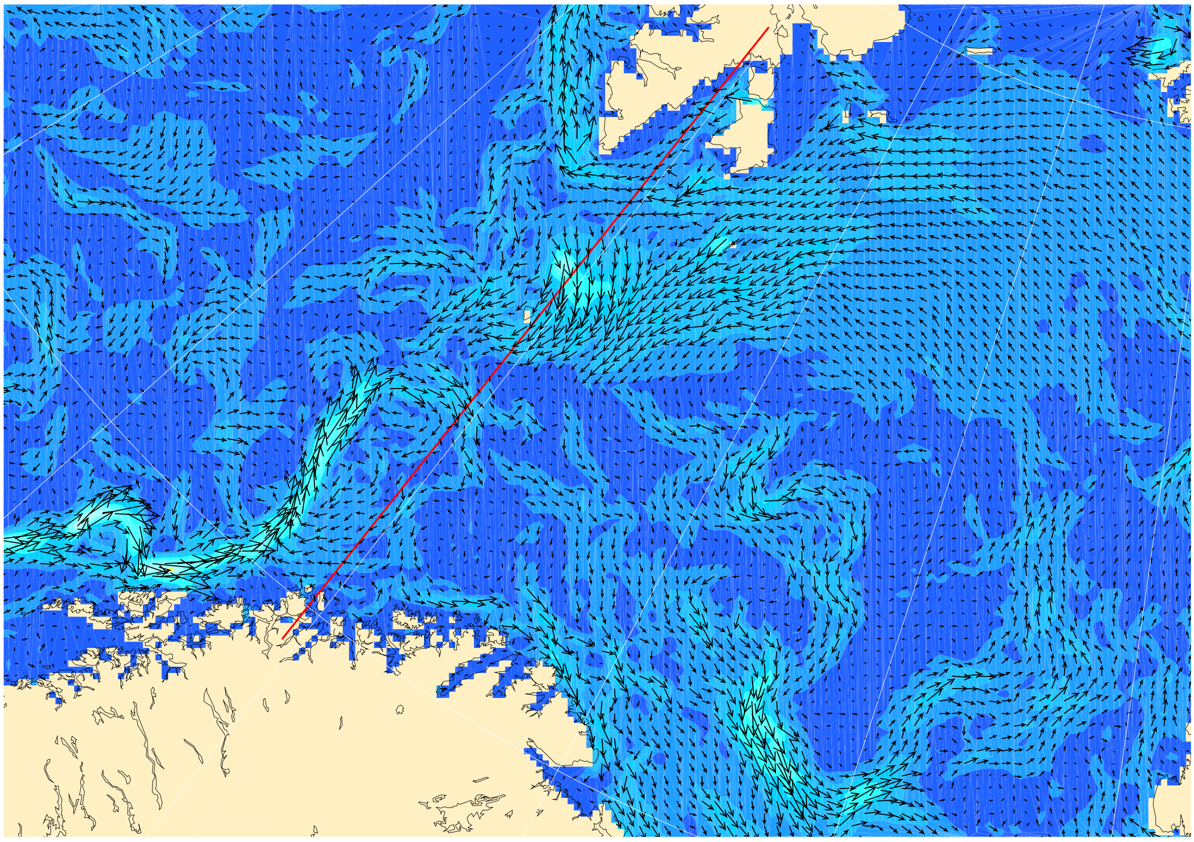

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Title

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Abstract

Considered are the volume fluxes and the water mass properties at the western entrance of the Barents Sea. Three different model simulations are done, and the results are intercompard. Two of the model runs are performed with a regional, σ-coordinate ice-ocean model with respectively 20km and 4km mesh size. Another model run is done with a global, z-coordinate, eddy-permitting (1/4°) ice-ocean model. The model results are compared with hydrographic measurements and mooring records from the years 1997-2001. Although all the models produce relatively fresh water, in particular the two regional σ-coordinate models, the Atlantic inflow from southwest is easily recognized. The Norwegian Coastal Current and the Bear Island Current are however poorly reproduced by the global z-coordinate model. This is explained by a poor representation of salinity gradients in the z-level model caused by the relaxation of sea surface salinity to climatology in this model. It should be kept in mind that the different models are designed for different purposes. The global, z-level model is mainly designed for climate purposes, while the other two models are more focused on the coastal water masses. The volume fluxes into the Barents Sea exhibit a strong seasonal cycle, with a maximum in the winter and a minimum in the summer. Focusing on the Atlantic water masses the simulated summer transports are in good agreement with what is observed, while the winter transports are 1-2 Sverdrups larger in the model results than in the observations.

Keywords

Barents Sea Inflow, Numerical Modeling

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1 Introduction

The objective of this study is to describe the inflow at the western entrance of the Barents Sea by investigating water mass properties and volume fluxes from three different model simulations. Two model simulations are performed with a terrain following, σ-coordinate ice-ocean model, with respectively 20km and 4 km mesh size. Results from these two model runs are compared with the outcome from a z-coordinate, global, eddy-permitting (1/4°) ice-ocean model simulation. Finally, the model results are compared with hydrographic measurements and mooring records published by *Ingvaldsen et al.* (2004).

The inflow to the Barents Sea is dominated by relatively warm and saline Atlantic water masses (temperature$>3^\circ$C, salinity>35 psu) from south-west. Along the Norwegian coast, The Norwegian Coastal Current brings fresher and warmer water into the Barents Sea (temperature$>3^\circ$C, salinity<34.7 psu). On its way through the Barents Sea the Atlantic water changes it's characteristics due to mixing with the surrounding water, cooling and ice formation (*Midttun*, 1985). *Loeng* (1991) argues that most of it enters the Arctic Ocean through the strait between Novaya Zemlya and Frans Josef Land, but some of it also enters the Norwegian Sea with the Bear Island Current in west. It is well documented that the climatic variability of the Barents Sea depends on the amount and properties of the inflowing water. As documented by *Loeng* (1989), there is a close relation between temperature variability and fish population parameters of commercially important stocks. To improve our understanding of the inflow to the Barents Sea is therefore important both in a climate perspective and for commercial interests like the fish industry.

The climate of the Barents Sea varies with both long- and short-term quasi-regular fluctuations. *Ådlandsvik and Loeng* (1991) suggest that the climate of the Barents Sea oscillates between a warm and a cold state. The transition from one state to the other is likely to be enforced externally by variations in larger-scale oceanic and atmospheric circulation. *Ingvaldsen et al.* (2004) started their measurement program in a transition year, while the last three years were sampled during a warm state (1997-2001). The seasonal cycle does not have to be the same for a transition year and a stable state year. This may explain the lack of seasonal cycle in the monthly mean Atlantic inflow presented in their Figure 5 and quoted in Figure 12.

Numerous modeling studies are done for the Barents Sea. A wind-driven model was used by *Ådlandsvik and Loeng* (1991) to calculate the variability of the inflow through the western boundary of the Barents Sea. *Støle-Hansen and Slagstad* (1991) were among the first to do a baroclinic model experiment, while *Ådlandsvik and Hansen* (1998) did the first baroclinic model experiment with horizontal resolution finer than 10 km in the Barents Sea. Finally, *Slagstad and McClimans* (2005) used a physical-chemical-biological model with 4km mesh size to simulate the necessary conditions for primary production. The present study extends the work of *Ådlandsvik and Hansen* (1998) in that a coupled ice-ocean model is used, tidal forcing is applied and the model domain covers the whole Barents Sea opening. *Slagstad and McClimans* (2005) used a similar model resolution as presented here, but they did not have a coupled ice-ocean model which is important to model the heat fluxes correctly. The work described in the present paper is also more extensive than what has previously been documented in that simulations with three different models are performed and the results are compared.

The report is organized as follows. Section 2 briefly describes the numerical ice-ocean models in use. This is followed by a description of the water mass properties in the Barents Sea inflow area in Section 3. Both the water mass properties and the volume fluxes through the western entrance of the Barents Sea, Section 4, are compared with the observations described by *Ingvaldsen et al.* (2004). Finally, Section 5 provides a summary and some concluding remarks.

2 Numerical experiments

The numerical experiments are performed with two different sea-ice model codes, both being fully three-dimensional and based on the primitive equations. There are however differences between them, e.g. in the vertical coordinate. Also, one of the models is global while the other is designed for the region studied. A major advantage of using the two models is that the global model experiment covers more years than the regional model. It thereby includes the years of the observations described by *Ingvaldsen et al.* (2004) as well as the simulation period for the regional ocean model. This makes it possible to evaluate the model results from both models by first doing a model inter-comparison and then comparing the results from the global model with the observations.

2.1 MIPOM/MI-IM

The coupled sea-ice model system consists of a physical oceanographic model (MIPOM) and an ice model (MI-IM). MIPOM is Norwegian Meteorological Institute's version of the Princeton Ocean Model, and it is documented by *Blumberg and Mellor* (1987), *Engedahl* (1995) and *Engedahl et al.* (2001). It utilizes the terrain-following σ-coordinate in the vertical. The dynamic-thermodynamic sea-ice model MI-IM is described by *Røed and Debernard* (2004).

2.1.1 ARCTIC20km

A coarse mesh model (20 km mesh size and 21 σ-levels) is set up for the whole Arctic Sea and North Atlantic adjacent seas as presented in Figure 1. The Arctic Sea model was first initialized on January 1, 1981 with monthly mean climatological values of hydrography, currents and sea surface elevation as described by *Engedahl et al.* (1997, 1998). Initial fields for the ice model are created by assuming 2 m ice thickness, 0 ice velocity and 75% ice concentration where the temperature in the climatological data is 0°C or below. A simulation was then performed for the years 1981-1995 with atmospheric forcing fields from the ERA40 dataset obtained from the European Center for Medium-Range Weather Forecasts (ECMWF) Data Server. A slightly modified version of the nudging method documented by *Albretsen and Burud* (2006) is applied to assimilate sea surface temperature and ice concentration in the present simulations. The fields assimilated are sea surface temperature from the ERA40 dataset and merged ice concentration fields from the Ice Sevice at Norwegian Meteorological Institute (http://met.no/kyst_og_hav/iskart.html) and from the ERA40 dataset. At the open boundary the physical oceanographic model is relaxed towards the climatology documented

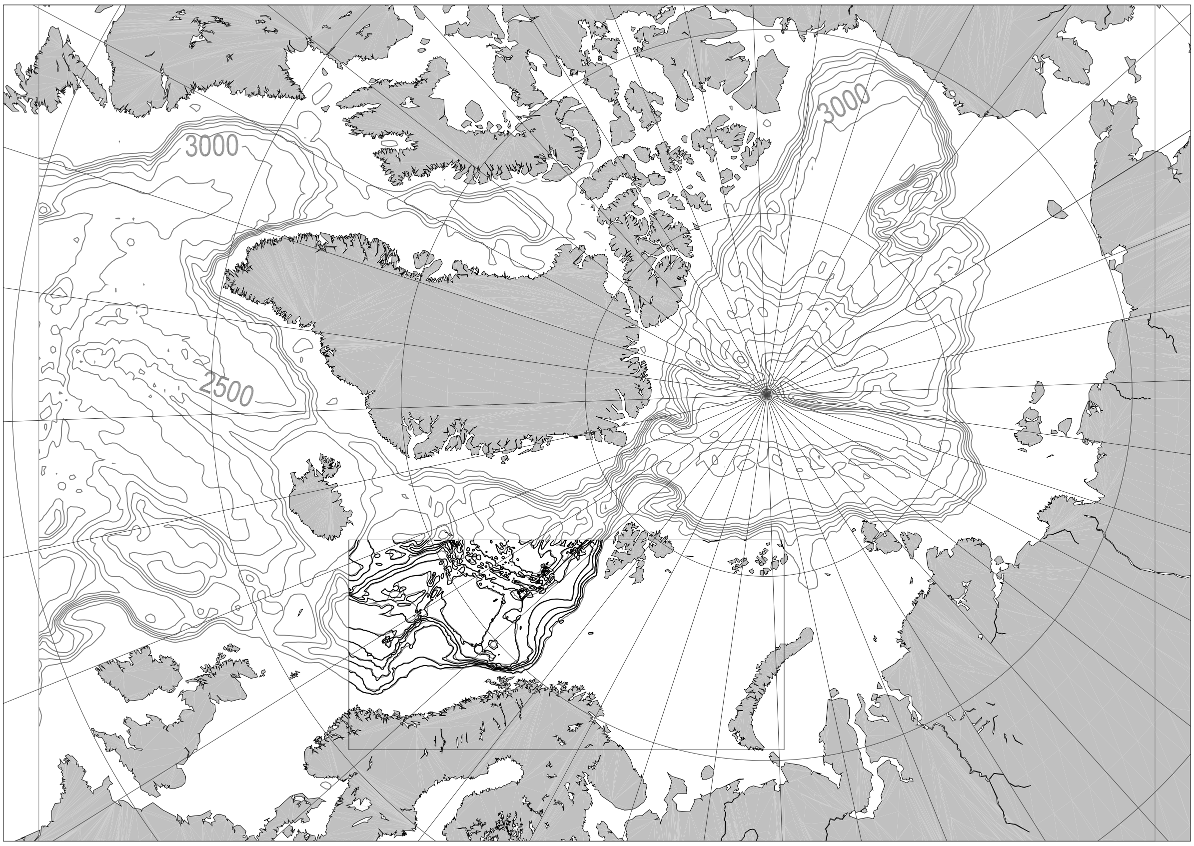

Figure 1: Nested model system. Grey contours give the isobaths for the coarse mesh model (20 km mesh size) covering the whole Arctic Sea and North Atlantic adjacent seas. Nested into this model is a model of 4 km mesh size covering the Barents Sea and most of the Norwegian Sea. The isobaths for the fine mesh model is marked with black. The bottom topography contour interval is 500 m. Straight gray lines correspond to a 10° by 10° latitude-longitude grid, and the North Pole is seen in the middle of the Arctic Sea.The southernmost latitude drawn is 50°N, while the longitudinal line shown in the southwestern corner of the domain corresponds to the Greenwich meridian.

by *Engedahl et al.* (1997, 1998), while the ice is only allowed to drift out of the model domain. No tidal forcing is included. As river runoff and Baltic outflow the climatological values and the method described by *Martinsen et al.* (1992) are used.

2.1.2 BARENTS4km

Nested within the Arctic Sea model is a model covering the Barents and Norwegian Seas with 4 km mesh size and 21 σ-levels (Figure 1). The model was initialized on January 1, 1985, by interpolating the corresponding simulated fields from the Arctic Sea model onto its mesh. The model was ramped up for 1985 using the atmospheric and freshwater forcing as described above, as well as assimilation of sea surface temperature and ice concentration. At the lateral boundaries tidal forcing (8 constituents) were prescribed together with the simulated fields from the Arctic Sea model. The resulting fields for January 1, 1986 are used as initial conditions for a 10 year simulation covering the years 1986-1995 with atmospheric forcing fields consisting of 12 hours prognoses produced twice a day at ECMWF.

2.2 ORCA-R025

ORCA-R025 is a z-coordinate, global eddy-permitting (1/4°) ocean/sea-ice model described by *Barnier et al.* (2006). The ocean-ice code is based on the Nucleus for European Models of the Ocean (NEMO) framework (*Madec et al.*, 1998) version 1.9. The present model configuration is described by *Treguier et al.* (2007).

3 Water mass properties

Figure 2 shows horizontal maps of the 10 year mean salinity for the Barents Sea inflow area from all the three models used. Relatively saline water masses are seen southwest of Spitsbergen and also in the middle of the Barents Sea opening. This is associated with the two branches of the Norwegian Atlantic Current, one flowing northwards on the western side of Spitsbergen and one flowing eastward into the Barents Sea. The salinity values are however different between the models, the ORCA-R25 being the most saline, then the BARENTS4km model and the ARCTIC20km model is the least saline. The BARENTS4km model has very well defined gradients and more variability than the other two models. Both the Norwegian Coastal Current carrying less saline waters into the Barents Sea as well as the Bear Island Current with Arctic water flowing out of the Barents Sea, is very well reflected in the BARENTS4km model. Although the gradients are less sharp, these currents are easily recognized in the ARCTIC20km model as well. However, in the ORCA-R25 model the salinity gradients towards the Norwegian coast and the Bear Island are very weak. This is clearly not very realistic, and may be explained by the relaxation of the sea surface salinity to the monthly climatology of Levitus.

The structure of the 10 year mean temperature, presented in Figure 3, is different from the structure of the salinity. The temperature pattern is very similar in the ORCA-R25 model and the BARENTS4km model, and the variability is clearly larger for these two models than for

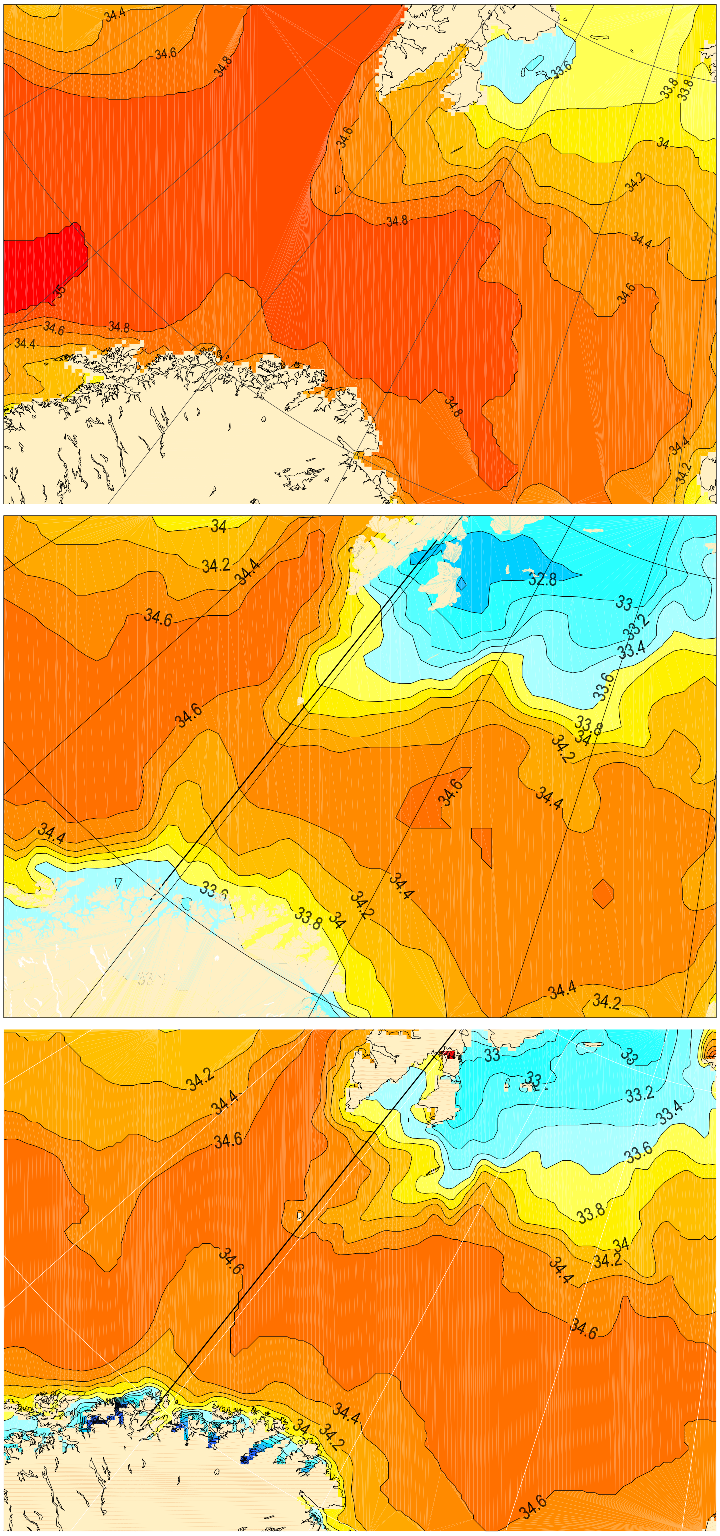

Figure 2: Mean salinity for the years 1986-1995 in the western Barents Sea. The northern coast of Norway is seen in the southwestern corner, while Spitsbergen is seen at the northern border. The contour interval is 0.2 psu.The uppermost panel shows the salinity produced by the ORCA-R025 model, the middle panel represent the ARCTIC20km model and the lowermost panel is the salinity from the BARENTS4km model. Note that the ORCA-R25 model produce more saline water masses than the other two models. Also note that the gradients along the Norwegian coast are more pronounced for the ARCTIC20km model and the BARENTS4km model than for the ORCA-R25 model.

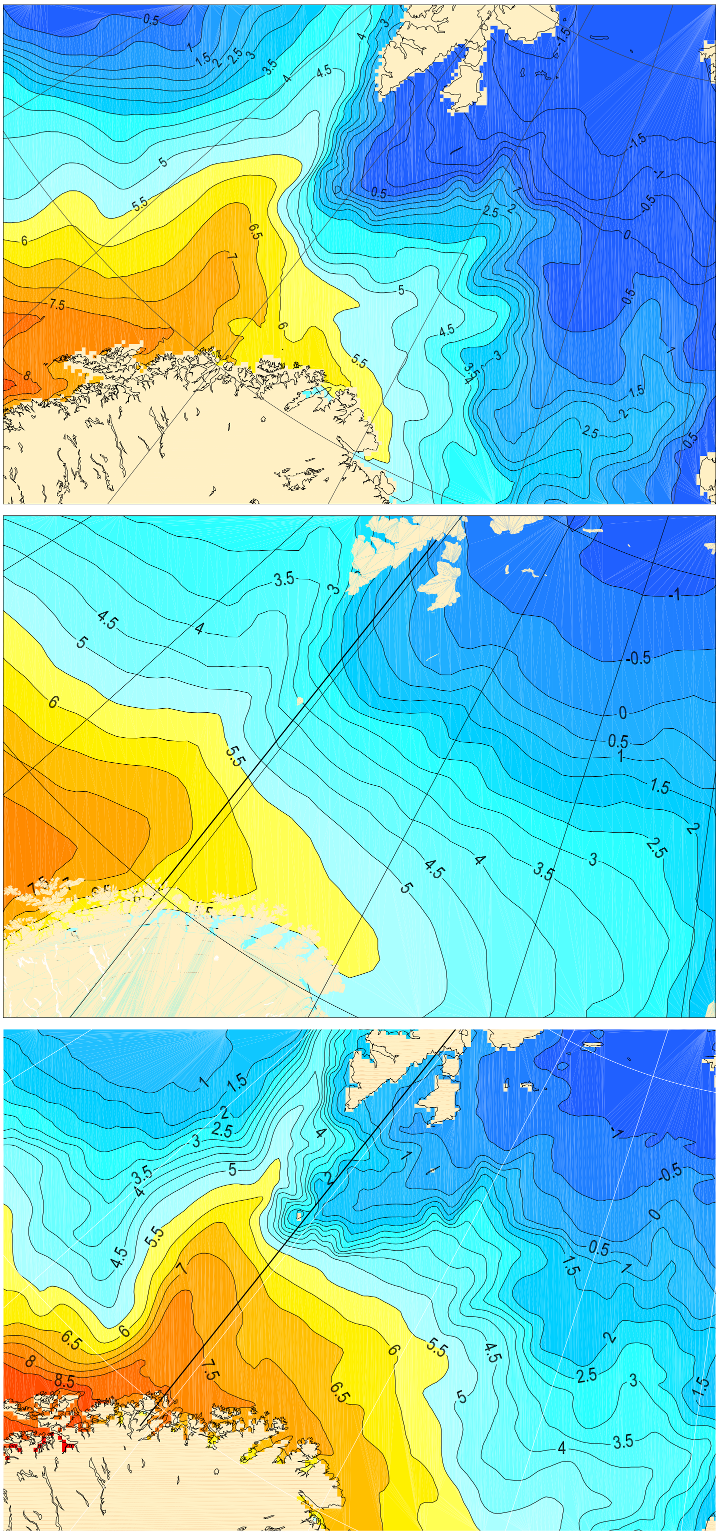

Figure 3: Mean temperature for the years 1986-1995. The geographical area corresponds to what was shown in Figure 2. The Contour interval is 0.5°C. The uppermost panel shows the temperature produced by the ORCA-R025 model, the middle panel represent the ARCTIC20km model and the lowermost panel is the temperature from the BARENTS4km model. Note that the temperature pattern shows more of the mesoscale structure in the ORCA-R25 model and in the BARENTS4km model than in the ARCTIC20km model.

the ARCTIC20km model. This reflects that the effective model resolution of the ORCA-R25 model is relatively high (13 km) in the Barents Sea.

Figure 4 shows 10 year mean hydrography in the section along 19.5°E covering the whole Barents Sea opening from northern Norway (69.5°N) to Spitsbergen (79°N). In all three models the water is colder and fresher north of Bear Island (74.5°N) than further south. This is consistent with the Arctic water masses there. The water is also cold in a narrow band south of Bear Island which reflects the Bear Island Current transporting Arctic water masses out of the Barents Sea toward the Norwegian Sea. A corresponding decrease in the salinity is evident at the same latitude in the ARCTIC20km model, but it is much less pronounced in the other two models.

In all the models a salinity maximum, with salinities close to 35 psu, is found between 71°N and 73.5°N. This is followed by temperatures above 3°C above respectively 300 m and 200 m south of 73°N in the ORCA-R25 model and the BARENTS4km model. Even though the salinities are not larger that 35 psu, they are so close that this water is associated with the Atlantic inflow. However, in the ARCTIC20km model water with temperatures higher than 3°C is confined to the upper 100 m where the salinity is less than 34.6 psu. This water has therefore properties of Coastal Water, and no Atlantic water is found in the ARCTIC20km model. In the deepest part of the section south of Bear Island the temperature is around 0°C or lower in all the models and the salinity is 34.7-35 psu. This meas that the temperature is consistent with Arctic water but the water is a bit too fresh. Since the salinities generally are a bit low compared to what is known about the area, the model results all seem to produce too fresh water.

From 71°N and southward to the Norwegian coast the water becomes gradually fresher reflecting the Norwegian Coastal Current in the ARCTIC20km model and the BARENTS4km model. The salinity varies much less in the ORCA-R25 model than in the other two models, and the ORCA-R25 salinity is never below 35.6 psu. Again, this may be explained by the relaxation of the surface salinity towards the Levitus climatology in the ORCA-R25 model.

Figure 5 and Figure 6 shows the 10 year mean salinity and temperature for January and August respectively in the section starting a bit north of the Norwegian coast (71.5°N) to Bear Island (74.5°N). It clearly illustrates the seasonal variation in the Barents Sea inflow with warmer upper layer water masses in August than in January. The salinity pattern does not have such a clear seasonal variation, but it seems like the less saline coastal water is more confined to the surface, but goes further north in August than in January in both the ORCA-R25 model and the ARCTIC20km model. This corresponds well to *Sundby* (1976) saying that the Norwegian Coastal Current is shallow and wide in summer and deep and wide in the winter. A similar change is not recognized in the BARENTS4km results.

Ingvaldsen et al. (2004) presented the mean salinity for the same section as in Figure 6 and Figure 5 from hydrography measurements sampled 6 times a year by the Institute of Marine Research in the time period 1997-2001. Their Figure 4. is quoted in Figure 7. In January the salinity is above 35 psu from top to bottom between 73.75°N and 71.25°N, while in August it is overlaid by a thin layer of less saline Coastal water extending northward from the Norwegian coast almost to Bear Island. The high salinity water corresponds well to both Atlantic water masses and possibly also Arctic water masses in the deeper layers. To distinguish the two, the salinity sections would have to be accompanied by corresponding temperature sections. The

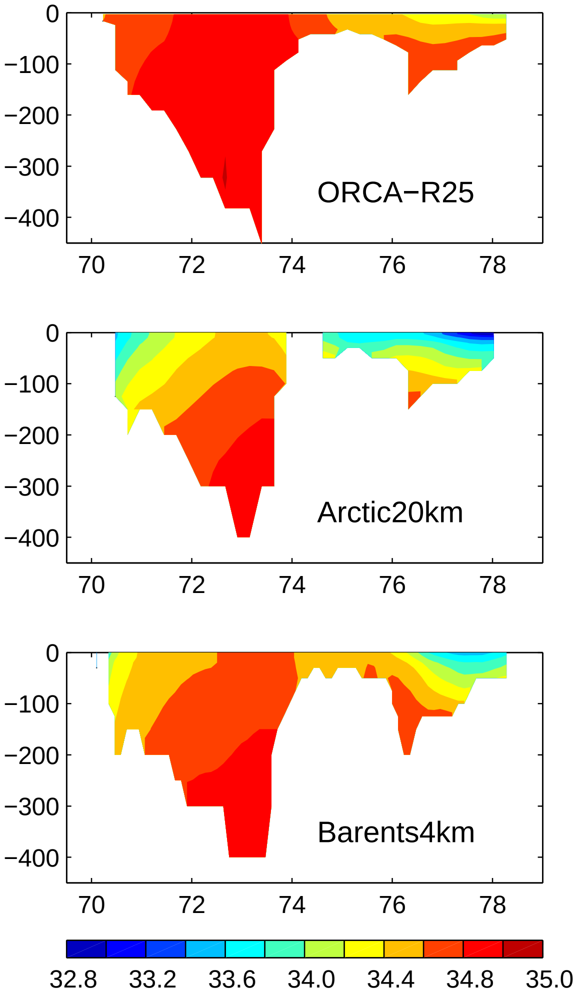

Figure 4: Mean salinity and temperature for the years 1986-1995 in the section along 19.5°E covering the whole Barents Sea opening from northern Norway (69.5°N) to Spitsbergen (79°N). The salinity are shown to the left and the temperature to the right. The upper panels represent the ORCA-R25 model, the middle panels the ARCTIC20km model and the lowermost panel the BARENTS4km model. The contour interval is 0.2 psu for the salinities and 1°C for the temperatures.Note the relatively saline water masses between 71°N and 73.5°N followed by temperatures larger than 3°C above 2-300 m in the ORCA-R25 model and the BARENTS4km model. This water is associated with the Atlantic inflow, while no Atlantic water is seen in the ARCTIC20km model. Also note the very weak gradients in the ORCA-R25 model, meaning that the Norwegian Coastal Current and the Bear Island current is poorly reproduced by this model.

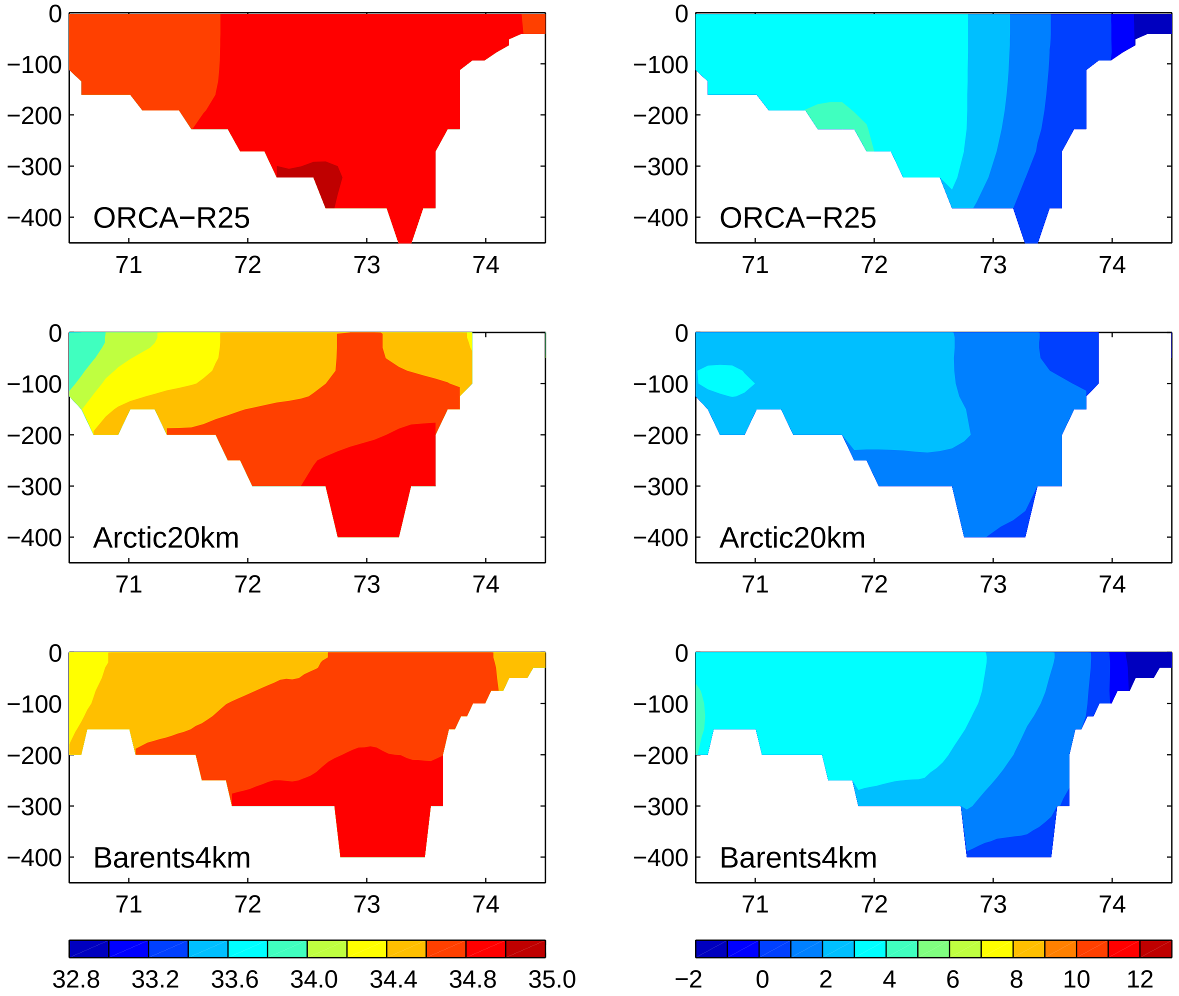

Figure 5: Mean salinity and temperature in January for the years 1986-1995 in the section along 19.5°E from north of the Norwegian coast (71.5°) to the Bear Island (74.5°).

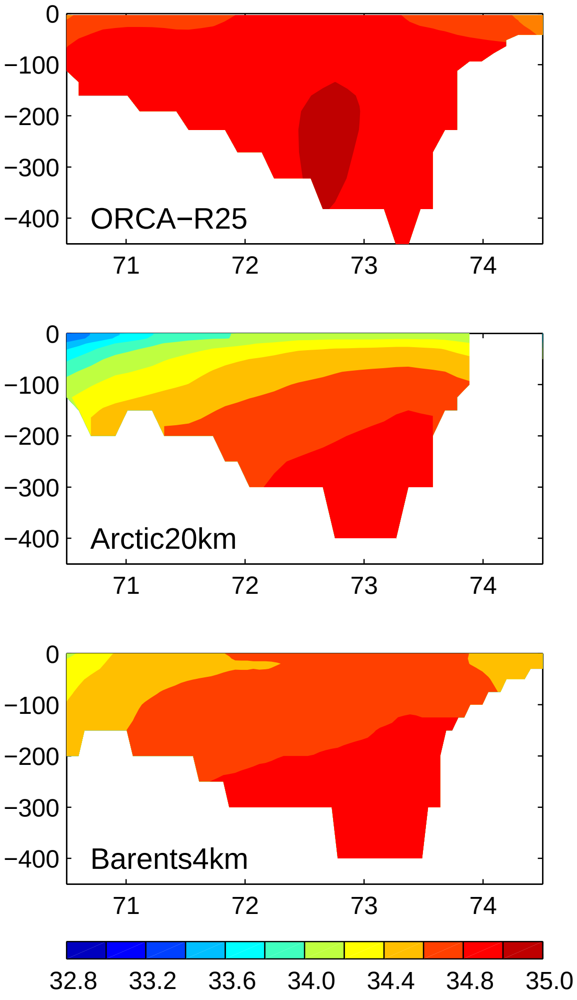

Figure 6: Same as in Figure 5, but for August. Note the warmer surface waters in August than in January. Also note that the coastal water stretches further northwards in the summer than in the winter.

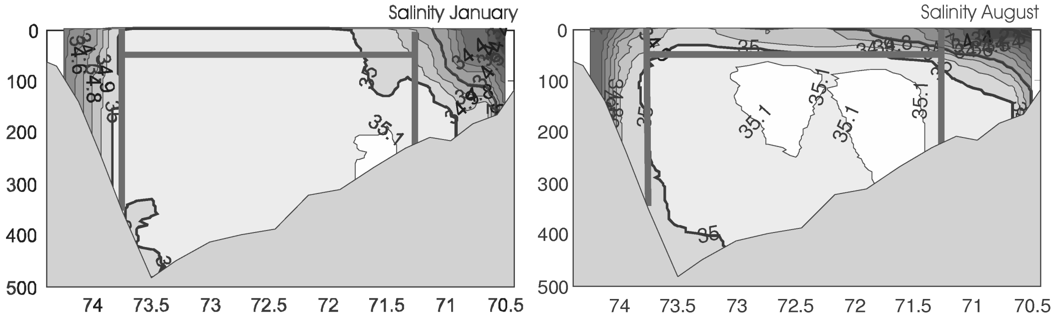

Figure 7: Figure 4. of *Ingvaldsen et al.* (2004). Mean salinity in January and August for the years 1997-2001. The area below the horizontal line (50 m depth) and between the two vertical lines, is the area occupied by the moorings. It corresponds to the area of the volume fluxes in Figures 10, 11, 12 and 13. The salinities are above 35 psu in the central part of the section. Also, the gradients towards the Norwegian coast and the Bear Island is very well pronounced.

salinity decreases clearly towards Bear Island and towards the coast of Norway reflecting the less saline Norwegian Coastal Current and Bear Island Current.

Since we only have results from the ORCA-R25 model for the years 1997-2001, the mean salinity for January and August for this model is presented in Figure 8. The seasonal variation with fresher water masses over the more saline waters in August is recognized. In the central parts of the section it seems like the simulated salinity is less than the observed. Remembering that the ORCA-R25 model is the model with the highest and most realistic salinity values, his is an alarming result. The comparison between the model results and the data also shows that the model produced salinity gradients are too weak and that the Norwegian Coastal Current as well as the Bear Island Current is not well reproduced by the ORCA-R25 model.

4 Volume fluxes

Figure 9 shows the mean volume flux for the three different models in a section from Norway to Spitsbergen along 19.5°E. The BARENTS4km volume flux is clearly larger and exhibits stronger variation than the other two models. That may be because the BARENTS4km model include tides. Also, this model is the only one resolving mesoscale motion like meanders and eddies. Since the time series presented are 10 year means most of both the mesoscale motion and the tidal motion is filtered out and only effects such as tide-surge interaction are kept.

Computing the mean volume flux for only that part of the section starting at 71.5°N and ending at 73.5°N, as given in Figure 10, the situation is very similar. The magnitudes are of course smaller than for the complete section (Figure 9). In the spring season the BARENTS4km model is the largest, while in the autumn the ORCA-R25 model is the largest.

In Figure 11 the volume flux is calculated based on only the water warmer than 3°C below 50m in the same section as in Figure 10. This corresponds to the definition *Ingvaldsen et al.*

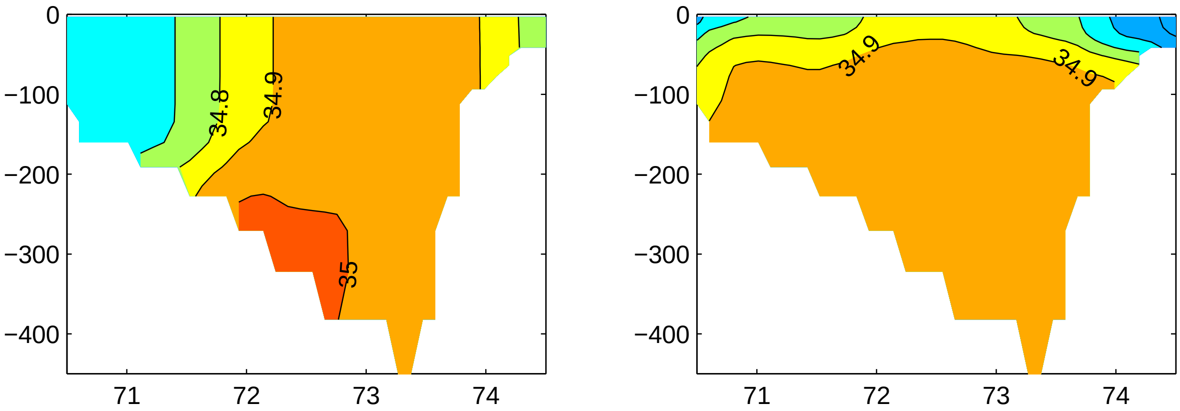

Figure 8: Mean salinity in January and August for the years 1997-2001 from the ORCA-R25 model. Note that the simulated salinities are smaller than the observed presented in Figure 7. Also note that the gradients towards Norway and the Bear Island are much weaker than in the observations, which means that the Norwegian Coastal Current and the Bear Island Current is not very well reproduced by this model.

(2004) used for Atlantic water in their observations, and their Figure 5a is repeated in Figure 12. Note that the time period is different in Figure 11 and in Figure 12. The seasonal variation present in the model results is not seen in the time series based on the data. *Ingvaldsen et al.* (2004) explains this by the fact that their measurement program started in a transition year between a cold state and a warm state of the Barents Sea. The seasonal cycle is not necessarily the same for a transition year and a stable state year, and the first year studied by *Ingvaldsen et al.* (2004) is not representative for the stable state (most usual) years. Based on this they estimate the winter transport of Atlantic water from 50m and down to be 1.5 Sv. and the summer transport to be 1.1 Sv. This means that the model produced winter volume flux is far too high compared to the data, while the summer values match quite well. Also, *Ingvaldsen et al.* (2004) found a very distinct minimum in April which is not evident in the model results. They suggested this to be a regional wind-induced effect.

To make sure that the actual years the volume flux is computed for is not important, the ORCA-R25 mean Atlantic water transport for the years 1997-2001 is presented in Figure 13. The June minimum is even more pronounced here than in Figure 11 which may be because the averaging period is shorter, but the overall impression is that whether the averaging period is 1986-1995 or 1997-2001 is not very important when it comes to studying mean volume fluxes in the Barents Sea opening.

5 Summary and concluding remarks

The inflow at the western entrance of the Barents Sea is investigated by the use of three different numerical ice-ocean models. The ORCA-R25 model is based on the Nucleus for European Models of the Ocean (NEMO) framework (*Barnier et al.*, 2006; *Treguier et al.*, 2007) and is

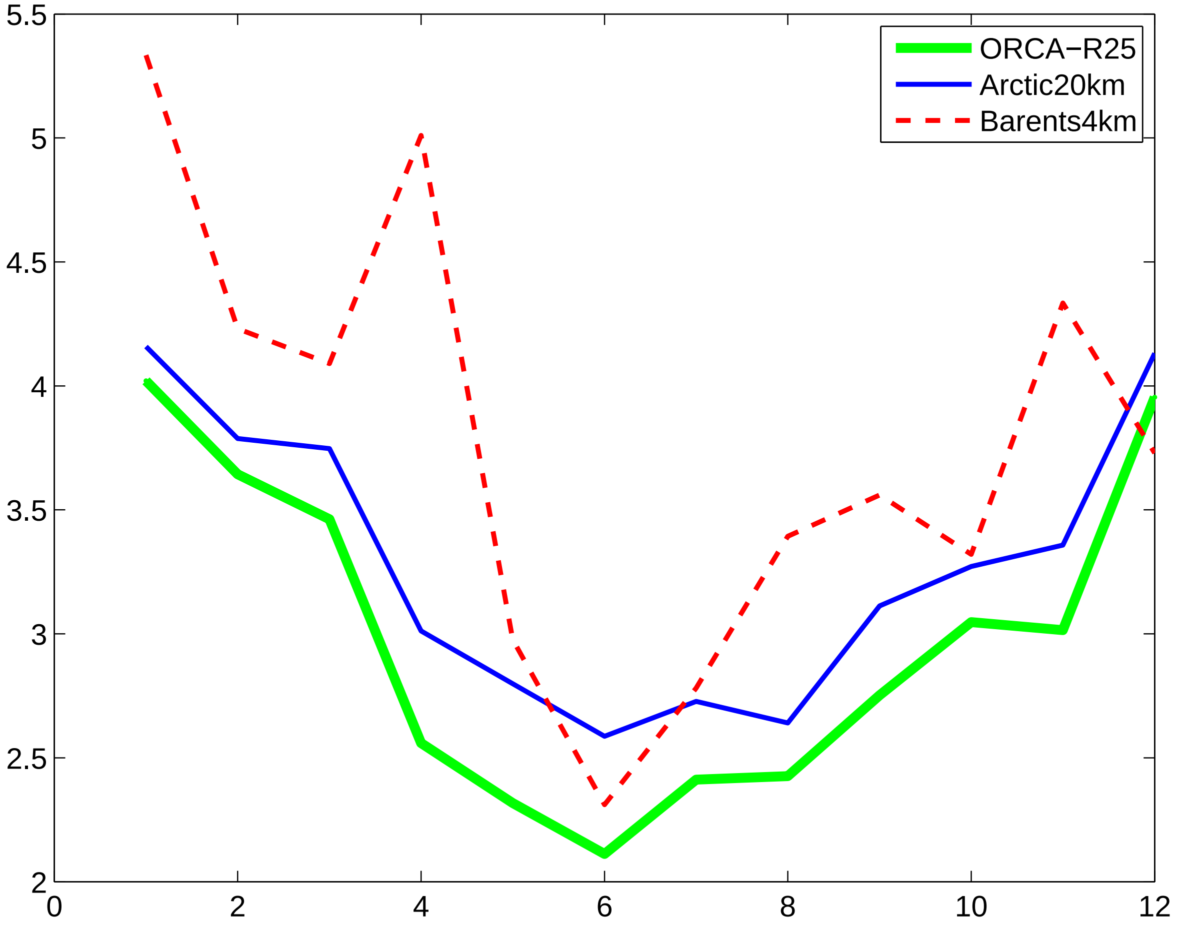

Figure 9: Mean volume flux in the section along 19.5°E from 69.5°N to 79°N for the years 1986-1995. The ORCA-R25 volume flux is represented with a thick green line, the BARENTS4km volume flux is shown with a dashed red line and the ARCTIC20km volume flux is represented with a solid blue line. The horizontal axis show months, while the vertical axis gives volume flux in Sverdrups. Positive volume fluxes are water flowing into the Barents Sea. Note that the BARENTS4km volume flux is clearly larger and has a larger variation than the volume fluxes from the two other models.

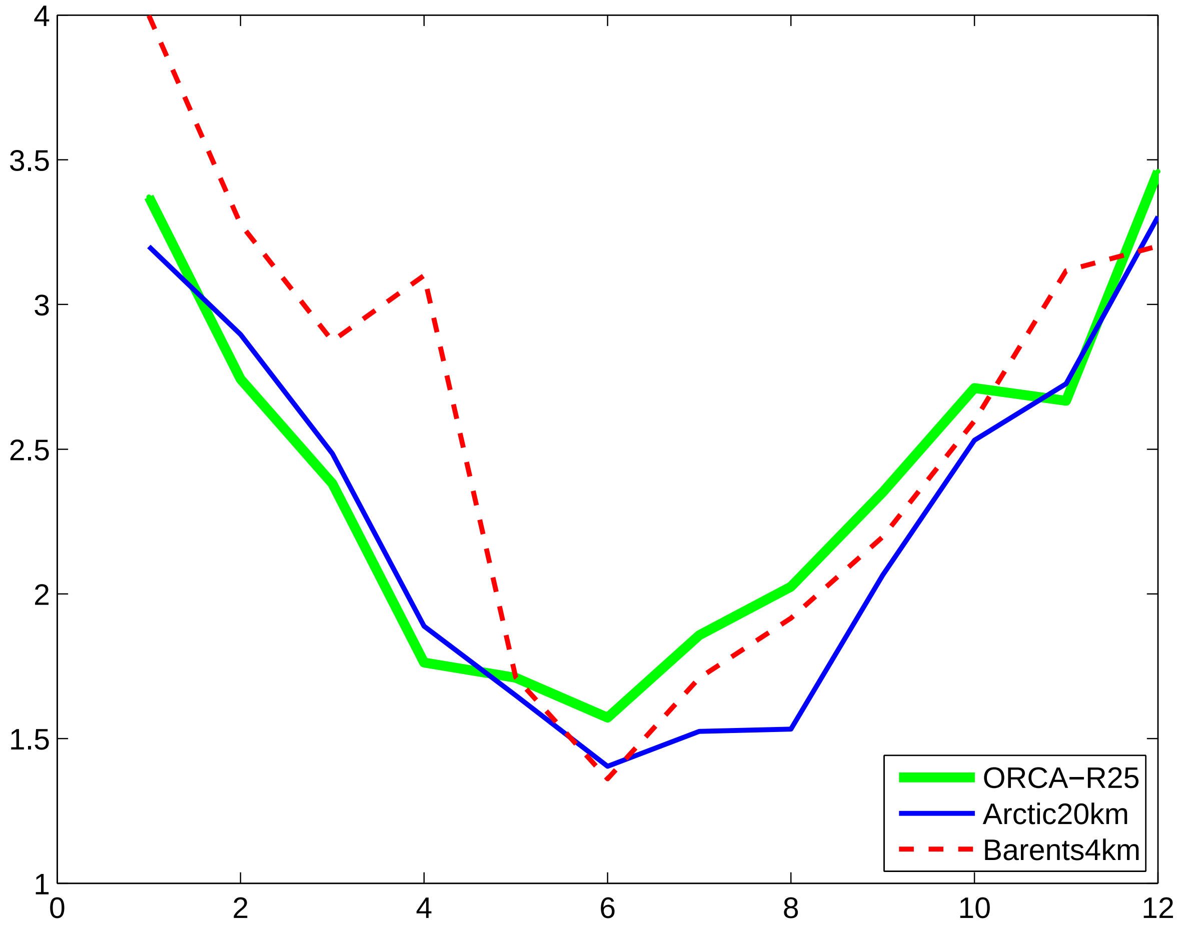

Figure 10: Similar mean volume fluxes as in Figure 9. Section is shortened and starts at 71.5°N and ends at 73.5°N.

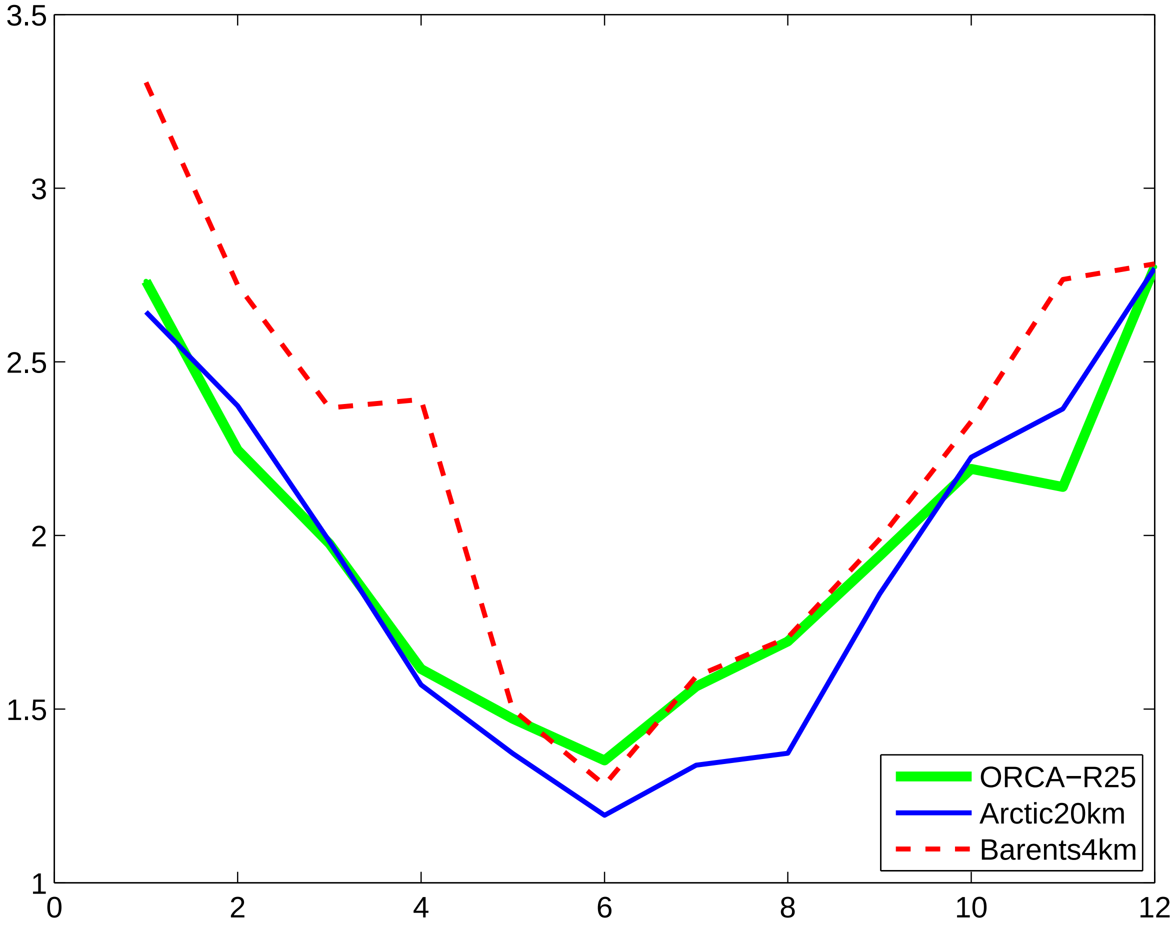

Figure 11: Mean volume flux of water warmer than 3°C below 50m through the section between 71.5°N to 73.5°N along 19.5°E. The seasonal variation is very similar to what was seen in Figure 9 and in Figure 10. Also, the differences between the different models are very similar. However, the magnitudes are smaller here than in Figure 10.

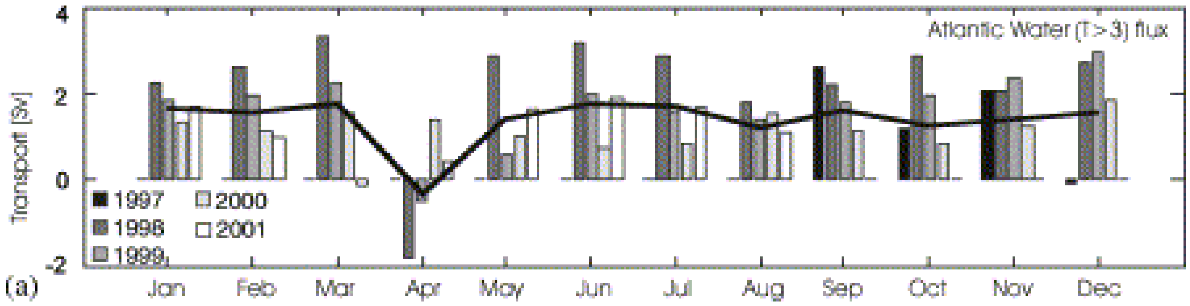

Figure 12: Figure 5 (a) of *Ingvaldsen et al.* (2004). Monthly mean volume flux of Atlantic water estimated from moorings deployed in the area between 71.5°N to 73.5°N. The bars show the individual years, while the solid line gives the average over the years 1997-2001. Note the volume flux minimum in April which is not present in the model results. Also note that there is no seasonal cycle.

a global, z-coordinate, eddy-permitting (1/4°) ice-ocean model. The other two model simulations (ARCTIC20km and BARENTS4km) are performed with Norwegian Meteorological Institute's version of the well known Princeton Ocean Model (*Blumberg and Mellor*, 1987; *Engedahl*, 1995), and are run with respectively 20km and 4km mesh size.

By comparing with the salinity measurements described by *Ingvaldsen et al.* (2004) all the models are clearly too fresh, with the ARCTIC20km and the BARENTS4km models being even fresher than the ORCA-R25 model. All the models produce relatively fresh water masses, with the ARCTIC20km and the BARENTS4km models being even fresher than the ORCA-R25 model. By comparing with the salinity measurements described by *Ingvaldsen et al.* (2004) the salinity values are clearly too low. It is also evident that the salinity fronts are too weak in the ORCA-R25 model, and that the Norwegian coastal Current and the Bear Island Current is poorly reproduced by this model. Knowing that the ORCA-R25 salinity is relaxed towards climatology this is not very surprising, and the salinity pattern seem much more realistic in the ARCTIC20km and BARENTS4km models. The representation of the temperature gradients are related to the model resolution, and the temperature distribution is more similar in the BARENTS4km model and the ORCA-R25 model than in the ARCTIC20km and BARENTS4km models.

There is a seasonal variation in the volume flux into the Barents Sea in all the three models, with a larger volume flux in the winter than in the summer. Computing the total volume flux through the section from Norway to Spitsbergen along 19.5°E, the winter volume flux is 4-5 Sv for the BARENTS4km model while it is 3-4 Sv for the two other models. The summer volume flux is 2-3 Sv for all the three models. Defining Atlantic water as water masses below 50 m with temperature larger than 3°C, and shortening the section to match the mooring observations described by *Ingvaldsen et al.* (2004), the magnitude of the volume fluxes decrease. The seasonal variation is still there and the winter volume fluxes are 2-3 Sv, while the summer volume fluxes are around 1.5 Sv. This means that the winter volume flux values are clearly too high compared to 1.5 Sv as *Ingvaldsen et al.* (2004) estimated from their

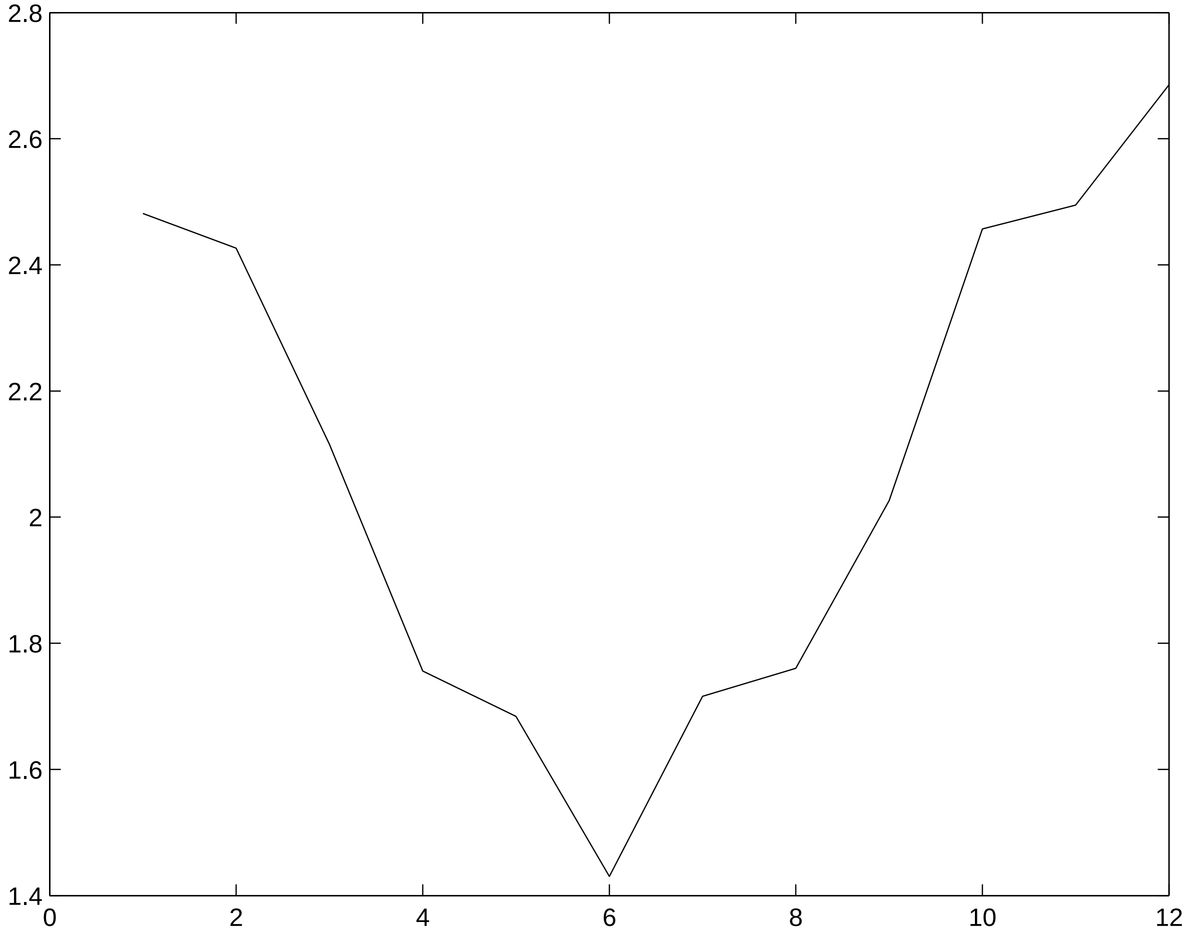

Figure 13: ORCA-R25 mean volume flux of water warmer than 3°C below 50m in the section along 19.5°E between 71.5°N to 73.5°N for the years 1997 to 2001.The magnitude is very similar to the mean volume flux for the years 1986 to 1995 presented in Figure 11. The minimum in June is shown more clearly here. That may be because of the shorter averaging period or the different vertical axes. Note that the minimum is in June and not in April as in the results of *Ingvaldsen et al.* (2004) presented in Figure 12.

observations, while the summer volume fluxes match well.

The present comparison of the model results with the observations described by *Ingvaldsen et al.* (2004) gives only an indication of how well the models work. To do a proper validation care should be exercised to extract the model results in precisely the same way as the observations are done. Also, statistics should be used to get quantitative measurements of the models performance. Finally, the 4-year long mooring record from one single section documented by *Ingvaldsen et al.* (2004) gives only a limited amount of data. To the authors knowledge the Institute of Marine Research collects observations regularly each year in several sections in the Barents Sea. This data-set would of course perform a much broader basis for the model validation and should be used in a future study.

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References

Albretsen, J., and I. Burud, Assimilation of sea surface temperature and sea ice concentration in a coupled sea ice and ocean modelel., in *European Operational Oceanography: Present and Future. Proceedings of the 4th International Conference on EuroGOOS.*, edited by H. Dahlin, C. Flemming, P. Merchand, and S. E. Petersson, pp. 661–666, Brest, France, 2006.

Barnier, B., G. Madec, T. Penduff, J. Molines, A. Treguier, J. L. Sommer, A. Beckmann, A. Biastoch, C. Böning, J. Dengg, C. Derval, E. Durand, S. Gulev, E. Remy, C. Talandier, S. Theetten, M. Maltrud, J. McClean, and B. D. Cuevas, Impact of partial steps and momentum advection schemes in a global ocean circulation model at eddy permitting resolution., *Ocean Dyn.*, *56*, 543–567, 2006.

Blumberg, A., and G. Mellor, A description of a three-dimensional coastal ocean circulation model., in *Three-dimensional Coastal Ocean Models*, edited by N. Heaps., vol. 4 of *Coastal and Estuarine Sciences*, American Geophys. Union, 1987.

Engedahl, H., Implementation of the Princeton ocean model (POM/ECOM-3D) at the Norwegian Meteorological Institute (DNMI)., *Research Report 5*, Norwegian Meteorological Institute, Oslo, Norway, 1995.

Engedahl, H., G. Eriksrød, C. Ulstad, and B. Ådlandsvik, Climatological oceanographic archives covering the nordic seas and the arctic ocean with adjacent waters., *Research Report 59*, Norwegian Meteorological Institute, Oslo, Norway, 1997.

Engedahl, H., B. Ådlandsvik, and E. A. Martinsen, Production of monthly mean climatological archives for the nordic seas., *J. Mar. Sys.*, *14*, 1–26, 1998.

Engedahl, H., A. Lunde, A. Melsom, and X. B. Shi, New schemes for vertical mixing in MI-POM and MICOM, *Research Report 118*, Norwegian Meteorological Institute, Oslo, Norway, 2001.

Ingvaldsen, R. B., L. Asplin, and H. Loeng, The seasonal cycle in the atlantic transport to the barents sea during the years 1997-2001., *Cont. Shelf Res.*, *24*, 1015–1032, 2004.

Loeng, H., The influence of temperature on some fish population parameters in the barents sea., *J. of N-W Atlantic Fisheries Sci.*, *9*, 103–113, 1989.

Loeng, H., Features of the physical oceanographic conditions of the barents sea., *Polar Research*, *10*, 5–18, 1991.

Madec, G., P. Delecluse, M. Imbard, and C. Levy, Opa 8.1 general circulation model reference manual., *Notes de 1 IPSL 11*, Université P. et M. Curie,, B102 T15-E5, 4 place Jussieu, Paris, 1998.

Martinsen, E., H. Engedahl, G. Ottersen, B. Ådlandsvik, H. Loeng, and B. Balino, Metocean MOdeling Project, Climatological and hydrographical data for hindcast of ocean currents., *Tech. Rep. 100*, Norwegian Meteorological Institute, 1992.

Midttun, L., Formation of dense bottom water in the barents sea., *Deep-Sea Res.*, *32*, 1233–1241, 1985.

Røed, L. . P., and J. Debernard, Description of an integrated flux and sea-ice model suitable for coupling to an ocean and atmosphere model, *met.no Report 4/2004*, Norwegian Meteorological Institute, 2004.

Slagstad, D., and T. A. McClimans, Modeling the ecosystem dynamics of the barents sea including the marginal ice zone: I. physical and chemical oceanography, *J. Mar. Syst*, *58*, 1–18, 2005.

Støle-Hansen, K., and D. Slagstad, Simulation of currents, ice-melting, and vertical mixing in the barents sea using a 3-d baroclinic model, *Polar Res.*, *10*, 33–44, 1991.

Sundby, S., Oseanografiske forhold i området Malangsgrunnen-Fugløybanken-Tromsøflaket. En oversikt., *Fisken og Havet B1*, Institute of Marine Research, Bergen, Norway, 1976.

Treguier, A. M., M. England, S. R. Rintoul, G. Madec, J. L. Sommer, and J. M. Molines, Southern ocean overturning across streamlines in an eddying simulation of the antarctic circumpolar current, *Ocean Sci.*, 2007, submitted.

Ådlandsvik, B., and R. Hansen, Numerical simulation of the circulation in the svalbardbankenarea in the Barents Sea, *Cont. Shelf. Res.*, *18*, 341–355, 1998.

Ådlandsvik, B., and H. Loeng, A study of the barents sea climate system, *Polar Research*, *10*, 45–49, 1991.