ICES STATUTORY MEETING

C.M 1995/ Add.Report
Hydrographic Commitee

BOTTOM WATER PRODUCTION IN STORFJORDEN

By

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Abstract:

Storfjorden in the western Barents Sea is an area with favourable conditions for dense bottom water production. A sill prevents part of the dense water from leaving the area, and cold, saline bottom water has been documented by several authors from hydrographic summer data.

Bottom water production and its interannual variability have been investigated in the proposed study using meteorological, oceanographic and ice cover data. A simple model is used to predict the development of mean ice concentration and the ice production in Storfjorden. The model is driven by meteorological 6-hourly station data and produces a corresponding time-series of the salt-flux. The results are in good agreement with ice cover maps from the Norsk Polar Institutt.

According to hydrographic summer observations and the topographic features of Storfjorden and its environment assumptions about the dynamics and the water mass incorporated in the production are made. Further informations are taken from current measurements in the outflow section of Storfjorden: the main assumption is that the bottom water leaves Storfjorden as a density current, controlled by depth and width of the sill.

The salt flux from the ice production generates water masses of different salinities at different depths, and a complete mixing is assumed. The outflow and residence time of Storfjorden are then controlled by the hydraulics of a time-varying homogeneous bottom water mass. A time-series of mass transport and salinity of outflowing dense water is calculated, which is in agreement with measurements from moorings in 1991/92. In other winters the model results are compared with the measurements of bottom water, which remained in Storfjorden until summer; variability and maximum values are reproduced.

Introduction

In recent years the importance of the Barents Sea for the ventilation of the deep waters of the Arctic Ocean has been indicated *(Aagaard, 1981; Swift et. al, 1983; Midttun, 1985; Rudels, 1986)*. The production mechanism is primarily brine rejection from freezing and produces high salinity water near the freezing point. In the lee of islands on shallow banks, where ice is steadily exported, the highest salinities are found *(Midttun, 1985)*.

The densest, most saline waters in the Barents Sea have been documented in Storfjorden *(Novitsky, 1961; Midttun, 1985)*. The favourable conditions for dense water production in the Storfjorden area were confirmed by *Anderson et al. (1988)*, who observed remnants of dense water at the freezing point with S=35.5 [psu]. *Quadfasel et al. (1988)* traced the sinking and mixing of these waters from the inner Storfjorden down the continental slope west of Svalbard. This bottom-attached sinking of the Storfjorden Water as a density current has been simulated in a numerical process study by *Jungclaus et al. (1994)*. Current measurements in the outflow area south of Storfjorden indicate high persistent production rates of high-salinity water in 1991/92 *(Schauer, 1995)*.

To estimate the strength, salinity range and interannual variablity of the bottom water formation in Storfjorden a detailed study of the process was performed *(Maus and Rudels, 1995)*. A model for the dense water formation, driven by the meteorological forcing, is suggested and compared to ice cover maps, hydrographic data and current measurements. In this paper the most important results from *Maus and Rudels* will be presented.

The time dependent quantification of the dense water production in principle requires the determination of three fundamentals:
- The input function of salinity at the sea surface is given by the *rate of ice production* which has to be determined from the meteorological forcing.
- The *properties of the source water*, possibly varying with time, have to be estimated.
- The dynamics and circulation of the production area have to be known to determine the *residence time* meanwhile the water attains its density from the salt flux.

In the following essentially the choosen assumptions and solutions for these fundamentals to formulate a model for the bottom water formation in Storfjorden are described and some results are presented.

Data

The discussed hydrographic data was gathered in Storfjorden and around Svalbard on cruises of the Norwegian Polar Resarch Institute with the research vessels 'Lance' in the summers 1984-1988 and 'Polarbjørn' in spring 1985. The accuracy of the CTD data, obtained with Neil Brown Mark III instruments, was better then 0.01 for Temperature [K] and salinity [psu]. Weekly ice cover maps from the Norwegian Meteorological Institute provide an accuracy of ±0.15 for the ice concentrations.

4 to 6-hourly data of wind speed and direction, temperature and thewing point from the Station at Hopen, operated by the Norwegian Meteorological Institute, are used to calculate the heat fluxes in Storfjorden.

The presented 6-hourly mooring data from 1991/92 30 km south of the sill of Storfjorden were collected by the Alfred Wegner Institut Bremerhaven. The currents were registrated 20 m, the salinities and temperature 10 m above the bottom. *Schauer (1995)* estimates the accuracies of salinity, temperature, current velocity and direction to 0.01 [psu], 0.1[K], 1[cm/s] and 7.5 [deg]. The time-series were filtered to remove the tidal signal *(Schauer, 1995)*.

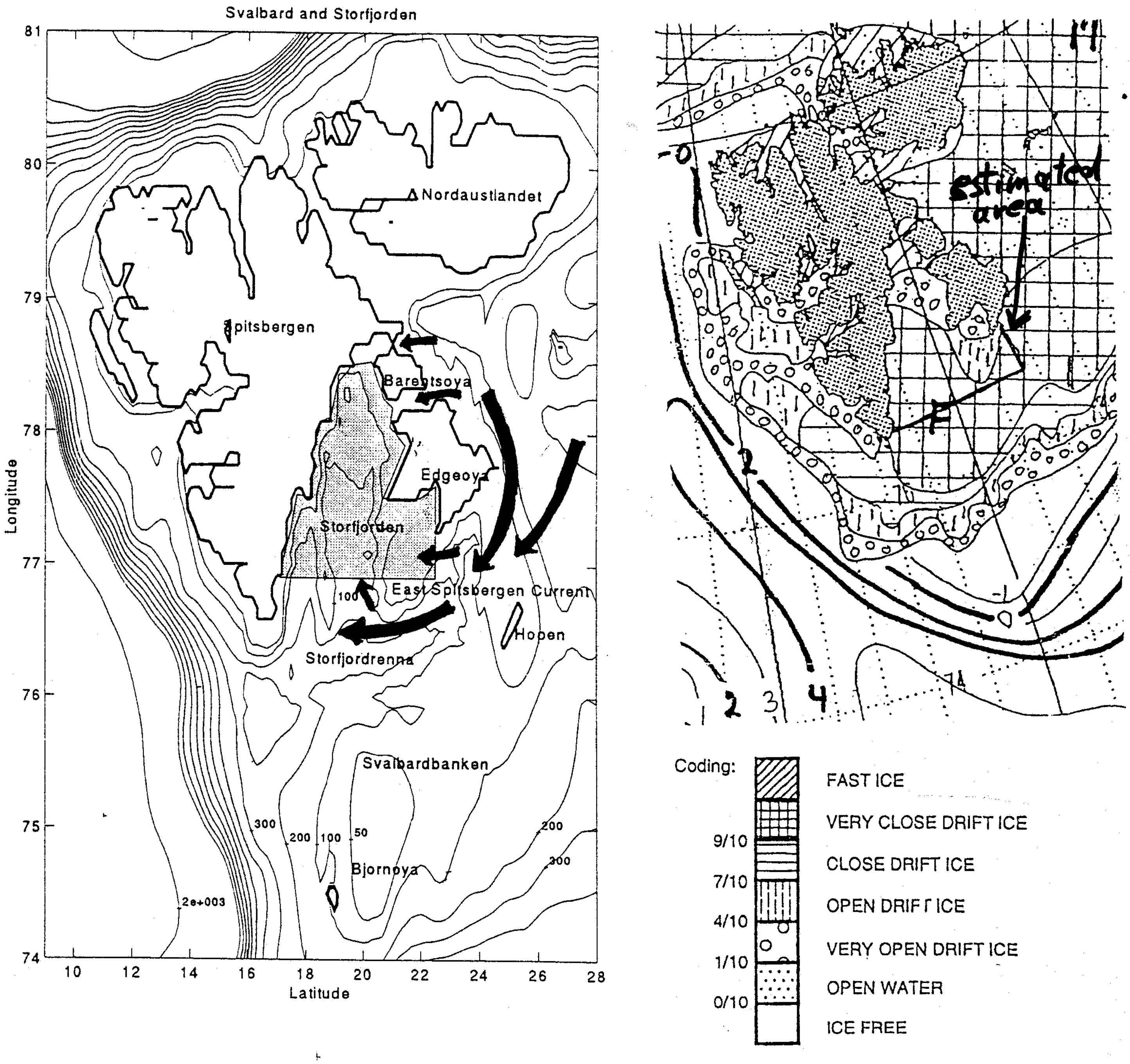

Fig. 1 Left: example of an ice cover map of the Norwegian Meteorological Institute; the region for which the mean ice concentration was estimated from the given coding is indicated.

Right: topograhics in the area of Storfjorden: depth contours are 50 m, 100 m with contour interval 100 m down to 1000 m, 2000 m; the ice concentration model gives the mean ice concentration for the shaded area; the East Spitsbergen current as the source water is indicated

The ice - concentration

Because of the isolating effect of an increasing ice-thickness the ice production essentially depends on the fraction of open water.The mean ice-concentration A for the Storfjorden area in figure 1 was estimated from weekly ice-cover-maps. The maps show the mean fraction of open water (1-A) with an accuracy of about 0.1-0.15. Related to typical winter values of open water concentrations (1-A) in Storfjorden in the range of 0.2-0.3 this would produce an error exceeding 50 %. Therefore a simple model for the mean ice concentration was formulated. The model accounts for a thermodynamic opening or closing term, an export term and a parametrization of the ice cover opening by ridging. It is described in detail in *Maus and Rudels (1995)*.

The thermodynamic closing is calculated similar to *Parkinson and Washington's (1979)* lead parametrization. The total heat flux during winter consists of turbulent fluxes of sensible and latent heat, mainly estimated according to *Andreas and Murphy (1986)*, and the netto longwave radiation,adapted from *Maykut (1978)*.

The ice is assumed to be exported at 2% of the zonal wind speed at the southern boundary of the shaded area in figure 1.

The ridging is accounted by an empirical ridging function, which describes the transfer of windstress energy into potential energy of ridged flows. From the wind speed a mean ridging rate is calculated, whose integral of the winter is in aggreement with the typical ridged ice mass in the Barents Sea, estimated after *Vinje (1985)*.

With the chosen parametrizations about 2/3 of the pemanent lead opening can be assigned to the export and 1/3 to the ridging. The model produces a 6-hourly time series of mean ice-concentrations and total heat flux from which it calculates the mean salt flux.

The time-series for the ice-concentration calculated from the 6-hourly hopen data is shown for 1985/86 in comparison with the linearly connected concentrations from the ice cover maps (figure 2). The agreement is not much worse in other years *(Maus and Rudels, 1995)*.

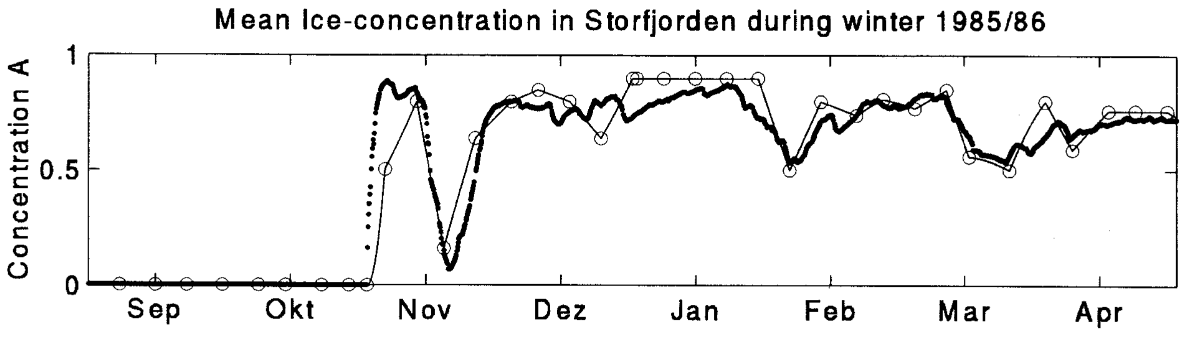

Figure 2: circels (connected by thin line) represent the mean ice-concentration of the shaded area in figure one according to weekly ice cover maps; thick dots/line are the concentations calculated by the ice-concentration model from 6-hourly meteorological station data from Hopen; only the point of time, when the ice formation starts is taken from the ice cover maps.

The source water

The second fundamental to estimate the properties of the produced dense water is the knowledge of the source water mass. The circulation in Storfjorden changes essentially from summer to winter *(Schauer, 1995; Maus, 1995)*. During summer the bottom water still sporadically flowing out from the inner fjord is replaced by Atlantic Water circulating in Storfjordrenna. During winter Arctic Water dominates in the upper 100 m of Storfjordrenna and no inflow of Atlantic Water into Storfjorden takes place. The outflow of dense water from the basin over the sill at about 77°N seems to be provided by permanent sinking from the adjactent shallow areas. Lacking observations during winter the origin of this water cannot be derived accurately, but it is assumed that it enters from the east. The inflow could occur south of Edgeøya, caused by wind driven Ekman transports *(Maus, 1995)* and by residual tidal transports, calculated by *Harms (1994)*. Such residual tidal currents are either suspected in the sounds Heleysundet and Freemansundet in northern Storfjorden, where extremly high tidal currents occur *(Norwegian Polar Research Institute, 1990)*. Furthermore a compensating inflow could occur at the sill, where the outflow was measured near the bottom, but no current meters were deployed in the upper layers *(Schauer, 1995)*.

In spite of this lack in knowledge it is assumed that the possible source areas are situated in the vicinity of the East Spitsbergen Current, a distinct winter feature indicated in figure 1. Accounting for the shallowness of the inflow areas the source water is expected to be provided by the upper 50 m of this arctic water mass. According to *Loeng (1991)* the mean salinity of the upper 50 m is about 34.0 [psu] in October and raises to about 34.5 -34.6 [psu] at the end of winter due to salt rejection from winter ice formation. These mean values are subjected to variations of about ±0.2 [psu] created by the interannual variablity of freezing and melting.

In the model the start mean value of 34.0 [psu] is used and assumed to raise with the ejected salt from the winter ice production, calculated from the Hopen station data. This gives a time-dependent source water mass for the bottom water production. Because no Atlantic water seems to be involved in the processes in Storfjorden during winter, the source waters are assumed to be at their freezing points.

The dynamic constraint

The third fundamental beside the salt-flux and the source water is the residence time of salinization, which has to be derived from the dynamics and circulation.

A few hydrograhic measurements in spring 1985, representing to some degree the winter conditions in Storfjorden, are not sufficient to derive the circulation and a synoptic time-scale. It is only evident from the profiles at central Storfjorden, showing a distinct saline stratification, that the dense waters in the basin are not formed locally but are advected from the shallow surrounding areas *(Anderson et al., 1988; Maus and Rudels, 1995)*.

To derive some aspects of the dynamics the observations of dense plumes outside Storfjorden have to be investigated. The height of the outflow was found to amount between 20 and 40 m from all available hydrographic stations in Storjordrenna, 30 m being the most often observed thickness *(Quadfasel et al., 1988; Schauer, 1995; Maus and Rudels, 1995)*. Data in Storfjordrenna from several years indicate that the width is between 10 and 20 km *(Maus and Rudels, 1995)*. The distance between the moorings from 1991/92 was 25 km and only at the western mooring an outflow was registrated *(Schauer, 1995)* which supports the upper bound. These assumptions of width and height, based on only a few observations, are confirmed by looking at the accurate topograhics of Storfjorden in (figure 3). The depth distribution at the sill shows that the deepest connection to inner Storfjorden is found at the western part of the sill with a depth of about 120 m and a width of 15 km. To the west and east the depths drop down to 100m or less, so that a concentration of the outflow seems logical.

The above examinations indicate that the outflow of dense water is concentrated at the deep western part of the sill with a flow section of 15 km x 20-40 m. Based on these values and typical densities for the upper layer and the outflow, geostrophic velocities would be an order of magnitude less than the current measurements from 1991/92 show. By contrast the assumption of an hydraulic outflow as a density current with the Froude-number $Fr = U/(g' \cdot H)^{1/2} = 1$ gives correct estimates *(Maus and Rudels, 1995)*.

The necessary dynamic constraint is therefore assumed to be the hydraulic control by the sill dimensions. In the proposed model an outflow of 30 m x 15 km controls the residence time of Storfjorden by the formula $U = (g' \cdot H)^{1/2}$. The outflow thickness H is set to 30 m, while $g' = g \cdot \Delta\rho/\rho_0$ is the reduced gravity with $\Delta\rho$ as salinity-dependent density difference between the outflow and its upper layer. The salinity of the outflows upper layer is assumed to consist by half of the time-varying upper 50 m salinity from the source water and half of the constant value of 34.6 [psu], characterictic for the water in the depth-range between 50 and 100 m in the area of the East Spitsbergen Current *(Loeng, 1991; Quadfasel et al., 1991;Pfirman et al., 1994; Maus, 1995)*.

The hydraulically controlled bottom water production

The point of the proposed hydraulic dynamics is that the water leaves the basin driven by its density excess over the upper layer. If a higher density excess on the shallows is produced, g' increases and the water will leave the basin more quickly, resulting in a lowering of the density excess, because the residence time on the shallows gets smaller. Thus by fixing the outflow section at 30 m x 15 km the salinity excess of the outflow is controlled by two conditions, corresponding to the hydraulics and the salt flux:

1. The assumption of a steady export of the salt injected in the shallows through a fixed flow section determines the product of velocity and salinity excess.
2. Assuming $Fr = 1 = U/(g' \cdot H)^{1/2}$ gives the salinity excess as a function of the velocity.

Different depths in the shallow areas are expected to produce different outflow salinities. Because numerical models show distinct tidal movements on the shallow banks of Storfjorden *(Gjevik and Straume, 1990; Harms, 1994)* a complete mixing of the waters produced in the areas shallower than 90 m is assumed. This deal with only one water mass is justified by the fact that observed plumes outside Storfjorden are vertically rather homogenous.

The area of inner Storfjorden is defined as the basin plus the surrounding part of the shallows, which slope down to the basin (shaded in figure 3). Then the calculations from the proposed model can be compared to the current measurements of the outflow from 1991/92 and to summer observations of remnant water in the basin. It is assumed that no overflow takes place at the western boundary of the Storfjorden basin and therefore all salt injected in the shallows will be exported in the sill-concentrated outflow.

The principle assumed scheme, in detail discussed in *Maus and Rudels (1995)*, is repeated as follows: the meteorological forcing determines the open water concentration and the salt flux in the shallow areas. The produced saline waters sink down into the Storfjorden basin and high tidal mixing generates a nearly uniform water mass. The salinity of this water mass is controled hydraulically by the outflow at the sill, which determines the residence time of the shallows. The mean salinity of the source water changes with the winter ice thickness west of Svalbard. The volume and area of the shallows are obtained from a detailed depth distribution of the above defined Storfjorden area, taken from a map of the Norwegian Polar Research Institute *(Vinje, 1985)*. The complete model is driven by meteorological station data and simulates the steady export of the salt ejected from ice formation into the water body of the shallows by a density current at the sill. Assuming total mixing the calculated outflow salinities should be interpreted as lower estimates of the maximum salinities.

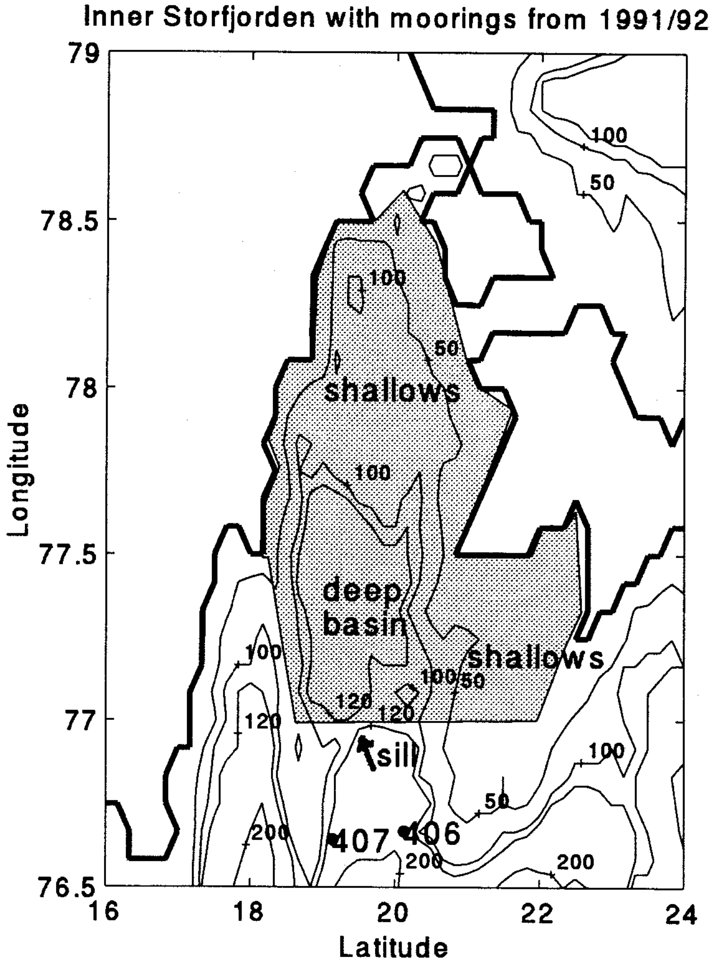

Figure 3: Topographics of Storfjorden corresponding to a map of the Norwegian Reserch Institute (from Vinje, 1985); depth contours for 50,100,120 and 200m; the sill at about 77°N is indicated; volume and area of the shaded inner Storfjorden are given below in table 3; the inner Storfjorden is defined consisting of the deep basin and that part of the shallows, which slopes down to the basin; thus the model results can be compared with the outflow measurements at mooring 407 and hydrographic summer measurements in the deep basin.

	Inner Storfjorden	shallow area depth < 90 m	deep basin below 90 m	deep basin above 90 m
area x 10^8[m^2]	111	73	38	38
volume x 10^9[m^3]	841	365	134	342

Comparison of model results and mooring data

The described model implies no time-dependence and is, strictly speaking, only valid for steady or mean meteorological conditions foe which it gives the expected outflow salinity. To compare the results with time-series from moorings mean-values of the salt flux have to be taken with the respect to the residence time-scale of the transformed water mass. Together with the assumed outflow section the current measurements from 1991/92 give a mean transport of 0.13 [Sv] during five months of strong, nearly constant outflow *(Schauer, 1995;* figure 5*)*. The volume of the shallow (production) areas is about 3.65 x 10^{10} m^3 (table 1), the resulting residence time about one month. Therefore at every point of time the salt-flux is smoothed 30 days backwards to get the mean salinity excess of the water mass leaving the shallows and entering the basin at this moment. This gives a mean salinity time-series of the water mass, when it leaves the shallows, and the corresponding transport for this water mass, when it leaves the basin at the sill. Because we expect a further residence of about one month in the basin, accounting for a permanent exchange of the deep volume and half of the upper volume of (see table 1), this water will arive at the position of the mooring 407 (figure 3) about one month later and the resulting time-series of the modeled outflow salinity is shown with one month delay to the measurements (figure 5).

It is expected that the model will produce no convenient results during the establishing phase of the hydraulic quasisteady state. It is suspected that at the earliest this state could be reached about one month after the ice formation has started. Up to this point of time the salinity on the shallows is statically increased and gives the start salinity for the hydraulically modeled outflow in figure 5 of about 34.8 [psu] at the beginning of december. Comparing the measured and modeled transports in figure 5 indicates that the outflow in fact starts in January, with the assumed one month delay.

It is natural that the simplifying hydraulic model, which does not account for any other dynamics, can not give a detailed agreement with the measurements, but the main variability and changes of the meaured and modeled salinity time-series seem to agree. The total outflow calculated from the hydraulics during the five month is 1.8 x 10^{12} m^3 and differs not much from the outflow inferred from the current measurements of 1.6 x 10^{12} m^3. The salinity ranges are shown in fig. 4, where the volume distributions of the total salinity outflows are compared.

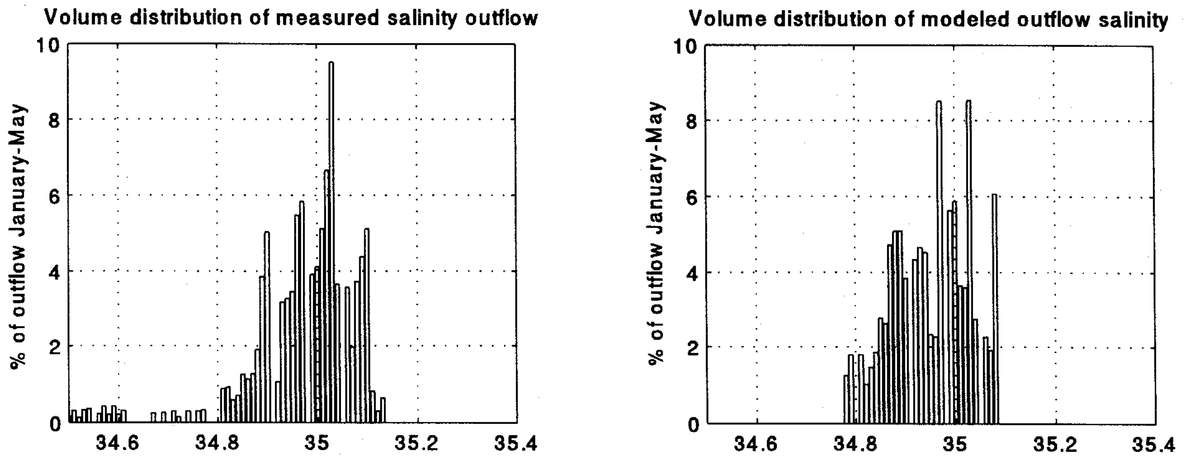

Figure 4: Salinity distribution of total measured outflow from January to May (left) and of total modeled production from December to April, assuming an outflow one month later

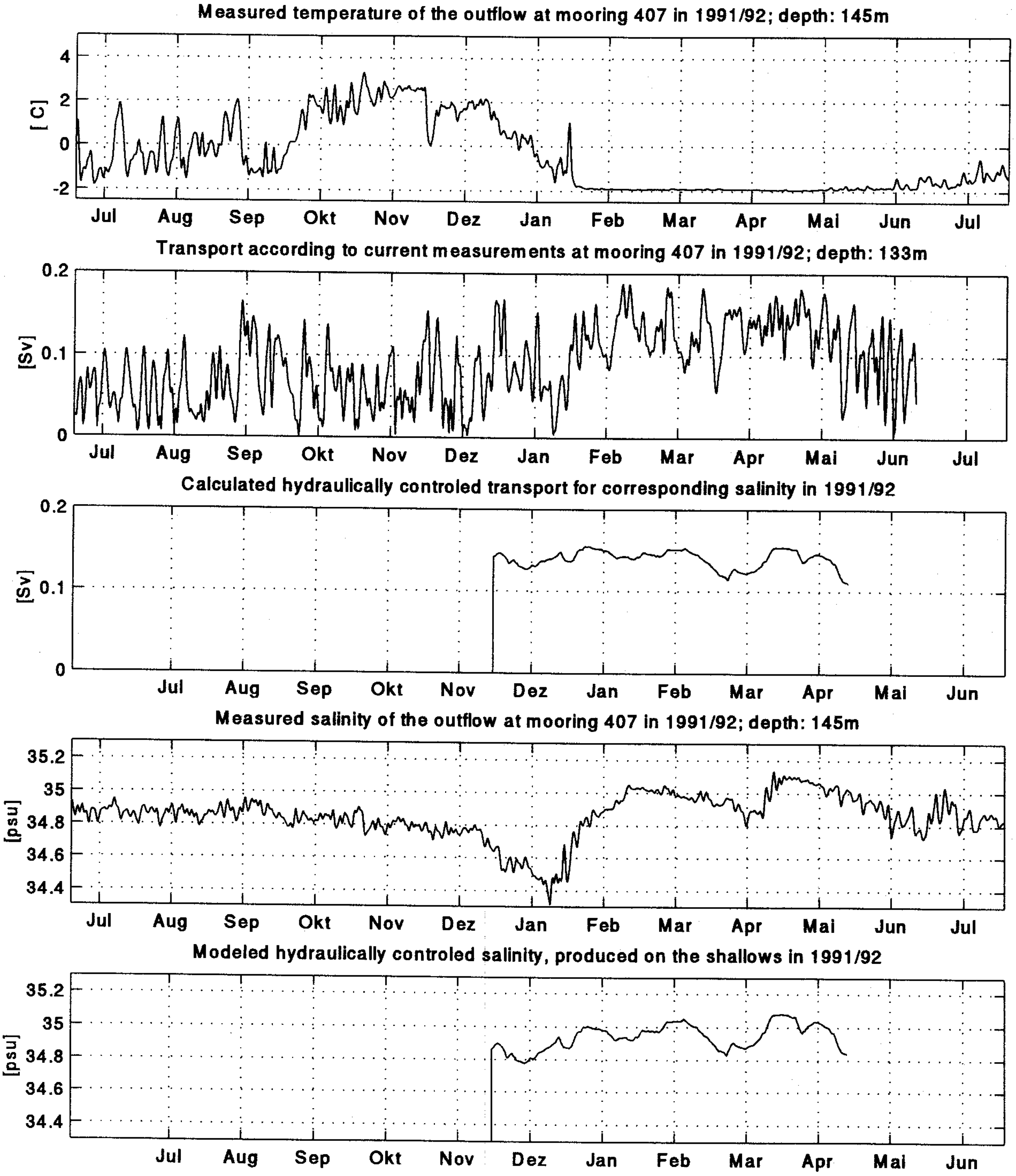

Figure 5: Time-series of measured temperature, salinity and transport from current measurements at mooring 407; for comparison with one month delay are the hydraulically modeled salinities and transports shown; the hydraulic is assumed one month after the beginning of the ice formation.

Comparison of model results with hydrographic data from several years

In other years no comparable current measurements are available but the results can be compared with hydrographic summer data, showing remnants of the dense water production in the deep basin. The small volume of the deep basin below 100 m is not statistically representative for the mean outflow; in 1991/92 it amounted to only 7% of the estimated total transport. Moreover the hydraulic control does not consider that in reality small amounts of very dense water, not involved in the assumed complete mixing, could drain into the basin. These absolute maximum values at the bottom of the Storfjorden basin are shown in table 2. Even if the hydraulic model will not reproduce these absolute maximum bottom salinities, it can be expected, that the most saline waters from the winter production will be stored in the deep basin. Thus the model is checked by comparing the mean salinities below 100 m in the basin with the maximum values from the proposed hydraulic control, also presented in table 2. The difference between the maximum hydraulically controled salinities and the measured means below 100 m varies from -0.17 [psu] for 1985/86 to +0.03 [psu] in 1987/88. The interannual variability of the maximum values is reproduced. It seems that the comparison with the hydrographic data from several years either supports the thesis that the hydraulic control is an important mechanism in determining the salinities of the Storfjorden outflow and that these salinities can be estimated in the proposed simple model.

Table 2: Comparison of absolute maximum salinities from the hydrographical data, mean hydrograhical salinities below 100 m and maximum modeled outflow salinities; (*) in 1991/92 no hydrographic measurements are available but the maximum measured outflow from the mooring time-series is given.

winter	1983/1984	1984/1985	1985/1986	1987/1988	1991/1992
Measured bottom salinity	35.06	35.15	35.50	35.50	?
Measured mean salinity below 100m	34.96	35.00	35.32	35.31	35.13(*)
Modeled mean salinity maximum	34.95	34.90	35.13	35.35	35.08

Discussion of accuracy and errors

The results have to be evaluated in view of the possible errors in the salt flux, the source water mass and the hydraulic assumptions.

The accuracy of the salt flux depends on the possible errors in the heat flux parametrizations and the open water fractions. The accuracy of the total heat flux is primarily gouverned by the coefficients of sensible and latent heat fluxes, which are subjected to a fetch and stability dependence *(Andreas and Murphy, 1986)*. It is estimated to amount to ±20%. The errors in the open water fraction would have exceeded 50% for the ice cover maps. Because of the application of the ice concentration model the error is estimated from the mean difference of both methods. It results in an absolute accuracy for the ice concentration A of ± 0.07, which for the typical concentrations of open water in Storfjorden of (1-A) ~ 0.2-0.3 corresponds to a relative error of 30% x (1-A). The overall accuracy for the salt flux, resulting from the product of the variables, will be ± 35%. In terms of the hydraulic controled bottom water production the model results of the outflow-salinities will change by about ±0.1 [psu]. This error should be sytematically the same for all years.

The second main error, which will not be systematic, is the interannual variability of the source water mass in the range of ±0.1-0.2 [psu]. This variability will be created in principal by the difference in winter ice conditions in the western Barents Sea. A winter of high ice production will transfer more salt into deeper layers of the Barents Sea. During the melting in the next summer the fresh water is only distributed in the surface layer so that the whole process creates a salinity loss for the surface layer. A comparison of the results from table 2 points towards this suspected dependence on the ice production: in the winter periods 1984/85 and 1985/86, each with a low ice production in the preceding winter, the maximum outflow salinities were underestimated by 0.1 and 0.17 [psu]. Because ice export, different current conditions and the mixing of saline Atlantic Water into the upper layer in the western Barents Sea *(Schauer, 1995)* are also important for the preconditioning of the source water mass, it is impossible to predict the variations only from ice production integrals. Better observations of the circulation and the conditions would be necessary to lower these error source in the prediction of the produced salinities.

The fixed hydraulic outflow conditions imply the last important error source of the model approach. Even if the width of the outflow section can be assumed constant according to the topograhics at the sill, variations in the layer thickness around the mean of 30 m are expected. A 40 m outflow will lower the hydraulic controled salinity for typical conditions in Storfjorden by 0.1 [psu] while a thickness of 20 m will increase the salinity by about 0.2 [psu] with respect to 30 m. At the same time the transports change, so that the same salt amount is exported in the outflow. In the beginning of each winter, when the Storfjorden basin fills with dense water and an outflow layer has to be established, this will lead to higher salinities than in the model's mean case. At the end of a winter somewhat lower salinities than calculated by the model could result. And in a winter with low ice production it could be possible that for a long time the outflow does not reach 30 m thickness and will be more saline than the model predicts.

The discussion has shown that even in the simple model there are considerable error sources related to the mean assumptions. Therefore in the previous sections all observations have been discussed in detail to choose mean values, which represent the situation well. Based on these mean values the model seems to simulate the dense water outflow from Storfjorden in agreement with the available data.

Contribution to the deep waters

In view of the presented model results a rough estimate of the possible ventilation of the deep waters in the Arctic Ocean system by Storfjorden will be given.
The sinking and mixing of the Storfjorden outflow have been discussed by numerical studies *(Jungclaus et al., 1995)* and from observations *(Quadfasel et al., 1988)* indicating the dependence on initial salinity, ambient water masses and topographic features. Without speculating on the properties of the Storfjorden water or if it enters the Norwegian Sea or the Arctic Ocean it is simply assumed that the Storfjorden outflow entrains ambient water masses west of Svalbard. These are East Spitsbergen Water, Atlantic Water and intermediate water

of the Norwegian Sea, for which a mean density of 28.00 σ_0 is assumed. The initial densities of the main Storfjorden outflow are lowered by entrainment to 28.07 σ_0, which represents about the upper density surface of the deep water sphere *(Aagaard et al., 1985)*. In table 3 the initial salinities, densities and transports of the main outflow in the investigated years are given together with the assumed entrainment rates and the resulting mass transports into the deep water. Because 1986/87 was a similar winter as 1991/92 the mean value of 0.1 [Sv] for the investigated years represents the period 1983-1988. The discussed error from the fixed hydraulics mainly distributes salt during one winter. The choosen initial source water gave a good agreement with the mooring data from 1991/92, the only winter where a quantitative comparison was possible. Therefore only the accuracy of the salt flux of ± 35% is assumed to estimate a mean ventilation of the deep waters of 0.1 ± 0.035 [Sv] by the dense water production in Storfjorden. If these estimations are carried out with a 0.1 [psu] higher source water mass in 1984/85 and 1985/86, when an underestimation was suspected from the data comparison, it is increased to about 0.12 ± 0.035 [Sv]. This value can be interpreted as an upper limit for the flux through the 28.07 interface, because higher entrainment will feed the above intermediate layers and less entrainment implies a deeper reaching plume and a smaller mass flux.

Table 3: Modeled salinities of the main outflow, densities assuming freezing point temperature and mean mass transports for several years are compared; entrainment of 28.00 ambient water is assumed until 28.07 is reached; the resulting mass flux through the 28.07 interface into the deep water is given.

winter	1983/84	1984/85	1985/86	1987/88	1991/92
main outflow salinity [psu]	34.78/34.92	34.78	34.90/35.00	35.05/35.20	34.90/35.00
main outflow density [σ_0]	28.01/28.12	28.01	28.10/28.18	28.23/28.35	28.10/28.18
mass transport [Sv]	0.034	0.03	0.056	0.063	0.057
entrainment of 28.00 ambient until σ_0 = 28.07	no / 71%	no	100%	314%	100%
flux through σ_0= 28.07 [Sv]	0.024	no	0.112	0.261	0.114

Final Remarks

The detailed examination indicates that essentially the hydraulic control of Storfjorden determines the production process of dense water and therefore the estimation of its strength by a simple model is possible. But it also shows the difficulties of the approach, concerning the assumptions of the source water mass and the dynamics. More current measurements would be needed to decide about the validity of the model estimates. Measurements in the northern sounds and a detailed winter hydrographie would be important to get more informations about the source water mass and the process. The sinking and mixing of the northern sounds and a detailed winter hydrographie would be important to get more informations about the source water mass and the process. The sinking and mixing of the outflowing plumes could be investigated in detail, if a time-dependent outflow-function could be established. All together Stofjorden seems to be a favorouble area to study the several stages of deep water formation on a shelf by small-scale investigations.

Aknowledgements

I am thankful to the 'Norwegian Research Institute' for providing the hydrographic data and to the 'Alfred Wegner Institut Bremerhaven' for the mooring data. The 'Deutsche Seewetteramt' deserves thanks for the used meteorological station data and the 'Bundesamt für Seefahrt und Hydrograhie' rendered insight to the ice cover maps.

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