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QUALITY ASSESSMENT OF THE HIROMB SIMULATION

Abstract

The High Resolution Operational Model for the Baltic (HIROMB) consists of a leveled three-dimensional primitive equation model, including one equation boundary layer dynamics and a viscous-plastic ice model. At SMHI it is driven by the High Resolution Limited Area meteorological Model (HIRLAM), and it has been running continuously in a pre-operational mode since October 1995. The quality assessment concentrates on the last year of the simulation from April 1997 to April 1998.

1. Overall Statistics

The quality assessment presented here covers the horizontal distribution of simulated and observed near surface quantities, the sea level, ice concentration, ice thickness and upper layer temperature, as well as the vertical profiles of simulated temperature and salinity at locations and times of shipboard conductivity temperature depth (CTD) sampling. The interested reader is also referred to an earlier validation study by Funkquist and Ljungemyr [2].

1.1. Sea level

For the analysis of the simulated free surface, records of 28 sea level gauges around Sweden have been considered for the time from June to December 1997. Hourly observations originate from "Havsarkivet" at SMHI (B. Broman, pers. comm.). Records of six-hourly simulations at near by gridpoints have been extracted from the HIROMB archives. Observational and simulated time-series have been interpolated on a common temporal grid, and then the high frequency spectrum has been removed by a third order Butterworth digital filter with a cut off frequency of $2\pi/48$ hours. For a subset of the locations also hourly simulations have been analyzed without filtering. But since the results do not depend much on the data treatment, only the first analysis will be shown below. Some differences between the two datasets appeared along the Swedish west coast, where the sea level is strongly influenced by the external tides. By obvious reasons, without filtering at those locations the standard deviation (STD) was some centimeters higher. The correlation, however, was about the same. Within the hourly resolution the phase relation of the simulated and the observed records was perfect, whereas in a third dataset basing on six-hourly simulations, but without lowpass filtering, up to four hours systematic phase shift could be detected.

For the Scandinavian subcontinent has been rising about 1 cm/year since the last ice-age, the observations in "Havsarkivet" are continuously adjusted to build anomalies from long-term means. This effect is not included in the model, and thus, no absolute sea levels can be compared. But the mean sea-level sloping down 50 cm from the Bothnian Bay to the Holstein coast as a result of the combined effect of the prevailing southwesterly winds and the horizontal salinity gradient is in good agreement with gravimetric observations by Ekman & Mäkinen [1].

The locations of the 28 sea level stations of the first dataset are given by stars in Fig. 1. For reference some of the locations are labeled with the two first characters of the station name. From the left to the right Fig. 2 shows the spatial distribution of the correlations along the Swedish coast from Kalix in the Gulf of Bothnia to Kungsvik in the Skagerrak. Correlations are better than 0.9 in the Gulf of Bothnia, and always above 0.85 along the Swedish east coast. Only in the Sound the correlation drops down to 0.64. At the west coast they are higher than 0.8 again. STDs are found at all stations between 8 and 13 cm with a median at 10 cm. To get a measure for the correlation and STD numbers, the two stations Flinten and Oskarsgrundet are compared. They are separated less than 2 km and have a STD of 5.8 cm, and a correlation of 0.93. This numbers are considered to be the upper limit of what could be reached by the numerical model.

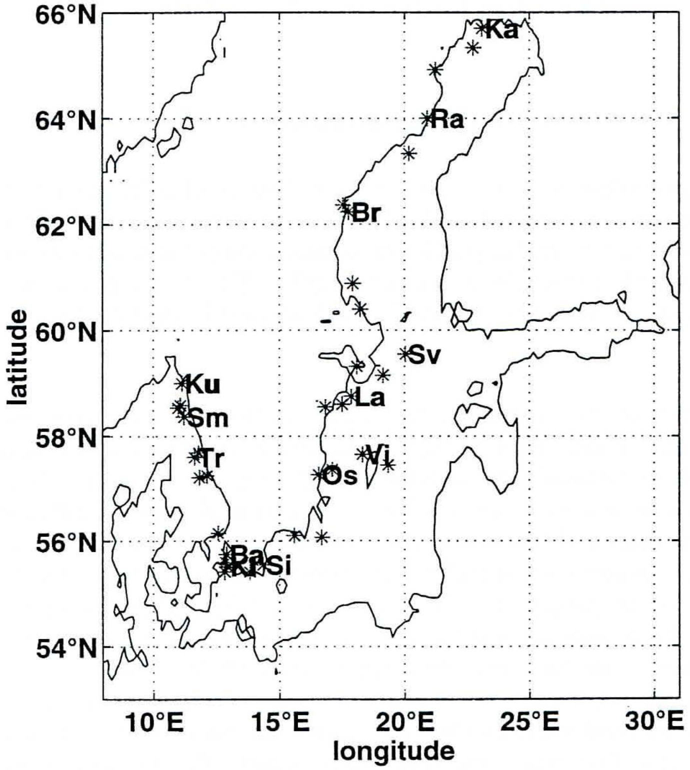

Fig. 1. Locations of the 28 sea level stations under consideration

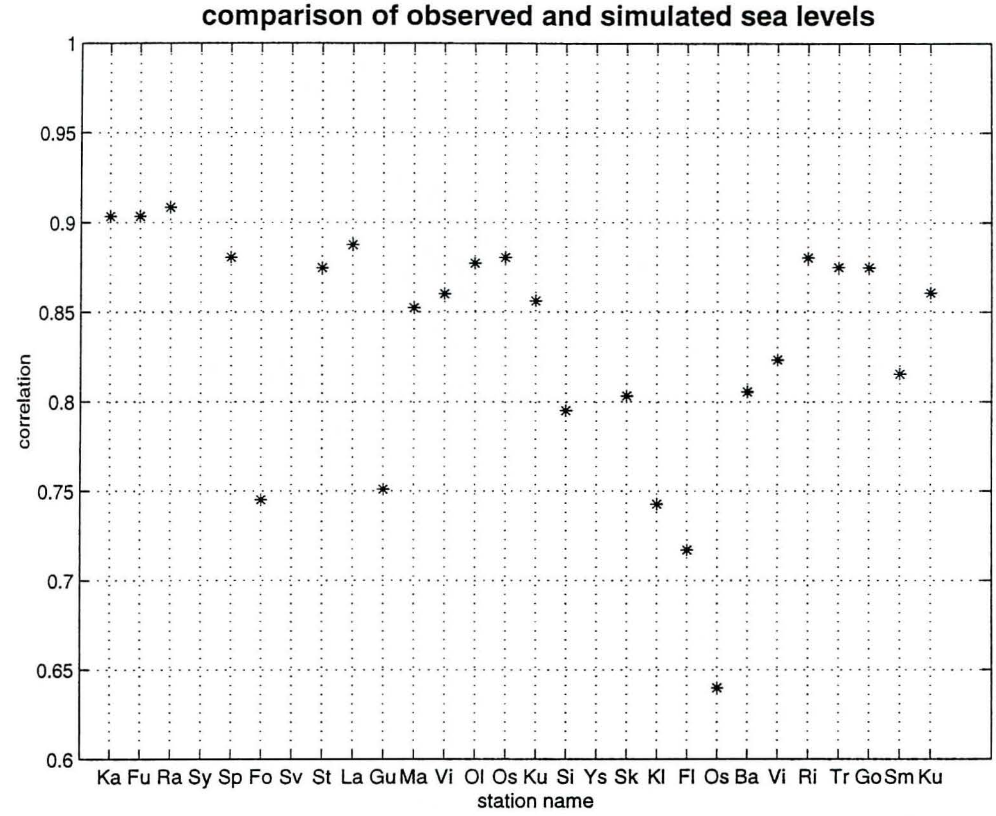

Fig. 2. Spatial distribution of the correlations along the Swedish coast from Kalix (Ka) in the Gulf of Bothnia to Kungsvik (Ku) in the Skagerrak

1.2. Ice Concentration and Ice Thickness

For the assessment of the HIROMB ice model the simulation has been compared with observations as well as with another model. To support the winter navigation in the Baltic Sea the SMHI Iceservice publishes several Icemaps per week (J.E. Lundqvist, pers. comm.). These maps are analyses based on reports from icebreakers on sea and coastal observations, as well as on satellite visual, infrared, microwave and SAR images. As an additional source of information, the Iceservice uses the BOBA model (Bohai and Baltic Sea) [3] which is the ice module within a coupled atmosphere and ocean forecasting system operationally run by the SMHI weather prediction service [4].

For the analysis three areas of the Baltic Sea have been considered. The areas referred to as the Bothnian Bay, the Bothnian Sea and the Gulf of Finland are given by the map in Fig. 3. For the winter 1997/98 132 Iceamps have been digitised manually and the ice concentration was taken as the product of the fraction of the area covered by the ice, multiplied with the predominant ice concentration. The observed ice thickness was taken as the range of the reports of ice thickness. From the models the ice concentration was taken as an area mean, and ice thickness as a mean value out of all gridpoints having concentrations exceeding 95%. The choice of this concentration was somehow arbitrary, but it turned out that in fact most of the reports originated from areas with very high ice concentrations.

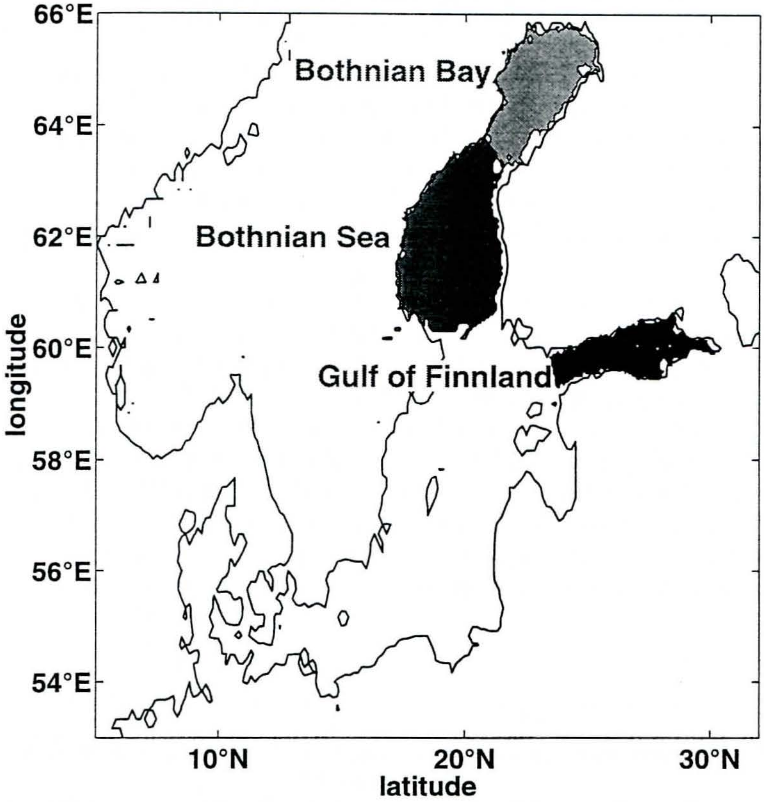

Fig. 3. Definition of the 3 areas referred to as the Bothnian Bay, the Bothnian Sea and the Gulf of Finland

Observed and modelled ice concentrations are given in Fig. 4a. The onset of the freezing in the Bothnian Bay middle of November is modelled well by the HIROMB. Also the increase of the ice concentration in the Bothnian Sea and the onset in the other areas in December is well captured. After Christmas, however, the ice growth was overestimated by both models. This led to a reinitialisation of the HIROMB ice model from more realistic ice conditions in the middle of January. After this restart the HIROMB predicted the ice concentration in the Bothnian Sea and the Bothnian Bay in good agreement with the later analysis. At the end of February it was a rather simple procedure to deal with the observation that did not recognise opening leads, which in fact were present as well in the Icemaps as in the models. In the Gulf of Finland the ice concentrations are very often overestimated by the simulations.

The observed ice thickness in Fig. 4b is given by bars indicating the range of the icebreaker reports. The icebreakers operate under compact ice or fast ice conditions. Thus, they do not sample the sea ice representatively, and it is hard to derive solid statistics from the observations. Ad hoc it was assumed that seamen report extreme conditions, and that a thickness below the mean is more likely than one above it. Comparing the records, the observations follow the predicted quantities in the three areas quite well. Looking at the spatial thickness distribution in more detail, however, it turned out that the models overestimate the ice thickness.

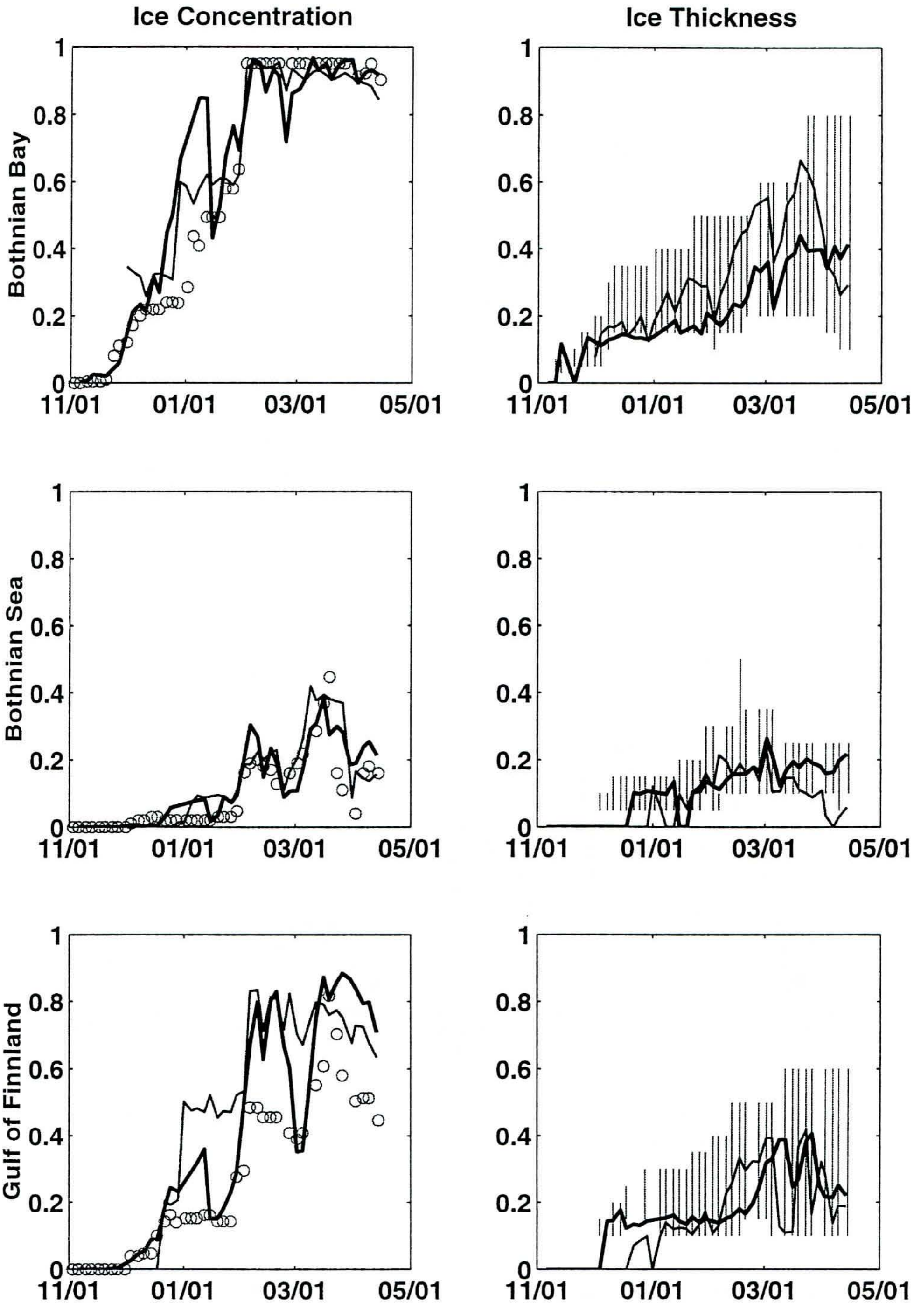

Fig. 4. Ice concentration and ice thickness in the 3 areas, the Bothnian Bay, the Bothnian Sea and the Gulf of Finland, from the Icemaps (symbols), from the BOBA (thin line) and from the HIROMB (bold line)

1.3. Upper layer temperature

Upper layer temperature observations out of the time interval April 1997 to April 1998 have been considered. Therefore 94 upper layer temperature analyses from the SMHI Navigation Service (T. Grafström, pers. comm.) have been digitized on a 6 nm (nautical miles) grid. The manually drawn analyses are based on about 100 ship observations derived from hull temperatures or water temperature readings at the cooling water inlet. The random error contained in these observations is of the order of 0.5°C. Under clear sky conditions, the analysis is qualitatively complemented with satellite infrared maps. Leaving out frontal areas the error by the gaps filling procedure is supposed to add another 0.5°C. The error by the digitalization of the isolines of the upper layer temperature maps is hard to specify, but anyway, it biases the observation towards 0°C.

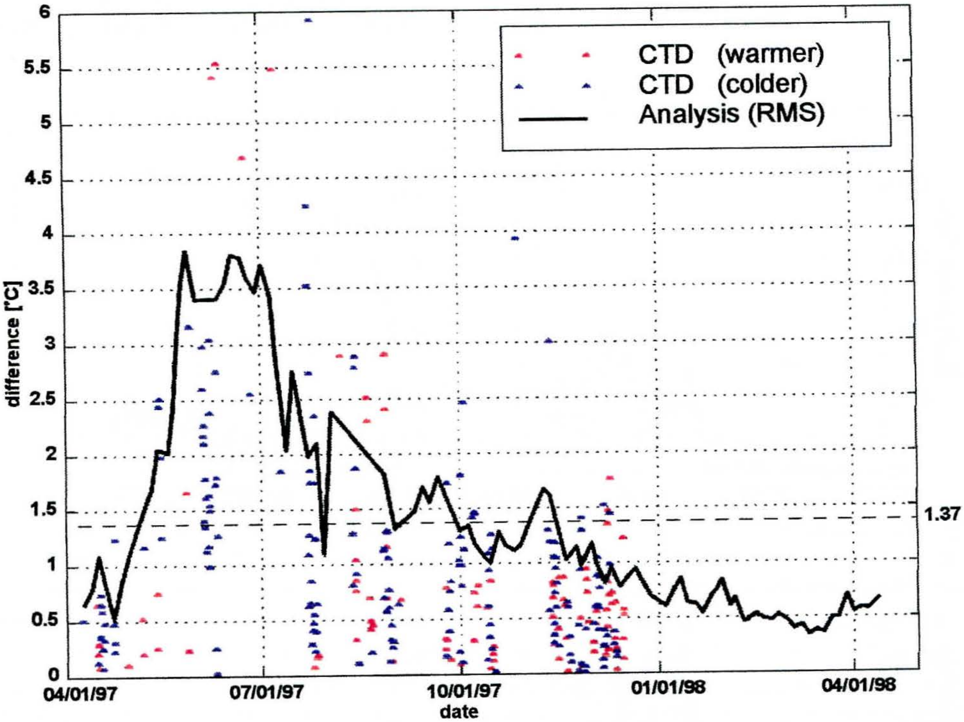

Fig. 5. Temporal evolution of the RMS difference of the upper layer temperature from the analysis (bold line). The mean difference is 1.37°C (dashed line). Most of the differences from CTD observations (dots) are below the bold line

For the quality assessment simulated temperatures of the uppermost level (0-4 m) have been extracted at the times of the analyses and subsampled on the 6 nm grid. Root mean square (RMS) differences have been calculated for each map, and their temporal evolution is given in Fig. 5. The RMS differences are small in fall and winter and high in spring and summer. They exceed 3.5°C during the heating period in May and June, which is the result of too rapid heating. This fact is evident from the temporal evolution of the Baltic Sea mean upper layer temperature, given in Fig. 6. Possibly the comparison with the analysis overestimates the simulation error. Comparing 5 m CTD observations with simulations at the same times and locations (dots in Fig. 5 and Fig. 6) the upper layer temperatures seem to be higher in summer than suggested by the upper layer temperature analysis. Also the CTD – model differences are generally smaller than the RMS differences from the upper layer temperature maps.

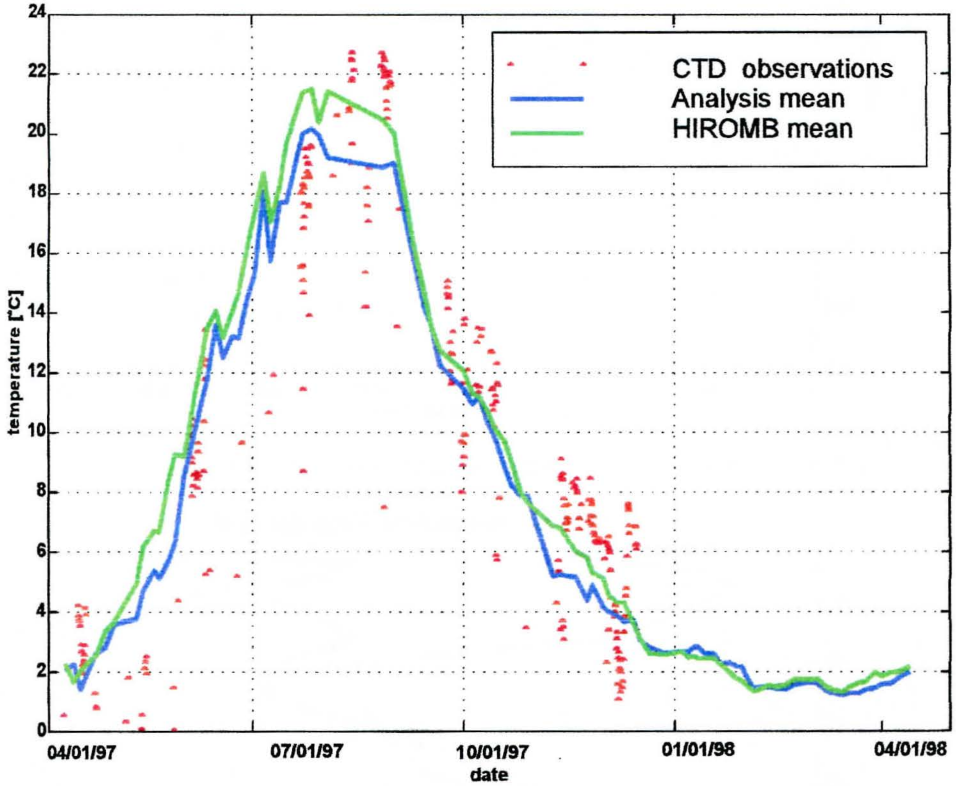

Fig. 6. Temporal evolution of the Baltic Sea upper layer temperature, from the analysis (blue), from the HIROMB (green), and from CTD observations (dots)

1.4. T/S profiles

To study the hydrography of the HIROMB, the forecasts for 329 temperature and salinity profiles from the Baltic Proper and the Gulf of Bothnia collected by the local coastguards and the SMHI Research Vessel Argos (courtesy N. Kajrup) have been investigated. Profiles to the west of 13°E have not been considered, because otherwise salinity differences as high as 25 psu in the frontal areas of the Danish Straits might bias the statistics. Fig. 7 gives the vertical distribution of the number of samples, and Fig. 8 the vertical distribution of the RMS differences. Salinity and temperature are predicted in the upper layers by 2 psu and 2 °C, and in the lower layers by 0.5 psu and 0.5°C, respectively. A more detailed discussion of the temporal evolution at selected positions follows below.

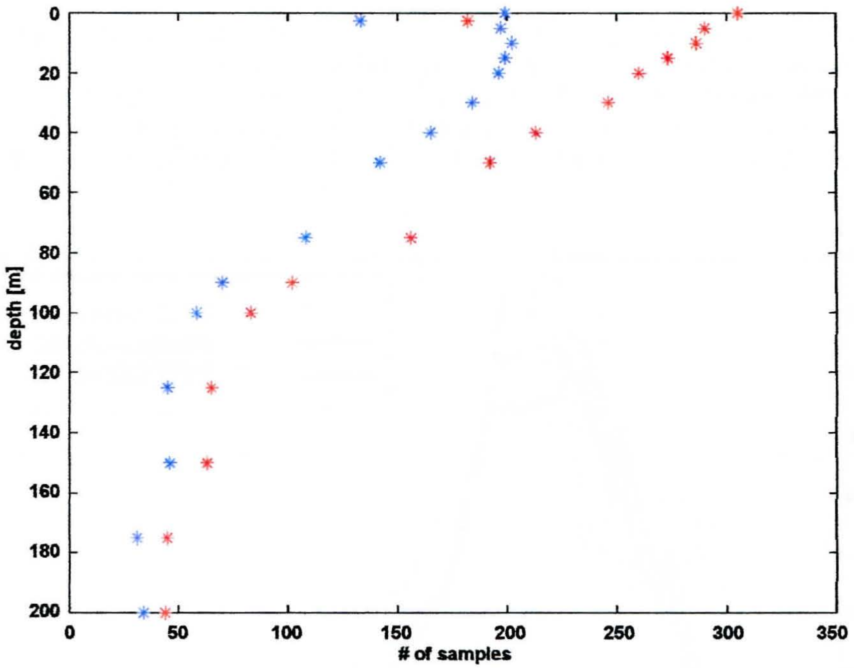

Fig. 7. Vertical distribution of the number of samples (salinity red, temperature blue)

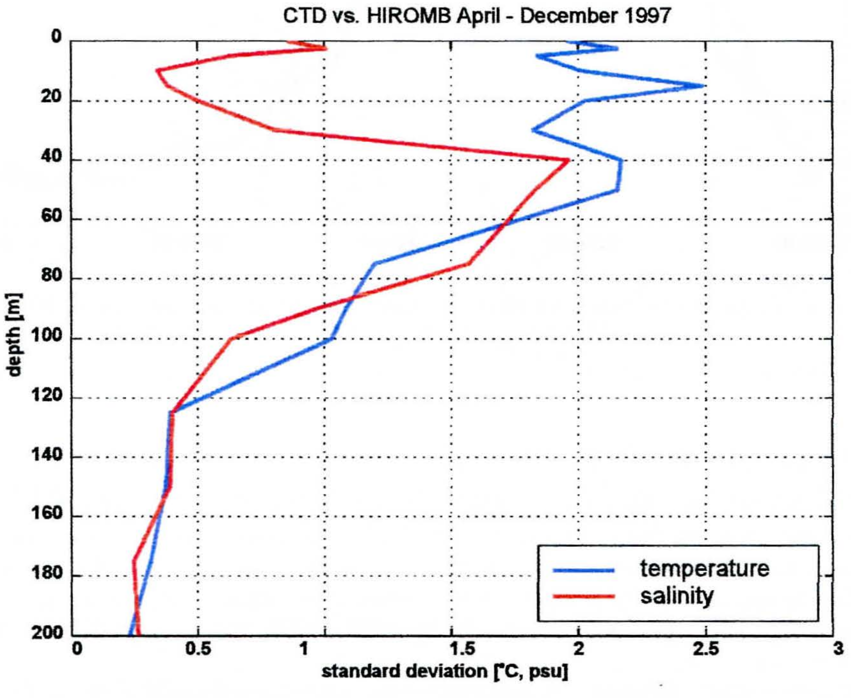

Fig. 8. Vertical distribution of the RMS differences of the forecasts from the observations (salinity red, temperature blue). Only profiles to the east of 13°E have been considered

2. Case studies

2.1. Salinity Stratification

During the validation period from April to September 1997, 17 monitoring stations in the Baltic Proper and the Sea of Bothnia have been visited more than 5 times. Out if these, salinity differences between forecast and observation are shown in Fig. 9 for three selected stations, Arkona (BY2), Gotlandsdeep (BY15) and Bothnian Sea (US5B). The temporal evolution of the salinity difference at station Arkona is dominated by an inflow event, detected in the observations in September 1997 which was totally missing in the simulation. The inflow water has salinities exceeding 20 psu, but still it can be considered to be a minor event. At the station Gotlandsdeep we only find small differences, rarely exceeding 0.5 psu. The salinity stratification is constantly maintained after the last reinitialisation in April 1997. In the Bothnian Sea the model constantly overestimates the salinity by 0.5 –1 psu. This comes from a biased salinity field used for the initialization in April 1997. At that time no actual observations were at hand for the Gulf of Bothnia, and thus the model had to be started from climatology. In the upper layers the salinity difference additionally exhibits a seasonal cycle, which is due to the river run-off held constant in the model.

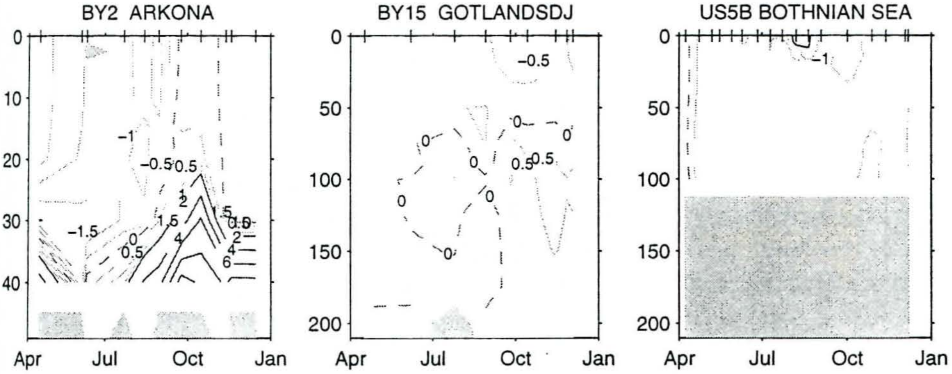

Fig. 9. Temporal evolution of the salinity difference (observation – simulation) for the 3 stations Arkona (left column), Gotlandsdeep (middle column), and Bothnian Sea (right column). Contour interval is 0.5 psu

2.2. T/S Characteristics

In Fig. 10 climatological, observational and simulated T/S diagrams are given. The climatology contains observations at hand out of 15 years from 1980 – 1995 (courtesy L. Axell). In the Arkona we see the properties of the inflow water at 24. September 1997 with 20.5 psu and 15°C, which had a density of 1015 kg/m³. In the climatology we see the most dense water in the Arkona during the major inflow in January 1993, which then had a density of 1018 kg/m³ (22 psu and 3.6°C). At the station Gotlandsdeep we see the observed temperature minimum of the pycnocline at 3 - 4°C. In the simulation the salinity stratification is too spread but it is well maintained. This is why the halocline water was continuously getting warmer. Unfortunately, this leads to a self-maintaining irreversible degradation of the simulation. The stability of the model temperature may be increased by enhanced vertical resolution. In the Bothnian Sea we can see the shift of the observations from the climatology towards lower salinity. One simulation profile is given before the reinitialisation in April 1997, which is in quite good agreement with the observation (see also Fig. 9). The too high salinity leads to too strong a stratification in intermediate layers and above may give rise to too much heating in summer and too much freezing in winter (cf. Fig. 4a).

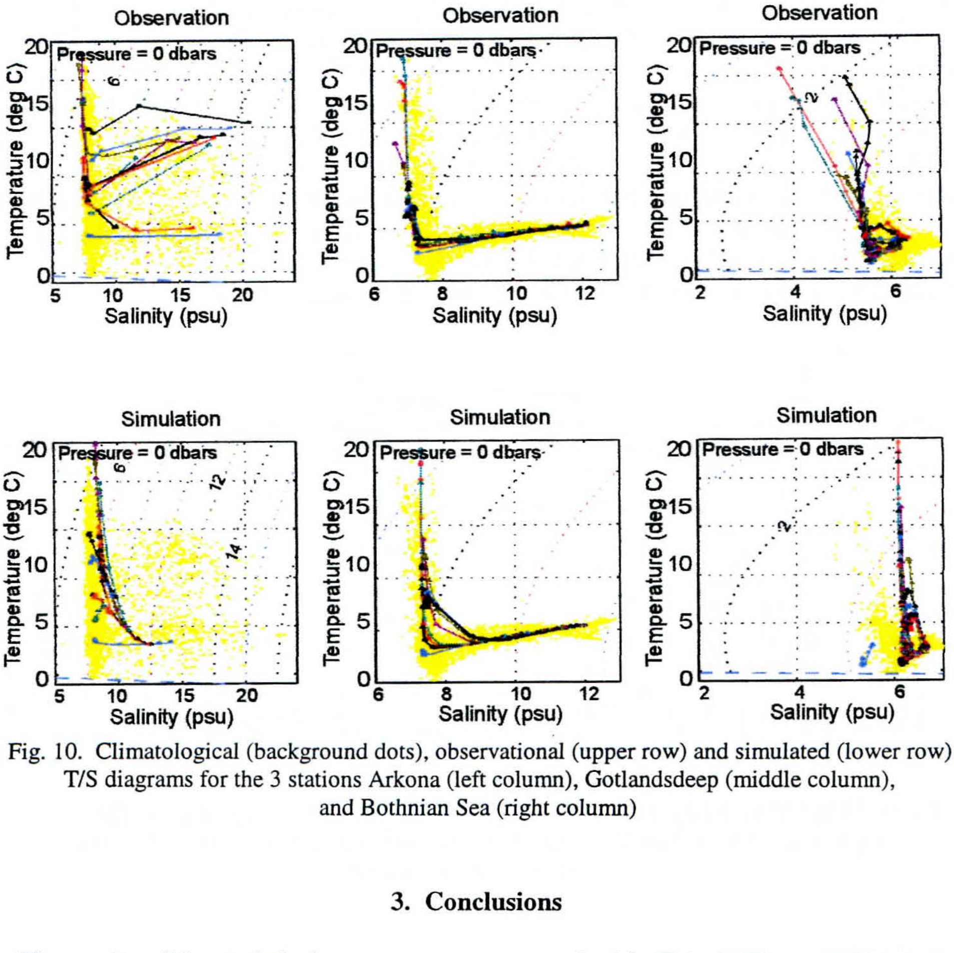

Fig. 10. Climatological (background dots), observational (upper row) and simulated (lower row) T/S diagrams for the 3 stations Arkona (left column), Gotlandsdeep (middle column), and Bothnian Sea (right column)

3. Conclusions

The results of the statistical assessment are summarised in Tab. 1. The model in its present setup is running every day and it looks like it is giving reasonable results. The results are slightly better than a first guess, but still they should be improved. In particular the following aspects should be addressed:

1. The simulation missed a minor inflow event in September 1997. Assumed the reason for this was too weak wind forcing, this problem may be overcome by assimilation of sea level data. We are presently working on that.
2. The upper layer temperature is overestimated in summer, and the ice extent is overestimated in winter. The reason for that might be too shallow mixing due to a too coarse vertical resolution. The resolution of the grid will be improved in summer 1998, when

we have migrated the model from the present vector machine to a parallel computer with distributed memory.

3. The present shortcomings of the freshwater balance will be opposed in fall 1998 when at SMHI daily updated hydrology for the whole Baltic Sea Skagerrak drainage area will be available.
4. Optimal initial conditions are an important prerequisite for the success of the forecast. This is why the development of an oceanographic data analysis system has been initiated.

Table 1. Overview about the statistical assessment of the HIROMB simulation

Simulation	Observation	Validation
sea level	Sea level gauges	std ≅ 10 cm, correlation ≅ 0.8
ice concentration and ice thickness	Icemaps	statistical description on competitive level
SST	SST maps	Δ SST < 2°C
temperature	CTD profiles	upper layers < 2 °C lower layers < 0.5 °C
salinity	CTD profiles	upper layers < 2 psu lower layers < 0.5 psu

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References

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