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# Forecasting Watercooling in the Kattegat, the Öresund, the Belt Sea and the Arkona Basin

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Some problems associated with forecasting water cooling in the entrance to the Baltic Sea are examined, using a diagnostic study from the severe ice winter of 1986/87 as a starting point. In the study, measured and numerically simulated data demonstrate that surface water cooling can be well simulated with the mathematical model presented by Omstedt (1987). Forecast tests during the same winter also indicate that the model may provide useful forecast information. However, because of the limited numbers of temperature and salinity profile measurements, the forecasts had to be accomplished with diagnostic calculations. These calculations will then produce the necessary initial data for the forecasts.

## Introduction

The purpose of the present paper is to examine the possibility of making accurate forecasts of water temperatures in the entrance to the Baltic Sea (Fig. 1) during autumn cooling.

Forecast models for different sub-basins within the Baltic Sea are today in operational use at the Swedish Meteorological and Hydrological Institute (SMHI), see Omstedt (1984). The experiences from four years' forecasts are encouraging. However, up to now only sub-basins with »weak« interaction to surrounding waters have been considered in the operational applications.

To extend the forecasting capability to more complicated basins, where interaction with surrounding areas is a predominant feature, Omstedt (1987) presented a

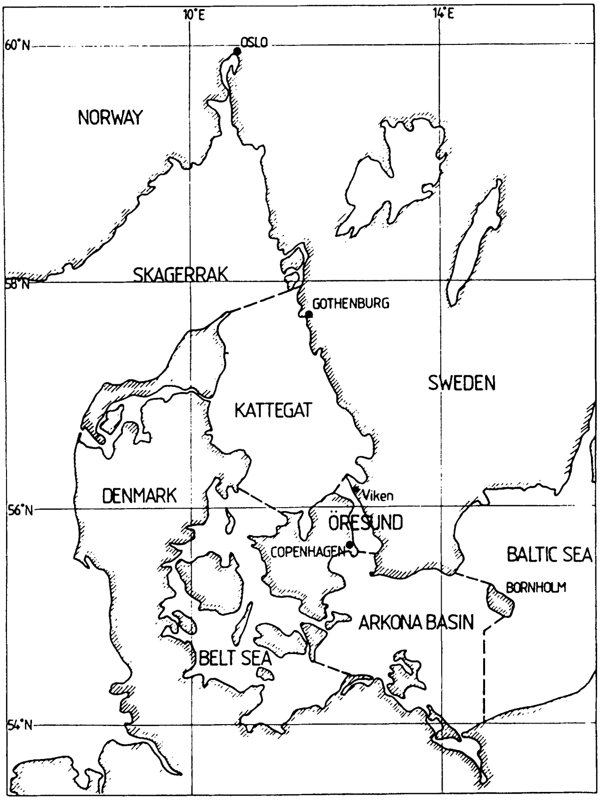


Fig. 1. Map of the entrance to the Baltic Sea.

model for the entrance to the Baltic Sea, in which four sub-basins were coupled to each other through parameterized in- and outflows. The four sub-basins considered were: The Kattegat, the Öresund, the Belt Sea and the Arkona Basin. Each sub-basin was treated as a horizontally homogeneous boundary layer with vertical mean velocities based upon the parameterized in- and outflows.

The equations were solved by using a general equation solver, PROBE (Svensson 1986). An older version of this equation solver is used in the earlier forecast models, but the new PROBE version can also handle coupled basins.

The model for the entrance to the Baltic Sea was analyzed by using measured data covering two cooling periods from the prelude of the severe sea ice winters 1984/85 and 1985/86. The results showed that the cooling events could be satisfactorily described by the model.

In the present paper, measured data from the severe sea ice winter 1986/87 will be analyzed by using the model mentioned above. During the winter 1986/87 some preoperational forecasts of water cooling were also performed. The results from these tests will also be presented below, together with a discussion concerning the requirements for making accurate forecasts in the entrance to the Baltic Sea.

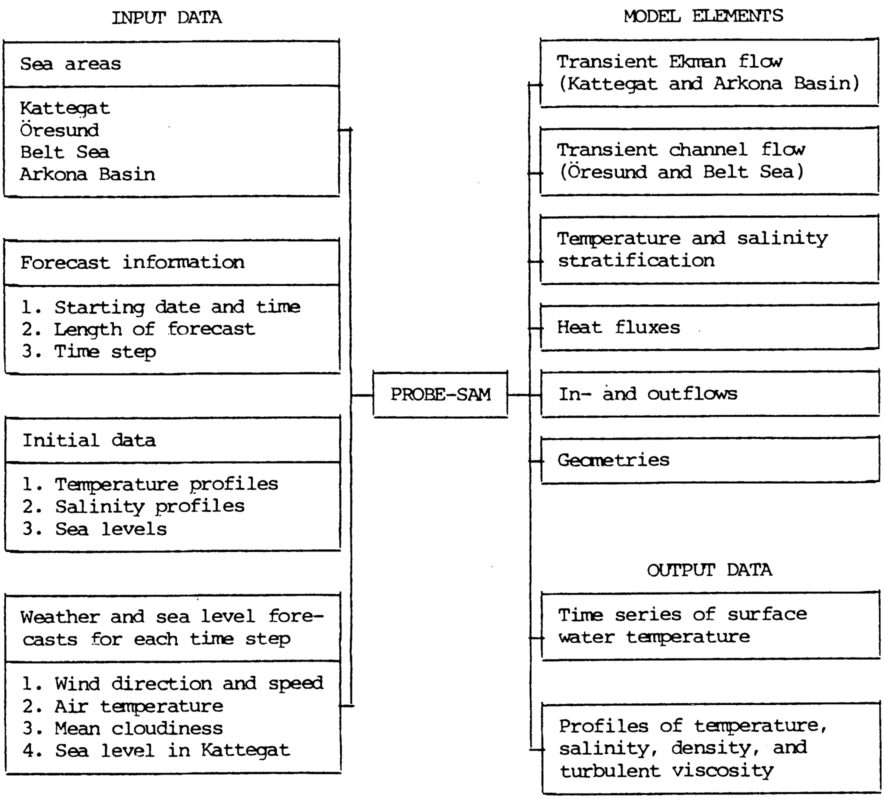


Fig. 2. Schematic representation of the forecast model.

## Model Structure

The structure of the forecasting model follows the one described by Omstedt (1984). The forecaster provides the model with data by answering questions on a terminal screen. The basic model structure is illustrated in Fig. 2, and in Fig. 3 the input data to the model are given. The initial profiles are defined by the surface and bottom temperatures or salinities, the thermocline or halocline depths and the thermocline or halocline thicknesses. It should be noticed that the Baltic Sea entrance domain is divided into four coupled sub-basins. The division is based upon geometrical and dynamical considerations. For a further discussion about equations, assumptions, etc., the reader is referred to Omstedt (1987).

To make a forecast one has to know the following parameters:

1) The initial temperature and salinity profiles in each basin.
2) The initial water levels in the Baltic Sea and the Kattegat.
3) The weather forecast over the sea area.
4) The water level forecast in the Kattegat.

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 1. Give the starting time (t0).

 2. Give the forecast period (n Δt).

 3. Give the forecast time step (Δt).

 4. Give the initial data:
        Temperature profile in the Arkona Basin.
        Salinity        "     "  "     "     "
        Temperature     "     "  "  Öresund.
        Salinity        "     "  "     "
        Temperature     "     "  "  Belt Sea.
        Salinity        "     "  "    "   "
        Temperature     "     "  "  Kattegat.
        Salinity        "     "  "     "

 5. Give the present sea level
        in the Baltic Sea (Stockholm)
        in the Kattegat (Viken)

 6. Give the wind direction and speed, air temperature,
    cloudiness and sea level in the Kattegat at time t0.

 7. Give the wind direction and speed, air temperature,
    cloudiness and sea level in the Kattegat at time t0 + Δt.
    ......................................................
    ......................................................
    ......................................................

 8. Give the wind direction and speed, air temperature,
    cloudiness and sea level in the Kattegat at time t0 +
    (n-1)Δt.

 9. Would you like to change any data (y/n)?
10. Would you like to do a new forecast (y/n)?
11. So long!
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Fig. 3.
The data terminal questions.

The weather forecast includes wind direction and speed, air temperature and mean cloudiness. The water level forecast includes water levels in the Kattegat represented by the station Viken (N 56° 09', E 12° 34'). The accuracy of any cooling forecast will depend partly on how well the model can simulate cooling in the studied area and partly on the success of the forecast. These aspects will be further discussed in the next chapter.

## Applications

### Introduction

In this chapter some applications of the model are given.

Firstly, measured and numerically simulated data from the prelude of the winter of 1986/87 are examined. The initial profiles of water temperature and salinity and water levels are taken from available observations, as well as the weather input data. The analysis may thus be considered as a diagnostic study and is similar to those performed by Omsted (1987).

Secondly, the forecasting problem is addressed. The initial profiles of water temperature and salinity and water levels are taken from observations. The weather forecast is taken from the model of the European Center for Medium Weather Forecasts (ECMWF), and the water level forecast from the model of SMHI (Nyberg 1983). The forecasts are subjectively time- and space-averaged by the oceanographer before entering into the model.

**Diagnostic Study**

In the present study, measurements covering a period from the beginning of November 1986 to January 1987 are considered. During that period, a measuring system was moored in Öresund, consisting of an Aanderaa type current meter, supplied with conductivity and temperature sensors. The data were sampled from a depth of 5 m every 15 min and stored in a recording unit. The meteorological data were taken every third hour from three synoptic weather stations along the Swedish coast. Daily mean water level data were taken from one water level station in the Kattegat (Viken).

The initial temperature and salinity profiles for the different sub-basins were based on an average of available data. The hydrographic data were sparse in space and time; besides sea surface temperature charts and data from one automatic station, only two temperature and salinity soundings were available: the first one from the Arkona Basin, which was performed by the Swedish Coast Guard on October 27, and the second one from the Öresund, which was performed by a local tug on November 3. In the middle of November, r/v Argos also performed soundings in the Kattegat, the Öresund and the Arkona Basin. The survey by Argos was, however, not used here, as the initial profiles had to represent the sea state in the beginning of November. No profiles from the Belt Sea were available.

In Fig. 4, the measured and numerically simulated data are given. Fig. 4a and 4b illustrate sea level variations in the Kattegat and in the Arkona Basin. The measured water levels in the Kattegat and the Arkona Basin are represented by the stations Viken (N 56° 09', E 12° 34') and Klagshamn (N 55° 31', E 12° 55') respectively. The calculated sea levels in Kattegat follow those at Viken. The response in the Arkona Basin, which is modelled to follow the mean sea level in the whole Baltic Sea, deviates from the measured data. However, the general trends of in- and outflows are reproduced in the calculations.

The time-temperature evolution in the Öresund is given in Fig. 4c. One can notice in this figure that the cooling is very well reproduced by the model.

In Fig. 4d, the measured salinities show how the conditions change from low values associated with outflowing water from the Arkona Basin to high values associated with inflowing water from the Kattegat. The calculated salinities follow the measured data, which implies that the model manages to simulate the in- and

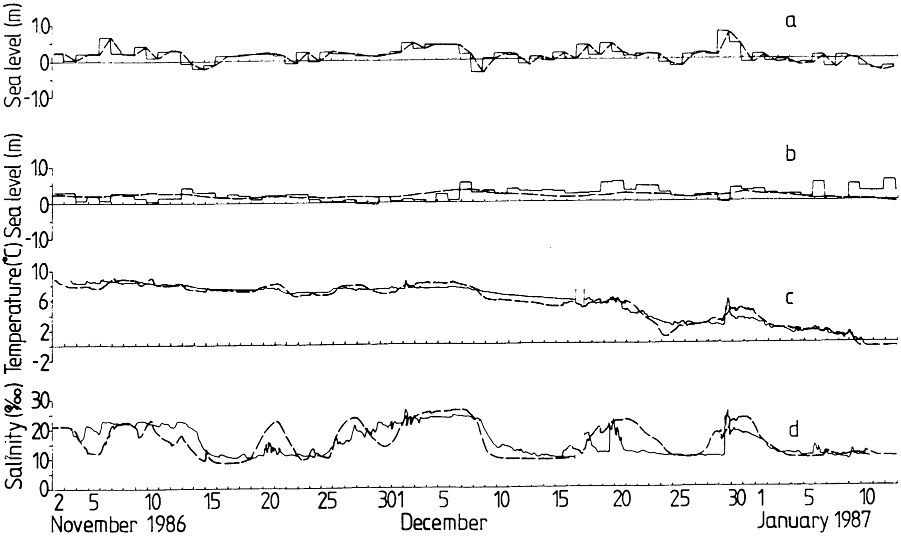


Fig. 4. Measured and calculated data from the Kattegat (a), the Arkona Basin (b), and from a depth of 5 m in the Öresund (c and d). Fully drawn lines represent the measured data. Broken lines represent calculated values.

outflows correctly.

A further test of the model is illustrated in Fig. 5, where calculated sea surface temperatures from all four sub-basins are given. From the figure one can observe that the surface temperature evolutions in the four sub-basins are different, even though the meteorological forcings are the same. This is due to the in- and outflows and to the fact that the sub-basins have different sizes. For example, the Öresund is one order of magnitude smaller than the Belt Sea and thus more sensitive to the exchanges through the entrance area. The pronounced cooling, starting on December 20 in Öresund, is associated with outflowing water from the Arkona Basin and strong stratification.

In the model, temperatures below the freezing point – which is a function of salinity – are put equal to the temperature for freezing. This explains why the temperatures in the Öresund and the Belt Sea reach constant values in January.

In Figs. 6 to 8, three ice charts based upon observations from January 8, 10 and 12 are also given. The chart from January 8 illustrates that no ice has yet started to form in the studied area. The chart from January 10 shows that ice is forming in the Öresund and the Belt Sea. Finally, the chart from January 12 shows that ice is also forming in the Kattegat, but the Arkona Basin is still ice-free. The agreement with the sea surface calculations in Fig. 5 is most satisfactory.

The present diagnostic study, together with the two studies in Omstedt (1987), illustrates that the model simulates cooling in a satisfactory way. The mixing, the horizontal exchange and the net heat loss are thus reasonably well modelled, and

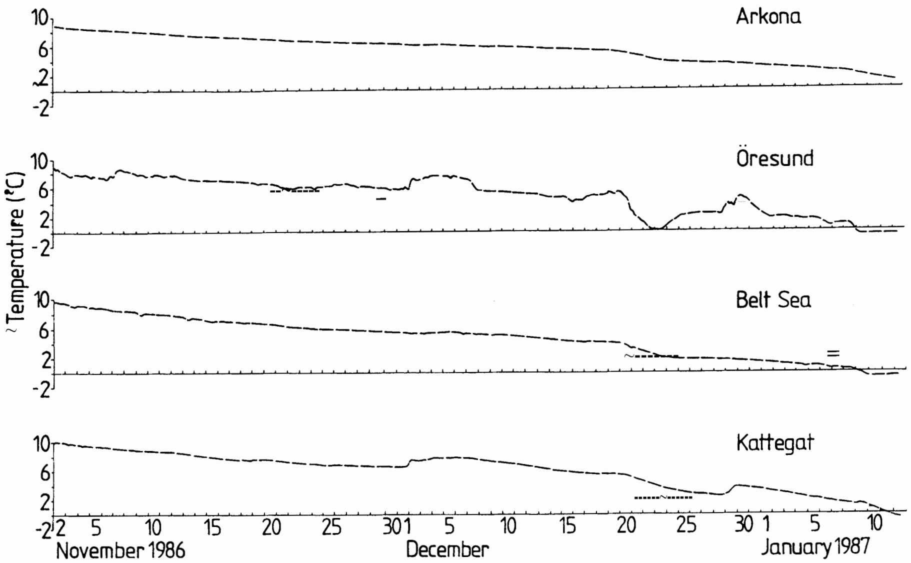


**Fig. 5. Calculated sea surface temperatures.**

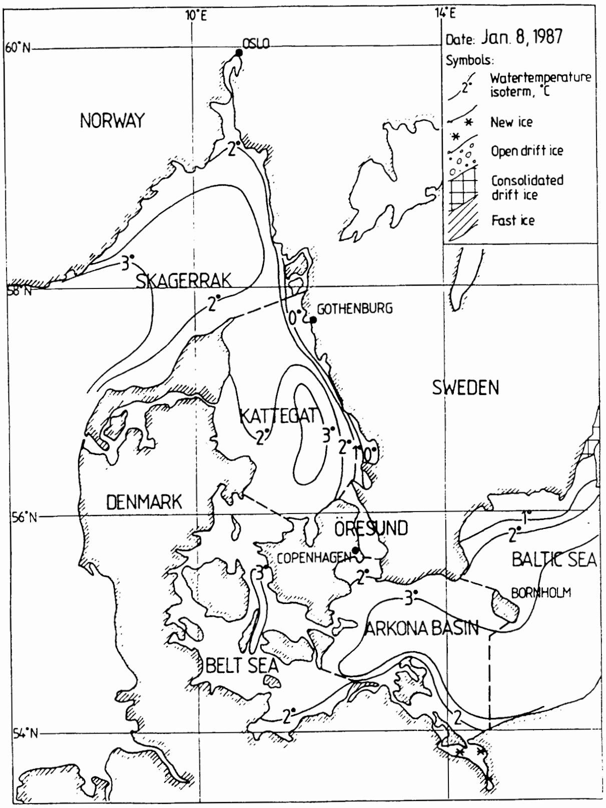


Fig. 6.
The sea surface temperatures and ice conditions on January 8, 1987.

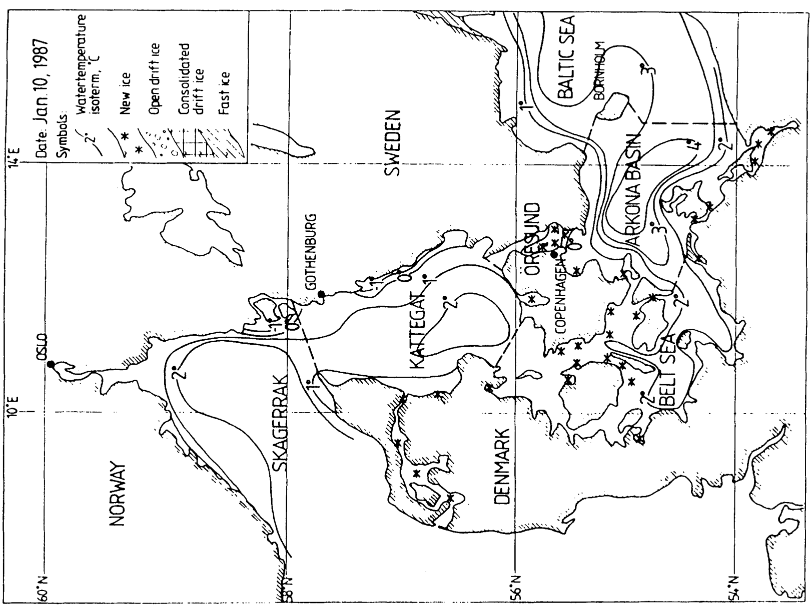


Fig. 7. The sea surface temperatures and ice conditions on January 10, 1987.

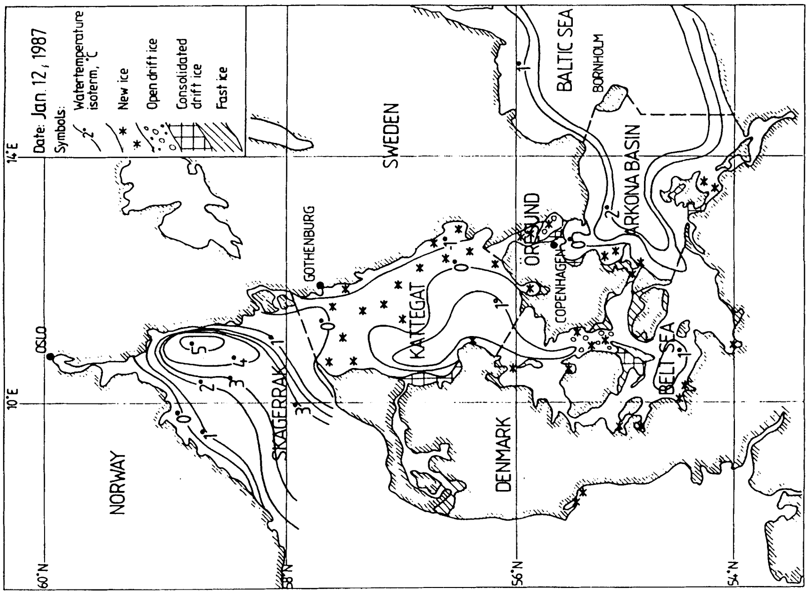


Fig. 8. The sea surface temperatures and ice conditions on January 12, 1987.

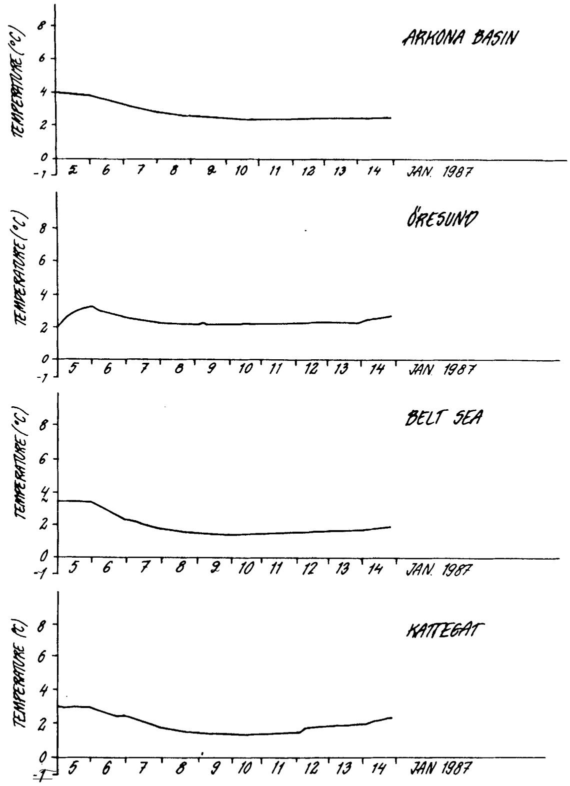


Fig. 9. A 10 day forecast starting on January 5, 1987.

the influence from the Skagerrak and the Bornholm Basin during the studied periods seems not to affect the results in any serious manner.

**Prognostic Study**

During the winter of 1986/87 forecast tests were also performed for the Baltic Sea entrance area. Several tests were performed from Novemer 1986 to January 1987. No risks of ice formation were predicted in November or December. The weather in January, however, became rather dramatic, with rapid cooling and ice formation. The forecasts presented below are therefore taken from that period.

On January 5, a 10 days' forecast was performed, see Fig. 9. According to the forecast from ECMWF, the weather should have become rather mild, and the calculations therefore did not indicate any risk of ice formation.

On January 6, the weather situation drastically changed, with a high pressure weather system over the northern part of Scandinavia and with cold easterly winds in the southern parts. On January 7, a new forecast was performed, see Fig. 10. In that forecast, the calculations predicted risks of ice formation in the Belt Sea on January 10, in the Kattegat on January 12, in the Öresund on January 13 and in the Arkona Basin on January 15. By comparing the results with Figs. 6 to 8, one can

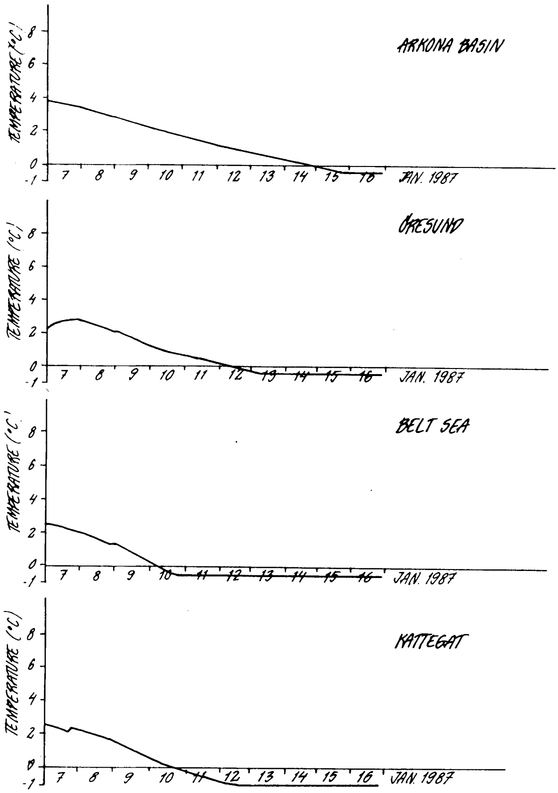


Fig. 10. A 10 day forecast starting on January 7, 1987.

notice that the sea surface temperatures in the Kattegat, the Belt Sea and the Arkona Basin were reasonably well predicted. The forecasted temperatures for the Öresund were, however, too high. The reason for this was undoubtedly the lack of accurate initial data at the forecast time, especially the temperatures in the Arkona Basin were probably too high, see Fig. 5.

Another forecast for January 7 is presented in Fig. 11. These calculations are based on the same weather and sea level forecasts as before, but the initial temperatures were taken from the diagnostic calculation in Fig. 5. The forecast now predicts risks for ice in the Belt Sea on January 9, in the Öresund on January 10, in the Kattegat on January 11, and in the Arkona Basin on January 12. This forecast seems more realistic, but the calculated surface temperature in the Arkona Basin is now too low.

These examples illustrate some problems when forecasting cooling and ice formation in the entrance to the Baltic Sea.

Firstly, the initial sea state with respect to salinity and water temperature must be reasonably well known. Today synoptic salinity and water temperature measurements from all four sub-basins are lacking.

Secondly, the initial water levels in the Baltic Sea and the Kattegat must be

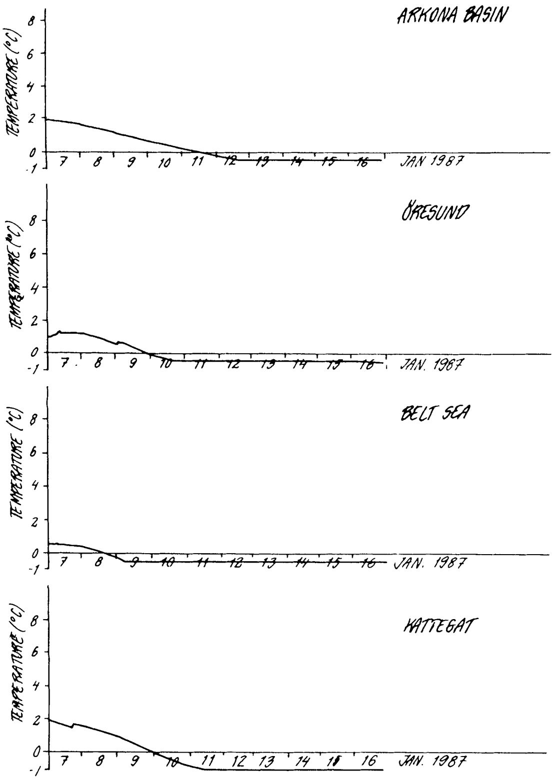


Fig. 11.
The same forecast as in Fig. 10, but with initial temperatures according to Fig. 5.

known. This is usually the case, since information from the water level stations Viken and Stockholm are automaticaly transmitted to SMHI.

Thirdly, the weather forecast has to be accurate. The weather situation in the beginning of January 1987, when the weather changed over to a severe winter, was not well predicted by the ECMWF model.

Fourthly, the water level forecast has to be accurate. This forecast relies on the predicted air pressure field over the whole of Scandinavia, and the accuracy thus relies on the weather forecast. In general three or four days' forecasts are quite reliable. Forecasts for longer periods have to rely on statistics, or estimated »worst cases« in the sense of ice formation.

## Conclusions

The conclusions may be summarized as follows:

1) Measured and numerically simulated data from the prelude of three severe ice winters in the entrance area to the Baltic Sea have demonstrated that surface water cooling can be realistically reproduced by the model presented by Omstedt (1987).

2) The diagnostic studies illustrate that the model simulations hold for at least some months. This fact indicates that the surrounding waters (the Skagerrak and the Bornholm Basin) do not significantly interfere with the surface watercooling in the studied area.
3) The forecasts rely to a high degree on the accuracy of the weather forecast and the knowledge of the present sea state. Since very few salinity and water temperature soundings are available, the forecasts may give unreliable information. This problem can, however, be reduced, if diagnostic calculations are coupled to the forecasts.

The experience from the winter of 1986/87 indicates that water cooling forecasts at the entrance to the Baltic Sea can give useful information to shipping and ice-breaking services. To increase the accuracy, diagnostic calculations should be made parallel to the forecasts. These calculations will then produce the necessary initial data to the forecast model.

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