Baltic Sea upwelling events in summer 1980 - comparison with the satellite based data

(hindcast modelling study) [a]

Andrzej Jankowski

Institute of Oceanology of PAS, Powstancow Warszawy 55, 81-712 Sopot, Poland

e-mail: jankowsk@iopan.gda.pl

Abstract

A three-dimensional baroclinic σ - coordinate model was applied to describe (study, investigate) the circulation and thermohaline variability in the Baltic Sea. The model is based on the **P**rinceton **O**cean **M**odel code of Blumberg & Mellor (1987), known as POM, and has horizontal resolution of ~ 5 km and 24 σ - levels in the vertical.

The variability of seawater temperature in the coastal regions off the Baltic coasts due to atmospheric forcing in summer 1980 are analyzed. The numerical simulations were performed with real atmospheric forcings for summer (July-August) 1980. Model results exhibit occurrence and development of intense upwelling-like events in several characteristic areas along the Baltic Sea coastline in July 1980.

A comparison of locations of those areas, computed and based on the satellite data (Bychkova & Viktorov 1987) show that the model reproduces their distribution in the Baltic fairly well.

However, the model results reveal more upwelling events than reported in Bychkova & Victorov (1987) for July 1980, especially, intense upwelling-like phenomena in the coastal regions along the Polish, the Lithuanian and as well as the Estonian coasts.

In order to attempt to support these model findings the patterns of the atmospheric pressure and cloudiness over the Baltic have been presented herein.

1. Introduction

As usual upwelling occurs when cold water from the lower layers of the oceans is raised towards the surface. Wind-induced upwelling of cold water is a phenomenon often observed on the coasts of oceans, shelf seas and large inland waters (see e.g. Csanady 1982, Robinson 1985). It is generally assumed that Ekman offshore transport in the surface layer, generated by a longshore wind blowing with the coast to the left (in the northern hemisphere), is compensated by the upwelling of cold water.

A physical and theoretical description of upwelling can be found in e.g. Gill & Clarke (1974), Smith (1968), Gill (1982). The large scale wind induced (Ekman) upwelling is well known, for example, from off the west coasts of North and South America in the Pacific Ocean and off West and South Africa in the Atlantic on an oceanic scale (cf., e.g., Robinson 1985).

On a smaller scale wind-induced upwelling also occurs in a shelf semi-enclosed sea like the Baltic Sea. Lehmann & Myberg (2008) published comprehensive review of the upwelling, its dynamics and reflections to ecosystem processes in the Baltic Sea. Using all relevant literature they tried to close the gaps of our present knowledge on the Baltic Sea upwelling-like events and o some recommendations for future work have been outlined.

Due to its importance, a deeper understanding of the upwelling process and its implication on the marine environment allow to improve forecast of the local weather prediction as well as algae bloom forecasting, transports and mixing of nutrients and harmful substances. First activities in that direction have been undertaken and results of this work have been presented at the Baltic Sea Science Conference in March 1922, 2007 at Rostock University reported in Myrberg et al. (2008).

1. Introduction ... continued

Satellite images provide convincing evidence for upwelling occurrence along the Baltic coast (Gidhagen 1984, 1998, Hansen et al. 1993, Siegel et al. 1994, Bychkova & Victorov 1987, Bychkova et al. 1988, Urbanski 1995, Krezel 1997).
Development of the upwelling events in the various parts of the Baltic have some specific features related to the local bottom relief characteristics as well as the coastline shape. Upwelling favourable wind patterns depend on local features as well.
Upwelling has been frequently studied at the Polish coast. Most often upwelling has been found to take place offshore Hel Peninsula (e.g. Matciak et al., 2001, Urbanski 1995, Krezel 1997). The upwelling of cold coastal water in the area off the open sea coast of the Hel Peninsula occurs each year, often during summer period (July - September).

Example of upwelling was reported by Malicki & Mietus (1994). The surface seawater temperature recorded in September 1989 at two coastal stations (off Kolobrzeg and Wladyslawowo) on the Polish coast exhibited a large upwelling-like fall (variations of the order 10 units (^{o}C)) and a duration of several days. This hydrological event was assumed to be related to the atmospheric situation obtaining in September 1989. Malicki & Mietus (1994) classified this atmospheric situation as typically causing a large fall in seawater surface temperature along the Polish Baltic coast.

According to Krezel et al. (2005), in the Hel area the upwelling region has a spatial range of 14 000 km^2 while in Leba area the range is 3500 km^2, that being at most 5000 km^2 in Kolobrzeg area. The temperature difference between upwelled deep water and surface water can reach 14 ^oC and the temperature gradient has a maximum value of 5 $^oC/km$ according to observations. The potential maximum area of upwelling along the Polish coast equal to 10 000 km^2 which is about 30% of the Polish economic zone (Krezel et al., 2005).

1. Introduction ... continued

There have been made some in situ measurements and observations (Fennel & Seifert (1995), Fennel & Sturm (1992), Haapala (1994), Matciak et al. (2001), Schmidt et al. (1998), Svansson (1975)), in which in which occurrence of upwelling - like event was revealed in different regions of the Baltic Sea. However, field data are not complete enough to allow description of the upwelling dynamics.

Hence, numerical simulations and modelling of specific hydrological situations with reasonable initial conditions, frequently used as basic tool, lead to an understanding of the dynamics of processes influencing circulation and thermohaline variability in the selected sea regions.

Several attempts have been made to investigate coastal upwelling phenomena in different regions of the Baltic Sea with 3-D numerical models (see e.g. Fennel & Seifert 1995, Lehmann et al. 2002, Myrberg & Andrejev 2003, Myrberg et al. 2010, Kowalewski 1998, Kowalewski & Ostrowski 2005, Zhurbas et al. 2004, Jankowski 2000, 2002).

In Jankowski (2002) upwelling was investigated under real Atmospheric conditions in September 1989 and it was pointed out that the characteristic variability of wind field and the bottom topography variations as well as coastline favour upwelling water movements at the southeastern Polish Baltic coast. Along the Hel Peninsula specific conditions for the occurrence and development of upwelling-like processes were found.

1. Introduction ... continued

This internet presentation is continuation of the previous ones, posted on the website of the Institute of Oceanology of the Polish Academy of Sciences in 2008 (Jankowski 2008)([a]) and in 2011 (Jankowski 2011) ([b]).

The comparison of the computed and measured temperature and salinity shown in the above mentioned presentations (Jankowski 2008, 2011) revealed that the model reproduces the vertical structure of seawater temperature and salinity in a good agreement to the *in situ* observations at some stations in the southern Baltic.

Hence, main intention of a present investigation is to analyse the modelled sea water temperature in surface layer in order to find areas where upwelling - like phenomena occurred in summer 1980, and next to compare their locations and time of occurrence in the Baltic Proper with those reported in the paper of Bychkova & Victorov (1987) based on satellite images (data, observations).

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[a] *On dynamics of upwelling in vicinity of the Hel Peninsula (Gdansk Basin) - insight from model simulations* available at upw_int0

[b] Jankowski A.,(2011), *Effect of wind variability on dynamics of upwelling in vicinity of the Hel Peninsula (Gdansk Basin) in summer 1980 (hindcast modelling study)* available at up80_in0

Model

The 3-D (σ - coordinate) model has been used here for hindcast simulations. The model is based on the Princeton Ocean Model code of Blumberg & Mellor (1987) and Mellor (1993), known as POM and was adapted to the Baltic Sea conditions (Jankowski 2002).

The simulations were performed for the whole Baltic with a horizontal resolution of ca. 5 km and 24 sigma- levels in the vertical. Simplified boundary conditions of the radiation type were applied at the open boundary of the model in the Skagerrak. The model bottom topography was elaborated on the basis of data from Seifert and Kayser (1995).

The numerical simulations were initiated with the climatological distribution of temperature and salinity for July. The initial 3-D fields of the seawater temperature and its salinity in July were constructed from the monthly mean (multi-year averaged) maps taken from Bock's (1971) and Lenz's (1971) atlases and additional available in situ data.

Model was driven by realistic atmospheric forcings (winds, atmospheric pressure and surface heat fluxes) calculated on the basis of meteorological data taken from BED (2000) for July and August 1980 and by climatological forcings and river inflows. The river runoff rates of the 31 main rivers (assumed as yearly means) were taken into consideration

Model ... continued

The wind fields were estimated from the atmospheric surface pressure charts. Wind stress components and surface heat fluxes were estimated by the bulk formula (for details cf. Jankowski (2002)).

The climatological forcings were calculated in the following way. The 2-D fields of the temperature (T) and salinity (S) at the sea surface for June, July, August and September were taken from the monthly mean (climatic) surface maps in Bock's (1971) and Lenz's (1971) atlases. Next, the 2-D fields of T and S were linearly interpolated in time with an interval equal to the internal time step. The climatological forcings were coupled to the model by so-called method of relaxation towards climatology (cf.Lehmann 1995, Jankowski 2000, 2002).

The model simulations were performed in two stages. The first step, pre-processing run, was used to initialize the model computations. At this stage the model started from the three-dimensional initial distribution of temperature and salinity and was forced only by the climatological forcings, without external atmospheric forcing. The initial fields of sea level, the current velocity vector components and the mean-depth current components were set equal to 0.

An adaptation of the model dynamics to the initial fields and climatology was achieved by a forward integration of the model equations over a period of 20 days after which a quasi-stationary state was reached. The second stage was started from the previous step's final results and consisted of a fully prognostic run. Besides climatological forcings, the model was now forced by real atmospheric forcings (atmospheric pressure, winds and heat fluxes) for a period of 62 days (01 July to 31 August 1980). In the simulation presented here, the surface salinity flux at the sea surface was assumed to be negligible and was set equal to 0.

Results of simulations

As stated above, main aims of this presentation is to analyse the computed sea water temperature in surface layer in order to find areas where upwelling - like phenomena occurred in summer 1980, and next to compare their locations and time of occurrence in the Baltic Proper with those, based on satellite images, and reported in the paper of Bychkova & Victorov (1987).

In the above mentioned paper authors found out 14 areas in the Baltic Proper, where upwelling - like events have been observed on the infrared satellite images. The locations of the areas are shown in Figure 1a on schematic chart, redrawn from their paper, and in Figure 1b - in model domain.

Table 1, present herein, their findings based on observations in period of 1980-1985 (data rewritten from that paper). In the next table, Table 2, the detailed results in summer 1980 are shown and as it follows from it, the upwelling - like features (events) occurred only in July 1980 and only in the 6 areas: 1, 5, 7, 9, 10 and 11 (cf. Figure 1 for their location and Table 2 - for more detailed information about phenomenon).

Figure 2 depicts exemplary vertical profiles of the modelled and the *in situ*([a]) measured sea water temperature and salinity on five hydrographic stations (points): **S1** - **S5** in the Southern Baltic during period of 17-27 July 1980 used in (Jankowski 2011) to test the reliability of the model calculations. The location of the selected points in the Baltic is shown in Figure 3.

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[a] data taken from the ICES Oceanographic Database and Service (http://www.ices.dk/ocean

Results of simulations ... continued

Hence, it seems to be pretty good, to choose for comparison purposes, the modelled sea water temperature at 2 meters depth and, assumming, in general, the similar structure of upper layer in the Baltic Proper, and to choose 15 oC isotherm, to distinguish up-welled cold waters (with temperature lower than 15-14 oC) from the local warm surface waters (with temperature higher than 15 oC).

Figure 4 displays the computed sea water temperature at 2 m depth, the response of stratified sea water to the realistic atmmospheric forcings (winds) over the Baltic Proper in summer 1980.

Snapshots of surface temperature on succesive days depict development of the upwelling events for period from 01 July to 01 August.

They demonstrate the temporal history of the emergence of coastal upwelling - like features, their evolution and decay in the different areas of the Baltic Proper in relation to local bathymetric conditions as well as coastline configuration.

From an analysing of charts presented in the Figure 4 it follows that the model reconstructs, reproduces fairly well upwelling - like phenomena in summer 1980 in the 6 areas on dates reported in Table 2.

Results of simulations ... continued

However, in comparison to findings described in Bychkova & Victorov (1987), the upwelling situations in these areas are occurred more frequently and on other dates too, e.g.:

on 02-03 and 30-31 July (areas 1 - off Rügen Is.) - cf. Figure 4a, 4h
on 03-06, 10-22 July (area 5 - Gulf of Riga) - cf. Figure 4a, 4b, 4c, 4d, 4e

on 04-07, 10-16, 25-31 July (areas 7 - Gulf of Finland - along Estonian coasts) - cf. Figure 4a, 4b, 4c, 4d, 4g, 4h

on 01-12, 16-19 July (area 9 - at Swedish coast) - cf. Figure 4a, 4b, 4c, 4d, 4e

on 01-08, 11-12, 27-30 July (area 10 - at western coast of Gotland Is.) - cf. Figure 4a, 4b, 4c, 4g, 4h

on 01-10 July (area 11 - western coast of Oland Is) - cf. Figure 4a, 4b

Results of simulations ... continued

In addition, the upwelling - like processes may also be observed during July 1980 in remaining 8 areas of the 14 ones described by Bychkova & Victorov (1987) and shown in Table 1.

In the charts shown in Figure 4 it is to easy to detect several intense upwelling events:
on 28 July to 01 August (areas 2, 3 - along Polish coast) - cf. Figure 4g, 4h.

on 10-13, 24-31 July (areas 4, - along Lithuanian coasts) - cf. Figure 4c, 4d, 4f, 4g, 4h

on 10-13 July (areas 6 - along Estonian coasts) - cf. Figure 4c, 4d

on 19-21 July (area 8 - Gulf of Finland) - cf. Figure 4e, 4f.

on 01-08 July (area 13 - Hanö Bay) - cf. Figure 4a, 4b.

on 01-31 July (area 14 - at southern Swedish coasts) - cf. Figure 4a - 4h

Results of simulations ... continued

In Jankowski (2008, 2011) it was shown in details that the upwelling - like phenomena along the Polish coast (area 2 and 3) had been related to characteristic atmospheric situations: rapid changes in wind direction to the upwelling favourable locally winds.

Similar mechanism conducive to occurr coastal upwelling and its evolution in the other areas may be assumed: i.e. the response of stratified sea water to changes in winds pattern linked with local hydrographic features (bottom topography and coastline shape).
To test this assumption in next Figure - Figure 5 we present the series of snapshots of the atmospheric pressure over the Baltic Proper in a time sequence of 1 day from 01 July to 01 August.

The charts visualize the atmospheric conditions (real atmospheric forcings) on 6 a.m. each day, i.e. 6 hours earlier than the snapshots with the sea water temperature at the depth of 2 m, shown in Figure 4.

Comparing both series of the snapshots one can conclude that the model results give a reasonable picture of the occurrence, development and decline of the wind-driven upwelling - like events in the Baltic Proper in summer (July) 1980.

Results of simulations ... continued

After above simple qualitative validation of the the model it is necessary to try to explain the discrepancies between the findings based on the model results and those, based on the satellite data, presented in Bychkova & Viktorov (1987).

So as the details of the satellite investigations are unavailable it seems to be the easiest way to link them with cloudiness conditions during period of observations.

In Figure 6 we present the series of snapshots of the cloudiness conditions over the Baltic Proper on 12 a.m. each day during summer 1980 from 01 July to 01 August.

The charts display rather crude conditions to perform satellite observations in coastal areas using technics of that epoch (eighties of the last century), hence one may really assume the cloudiness condition as one of most important causes of the considered discrepancies.

Final comments

The 3-D circulation baroclinic model of the Baltic Sea, based on the Princeton Ocean Model code was applied to investigate water circulation and thermohaline variability during summer 1980.

The variability of sea water temperature at 2 meters depth in the coastal regions off the Baltic coasts due to atmospheric forcing in summer 1980 has been analyzed. The model simulations were performed with the real atmospheric forcings for summer (July-August) 1980. Model results exhibit occurrence and development of intense upwelling-like events in several characteristic areas along the Baltic Sea coastline in July 1980.

The comparison of the locations of those areas, found from model results and those based on the satellite data (Bychkova & Viktorov 1987) show that the model reproduces their distribution in the Baltic successfully.
But the model results reveal more upwelling events than reported in Bychkova & Victorov (1987) for July 1980, especially, intense upwelling-like phenomena in the coastal regions along the Polish, the Lithuanian and as well as the Estonian coasts.

The patterns of the atmospheric pressure over the Baltic presented in the study validate qualitatively the model results as well as the charts of cloudiness allow to accept the cloudiness condition as one of most important causes of the discrepancies between the findings based on the model results and those, based on the satellite data, reported in Bychkova & Viktorov (1987).

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Table 1 List of areas with coastal upwelling events recorded in 1980-1985 on the basis of satellite data - rewritten from Bychkova and Victorov (1987).

No.	Area name	along-shore scale [km]	cross-shore scale [km]	Observation time	Wind conditions	Characteristcs (1)
1	NE off Rügen Is.	50-100	20-30	V-VII (1980-82); IX (1982)	W to E W to E	t = 4-5 days
2	Polish coast	150-200	10-50	VII,VIII, X (1982)	E, SE E, SE	t = 6-7 days
3	Hel Peninsula	50-100	10-20	VI (1980); VI-X (1982); VI (1983)	E, SE E, SE	ΔT=3K; t = 6-7 days
4	along Lituanian and Latvian coasts	250	6-20	1-5.VIII (1982); 12-14.VII(1983); 18-22.V (1985)	N N N	ΔT=4-8K; t =5-6 days g = 0.5-1 K /km
5	at eastern coast of Gulf of Riga	75-100	10-30	25.VII (1980); 15.VII (1982); 5.X (1982); 13-23.V (1985)	SE SE SE	ΔT=2-3 K; t = 0.5-10 days
6	at weastern coast of Saremaa Is.	55	5-30	1-2.VII (1982); 12-14.VII 1983	N N	g = 0.5 K / km
7	at southern coast of Gulf of Finland	20-30-40	5-40	26-28.VII (1980); 15.VII (1982); 26-30.V (1984)	E, NE E, NE E, NE	ΔT=6-8 K; t = 7-8 days; g = 0.5-1 K/km
8	at northern coast of Gulf of Finland	100-300	30-40	21-28.IX (1982); 18.VI (1983);	SW, W SW, W	ΔT=2-4 K; g = 0.5-1 K/km

(1) Characteristics include additional information: duration of upwelling event t [in days], horizontal gradient of sea surface temperature g [in K/km] and on range of temperature anomaly ΔT [in K].

Table 1 (continued)
List of areas with coastal upwelling events recorded in 1980-1985 on the basis of satellite data
- rewritten from Bychkova and Victorov (1987).

No.	Area name	along-shore scale [km]	cross-shore scale [km]	Observation time	Wind conditions	Characteristcs (1)
9	at western(Swedish) coast of Baltic	160	10-50	26.VII (1980); 15-21.IX (1982); 30.IX (1983)	SE SE SE	$\Delta T \leq 10$ K;
10	at western coast of Gotland Is.	80	1-5	7.VII (1980); 13-16, 25, 26.VII (1982) 23.IX (1982)	NE NE NE	
11	at western coast of Oland Is.	130	5-10	26.VII (1980); 3.VIII, 15.IX (1981); 23-30.IX (1983)	SE SE SE	
12	at eastern coast of Gotland Is.	30	5-10	6.VII (1981)	SE	
13	Hanö Bay	100	5-15	5-6.VII, 7.VIII (1981); 15.IX (1982); 28-30.IX (1983)	NW,W NW,W NW,W	$\Delta T \leq 10$ K; $g = 7$ K/ 9 km
14	at southern coast of Sweden	60	5-40	5.VII (1981); 29.VIII, 15.IX, 2-5.X (1982); 2-5.X (1982); 6.VI, 28.IX (1983)	SW, NW, W SW, NW, W SW, NW, W SW, NW, W	

(1) Characteristics include additional information: on duration of upwelling event t [in days], on horizontal gradient of sea surface temperature g [in K/km] and on range of temperature anomaly ΔT [in K].

Table 2 List of areas with coastal upwelling events recorded in summer 1980 on the basis of satellite data - rewritten from Bychkova and Victorov (1987).

No.	Area name	along-shore scale [km]	cross-shore scale [km]	Observation time	Wind conditions	Characteristcs (1)
1	NE off Rügen Is.	50-100	20-30	VII (1980);	W to E	t = 4-5 days
5	at eastern coast of Gulf of Riga	75-100	10-30	25.VII (1980);	SE	ΔT=2-3 K; t = 0.5-10 days
7	at southern coast of Gulf of Finland	20-30-40	5-40	26-28.VII (1980);	E, NE	ΔT=6-8 K; t = 7-8 days; g = 0.5-1 K/km
9	at western(Swedish) coast of Baltic	160	10-50	26.VII (1980);	SE	$\Delta T \leq 10$ K;
10	at western coast of Gotland Is.	80	1-5	7.VII (1980);	NE	
11	at western coast of Oland Is.	130	5-10	26.VII (1980);	SE	

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(1) Characteristics include additional information: on duration of upwelling event t [in days], on horizontal gradient of sea surface temperature g [in K/km] and on range of temperature anomaly ΔT [in K].

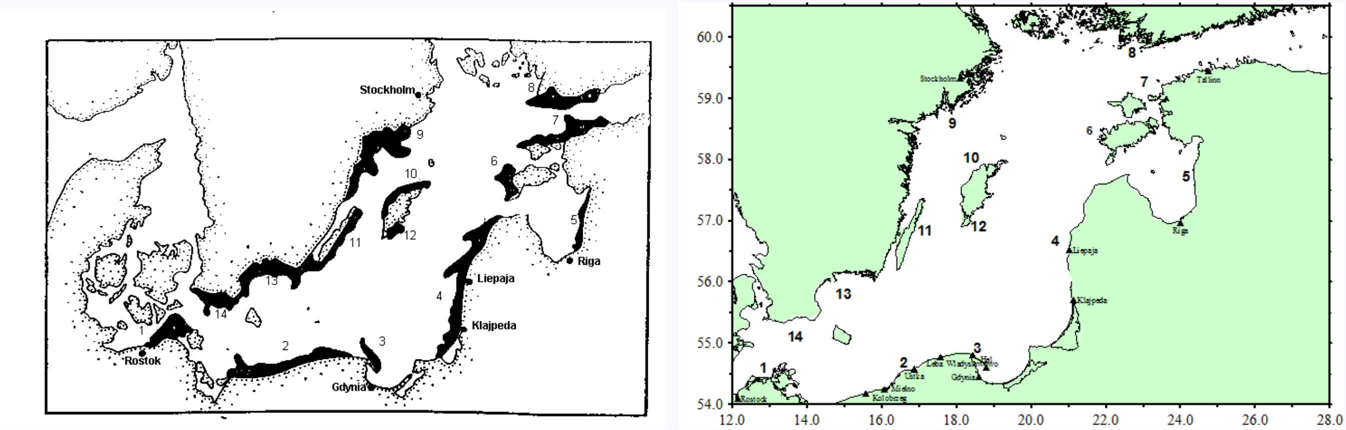


Figure 1 Location of main 14 areas with coastal upwelling in the Baltic Sea estimated on the basis of satellite images (data) during summer in period of 1980-1984 - schematic chart redrawn from Bychkova & Victorov (1987) - (left figure - Figure 1a) and location of these 14 areas in the model domain coastline configuration - (right figure - Figure 1b).

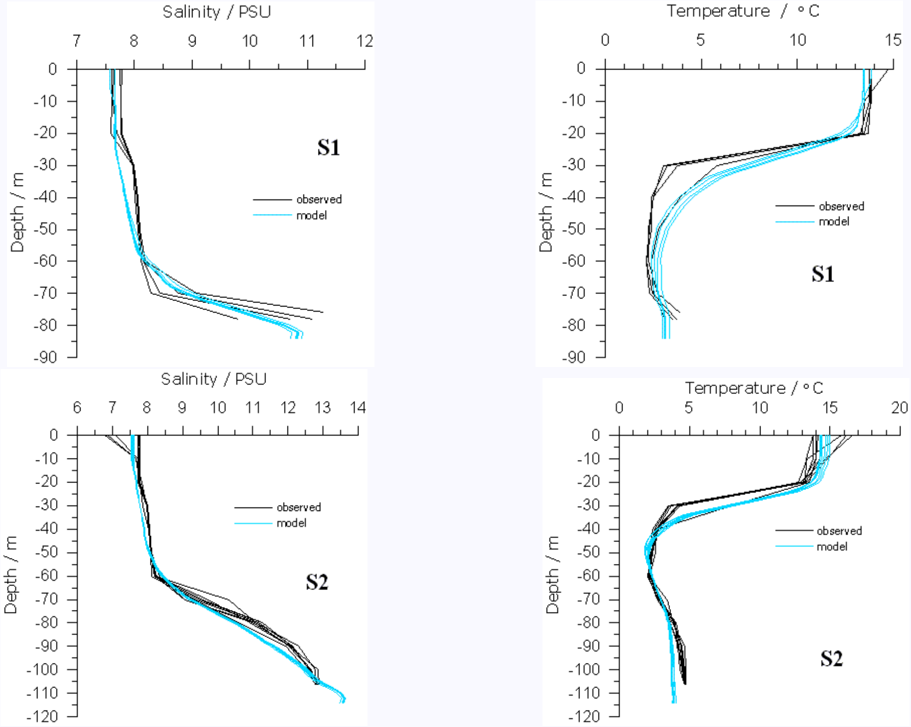


Figure 2 Modelled and *in situ* measured vertical profiles of temperature $[^oC]$ and salinity $[psu]$ at the selected hydrographic stations. Figure 2a - stations: **S1** and **S2**. For details of their locations - see Figure 3

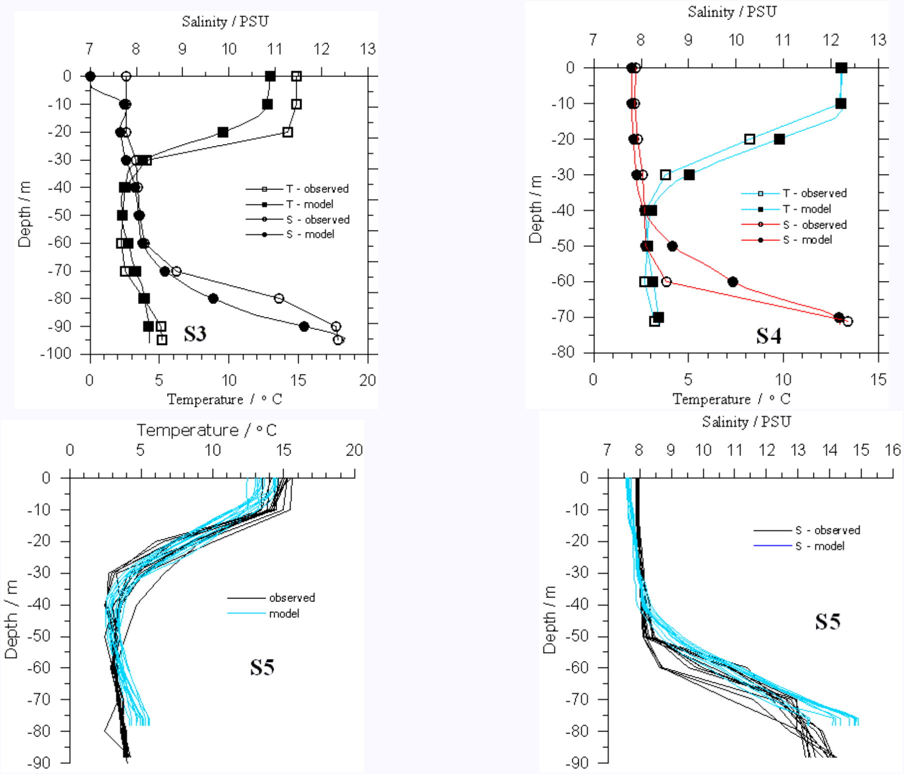


Figure 2 Modelled and *in situ* measured vertical distributions of temperature [^oC] and salinity [psu] at the selected hydrographic stations. Figure 2b - stations: **S3**, **S4** and **S5**. For details of their locations - see Figure 3

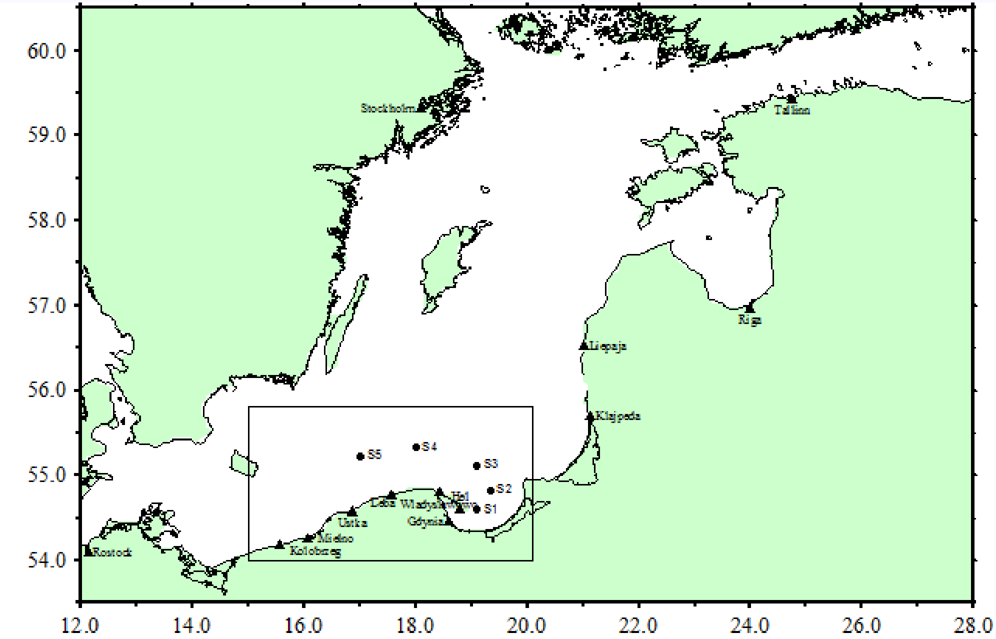
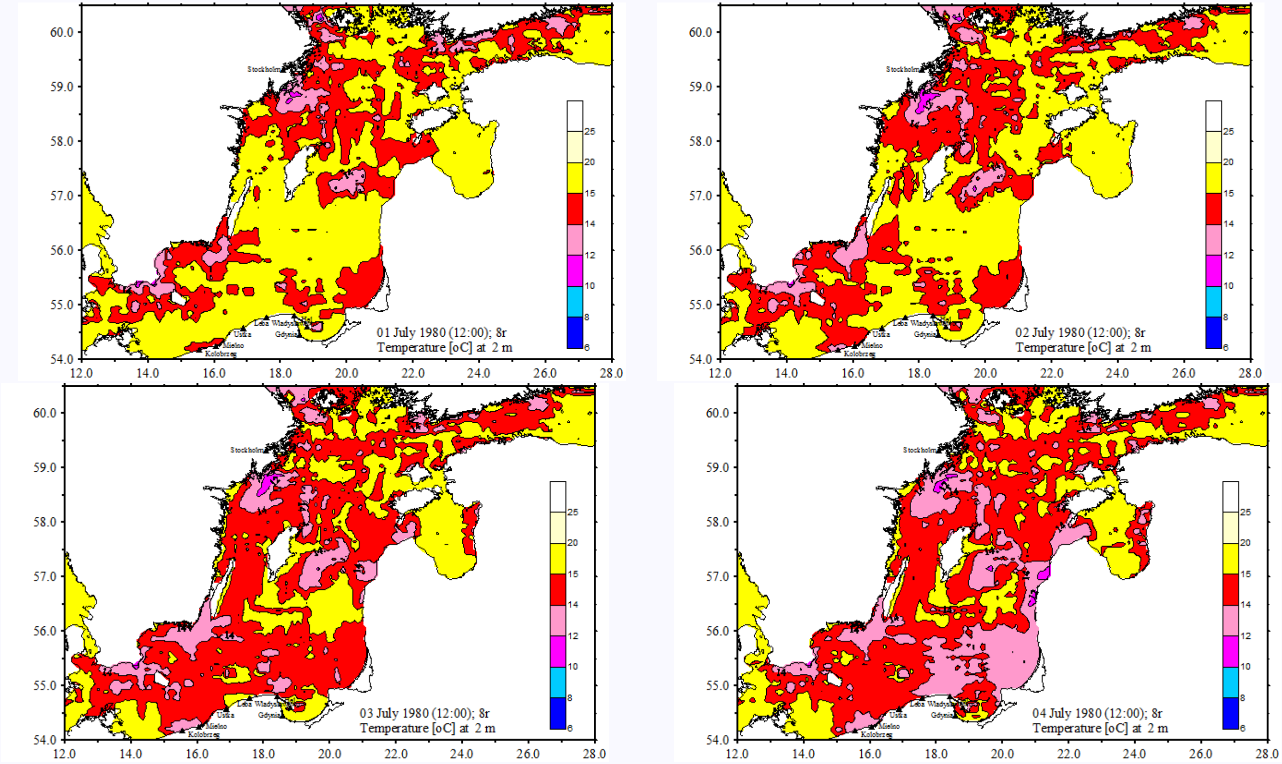


Figure 3 Location of points **S1-S5** used to visualize the vertical profiles of sea water temperature and salinity (cf. Figure 2) in the model domain coastline configuration.



01 July 1980 (12:00); 8r
Temperature [oC] at 2 m

02 July 1980 (12:00); 8r
Temperature [oC] at 2 m

03 July 1980 (12:00); 8r
Temperature [oC] at 2 m

04 July 1980 (12:00); 8r
Temperature [oC] at 2 m

Figure 4 Simulated sea water temperature [^{o}C] at 2 m depth in a time sequence of 1 day from 01.07.1980 to 01.08.1980. Case 8r - real atmospheric forcings. Figure 4a - days: from 01.07 to 04.07).

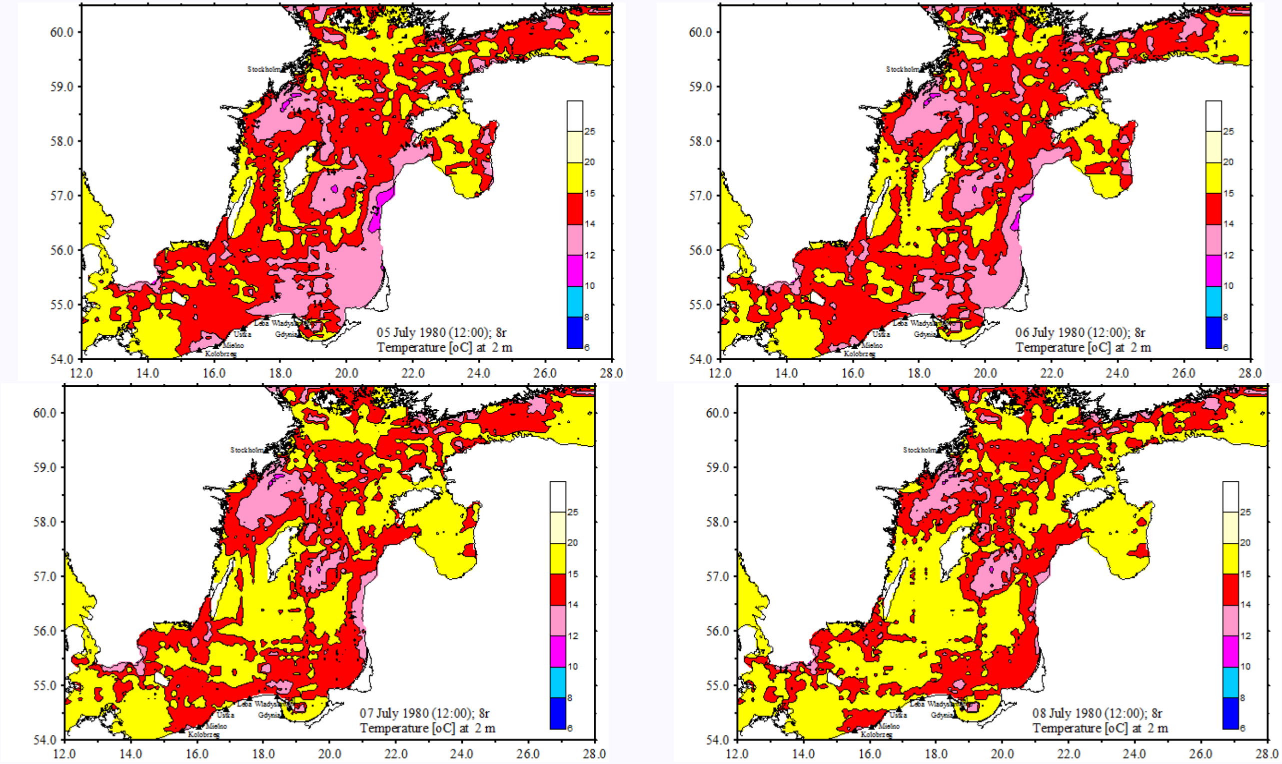
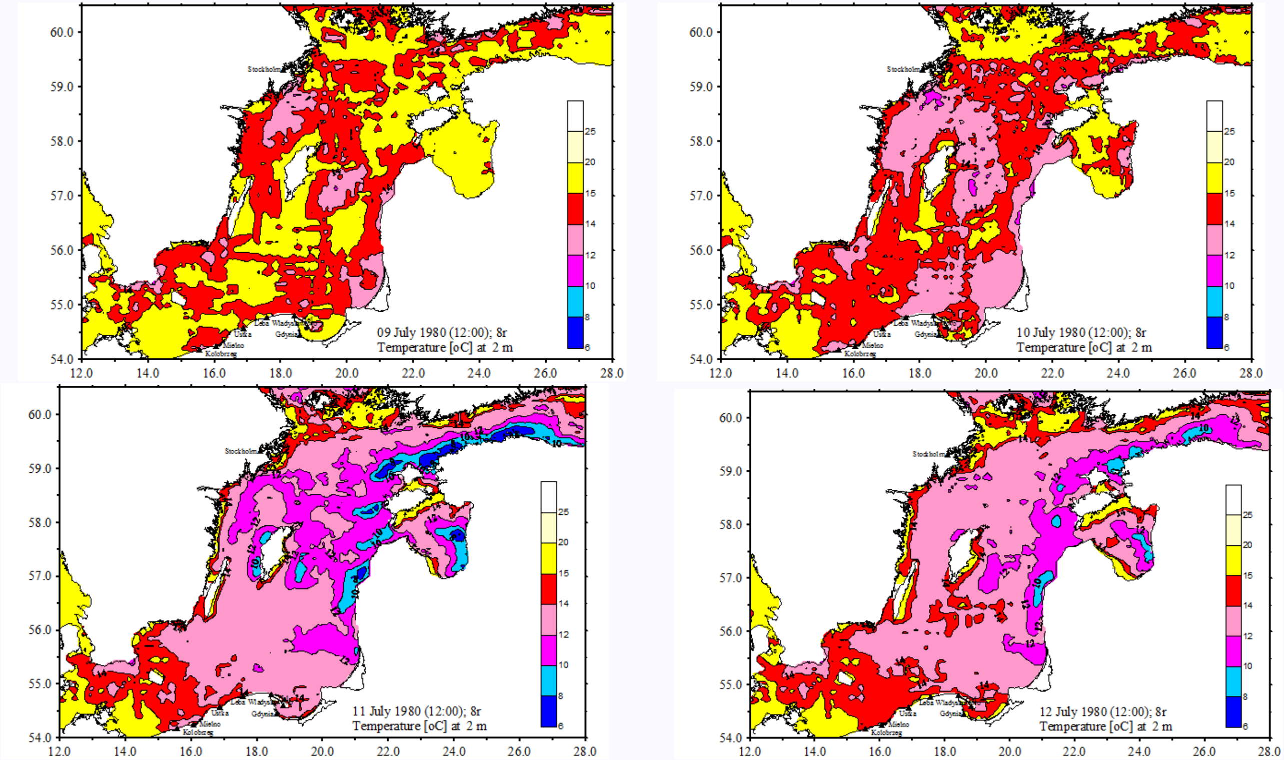


Figure 4 Simulated sea water temperature $[^oC]$ at 2 m depth in a time sequence of 1 day from 01.07.1980 to 01.08.1980. Case 8r - real atmospheric forcings. Figure 4b - days: from 05.07 to 08.07).



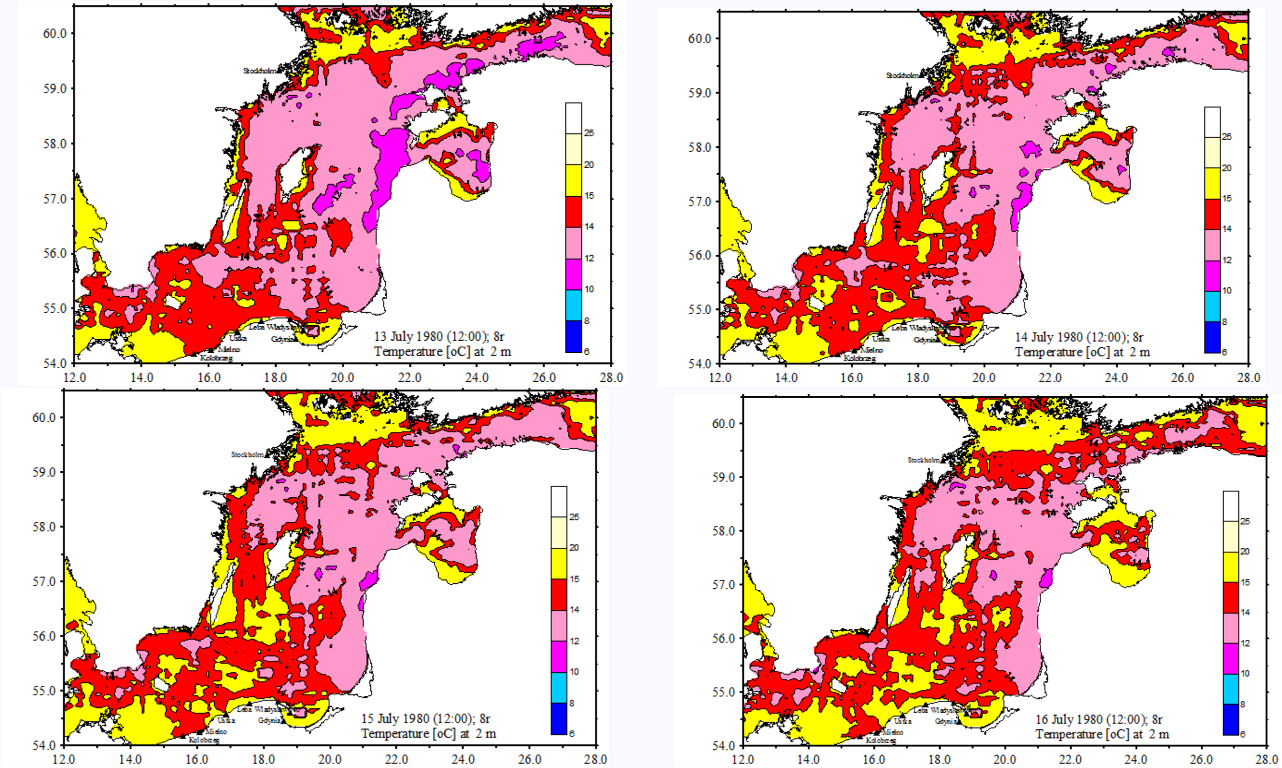
09 July 1980 (12:00); 8r
Temperature [oC] at 2 m

10 July 1980 (12:00); 8r
Temperature [oC] at 2 m

11 July 1980 (12:00); 8r
Temperature [oC] at 2 m

12 July 1980 (12:00); 8r
Temperature [oC] at 2 m

Figure 4 Simulated sea water temperature $[^{o}C]$ at 2 m depth in a time sequence of 1 day from 01.07.1980 to 01.08.1980. Case 8r - real atmospheric forcings. Figure 4c - days: from 09.07 to 12.07).



13 July 1980 (12:00); 8r
Temperature [oC] at 2 m

14 July 1980 (12:00); 8r
Temperature [oC] at 2 m

15 July 1980 (12:00); 8r
Temperature [oC] at 2 m

16 July 1980 (12:00); 8r
Temperature [oC] at 2 m

Figure 4 Simulated sea water temperature [^oC] at 2 m depth in a time sequence of 1 day from 01.07.1980 to 01.08.1980. Case 8r - real atmospheric forcings. Figure 4d - days: from 13.07 to 16.07).

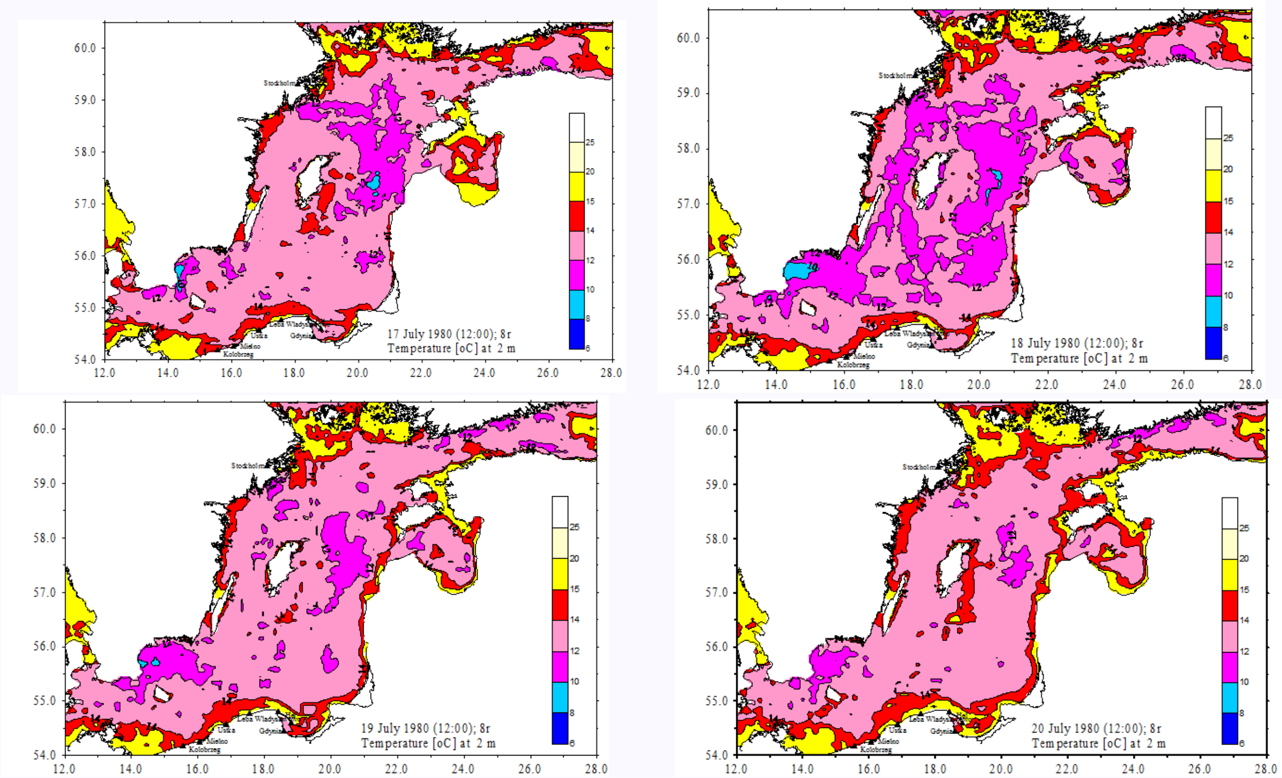


Figure 4 Simulated sea water temperature [^oC] at 2 m depth in a time sequence of 1 day from 01.07.1980 to 01.08.1980. Case 8r - real atmospheric forcings. Figure 4e - days: from 17.07 to 20.07).

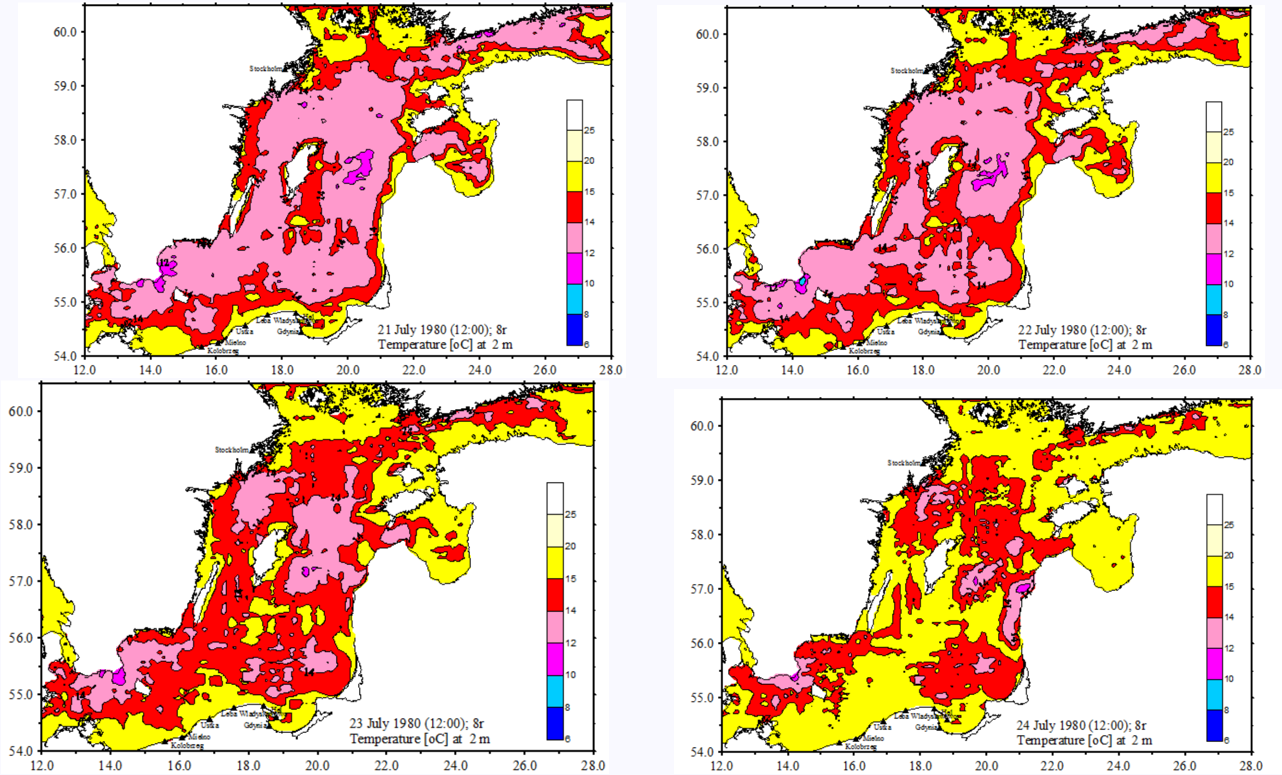


Figure 4 Simulated sea water temperature $[^oC]$ at 2 m depth in a time sequence of 1 day from 01.07.1980 to 01.08.1980. Case 8r - real atmospheric forcings. Figure 4f - days: from 21.07 to 24.07).

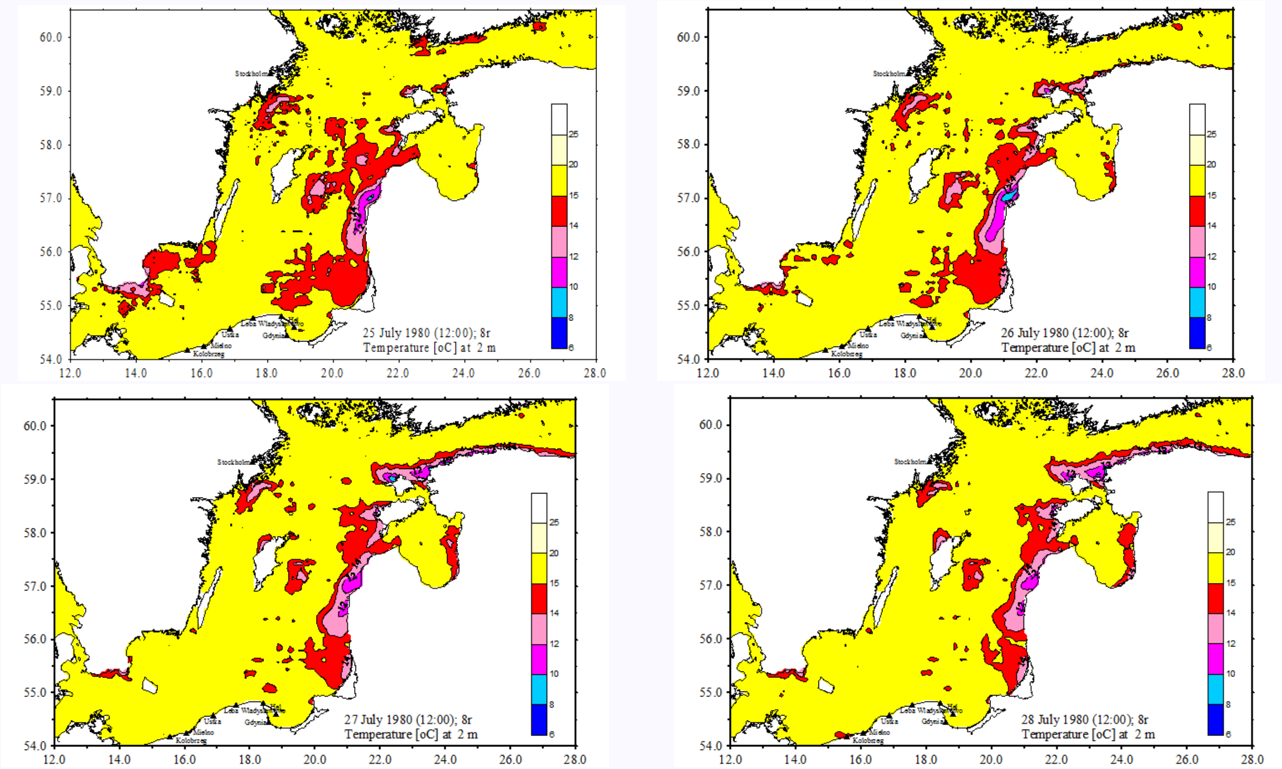


Figure 4 Simulated sea water temperature $[^oC]$ at 2 m depth in a time sequence of 1 day from 01.07.1980 to 01.08.1980. Case 8r - real atmospheric forcings. Figure 4g - days: from 25.07 to 28.07).

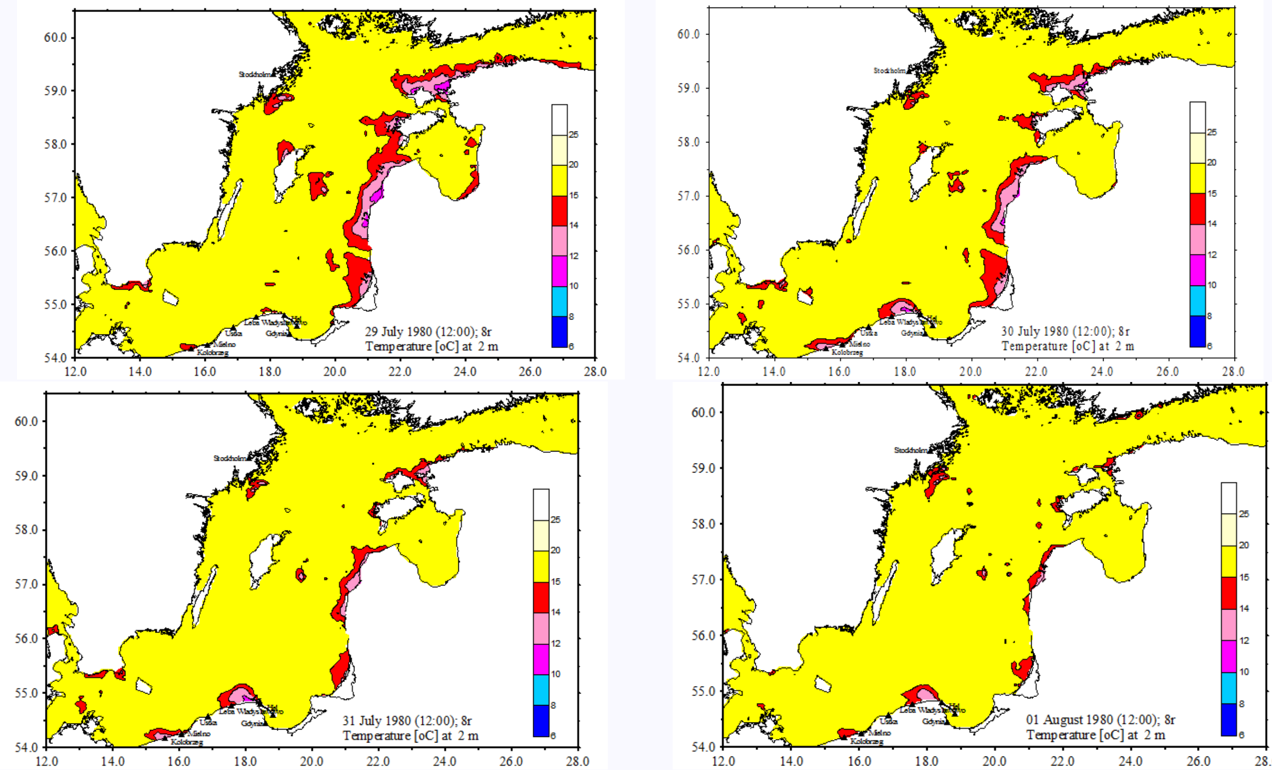


Figure 4 Simulated sea water temperature $[^oC]$ at 2 m depth in a time sequence of 1 day from 01.07.1980 to 01.08.1980. Case 8r - real atmospheric forcings. Figure 4h - days: from 29.07 to 01.08).

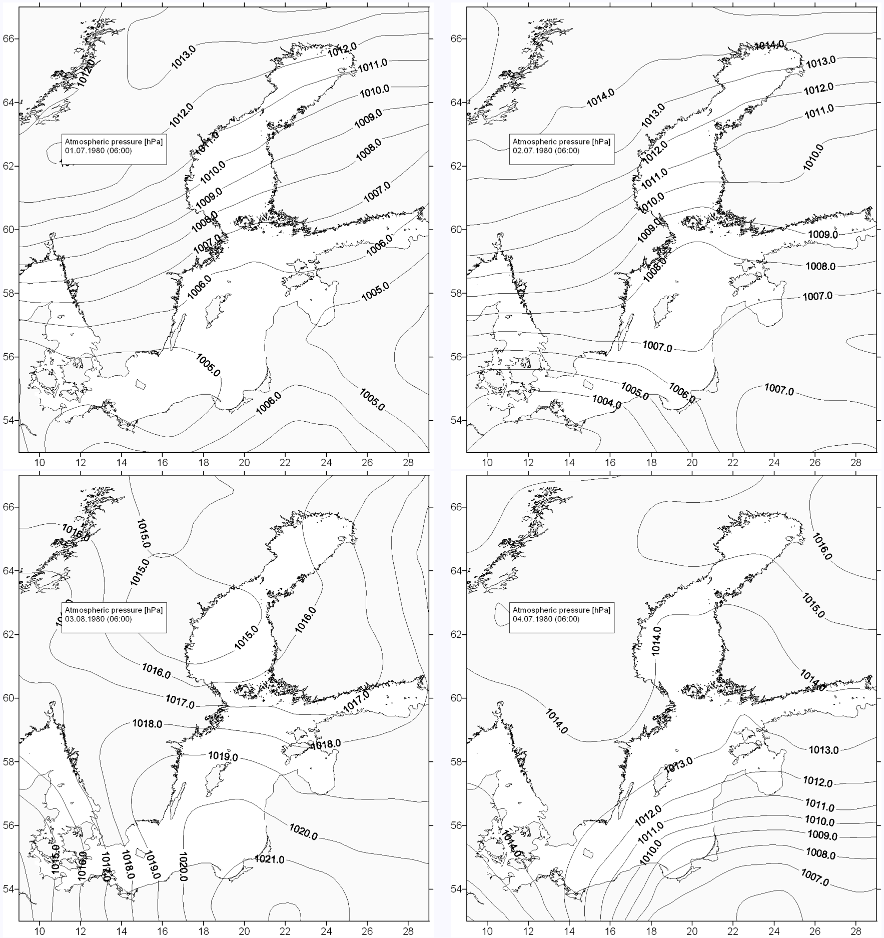


Figure 5 Atmospheric conditions above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isobars in [hPa].
Figure 5a - days: from 01.07 to 04.07).

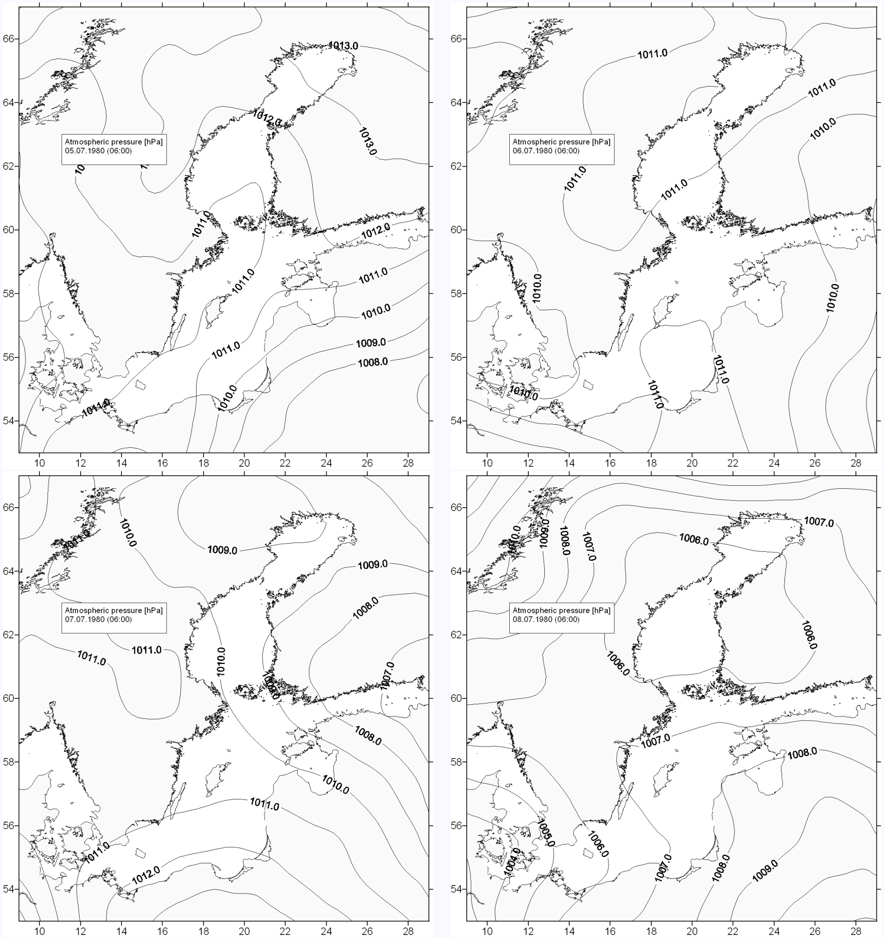


Figure 5 Atmospheric conditions above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isobars in [hPa].

Figure 5b - days: from 05.07 to 08.07).

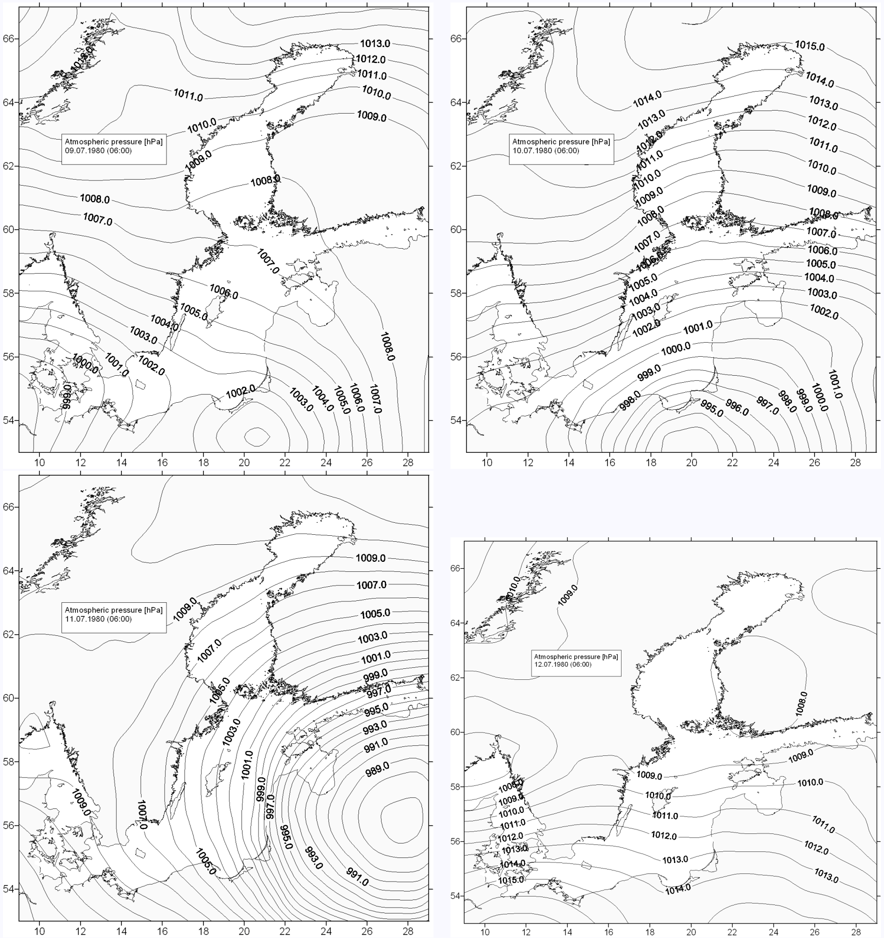


Figure 5 Atmospheric conditions above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isobars in [hPa].

Figure 5c - days: from 09.07 to 12.07).

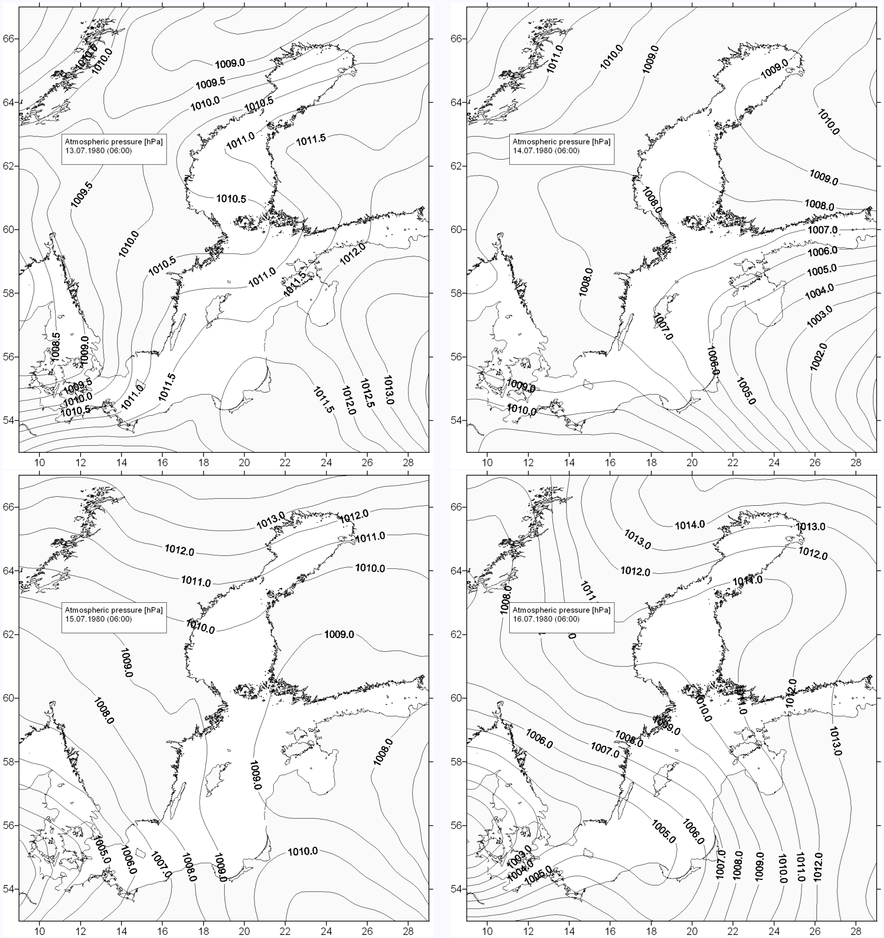
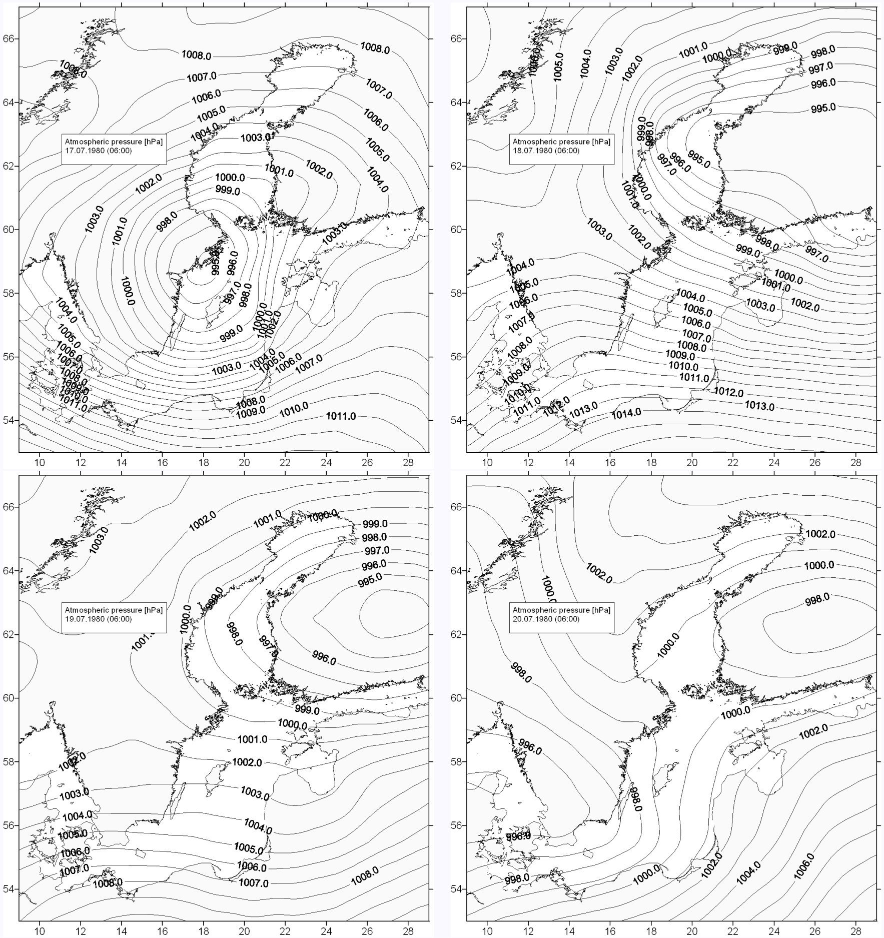


Figure 5 Atmospheric conditions above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isobars in [hPa].
Figure 5d - days: from 13.07 to 16.07).



Atmospheric pressure [hPa]
17.07.1980 (06:00)

Atmospheric pressure [hPa]
18.07.1980 (06:00)

Atmospheric pressure [hPa]
19.07.1980 (06:00)

Atmospheric pressure [hPa]
20.07.1980 (06:00)

Figure 5 Atmospheric conditions above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isobars in [hPa].
Figure 5e - days: from 17.07 to 20.07).

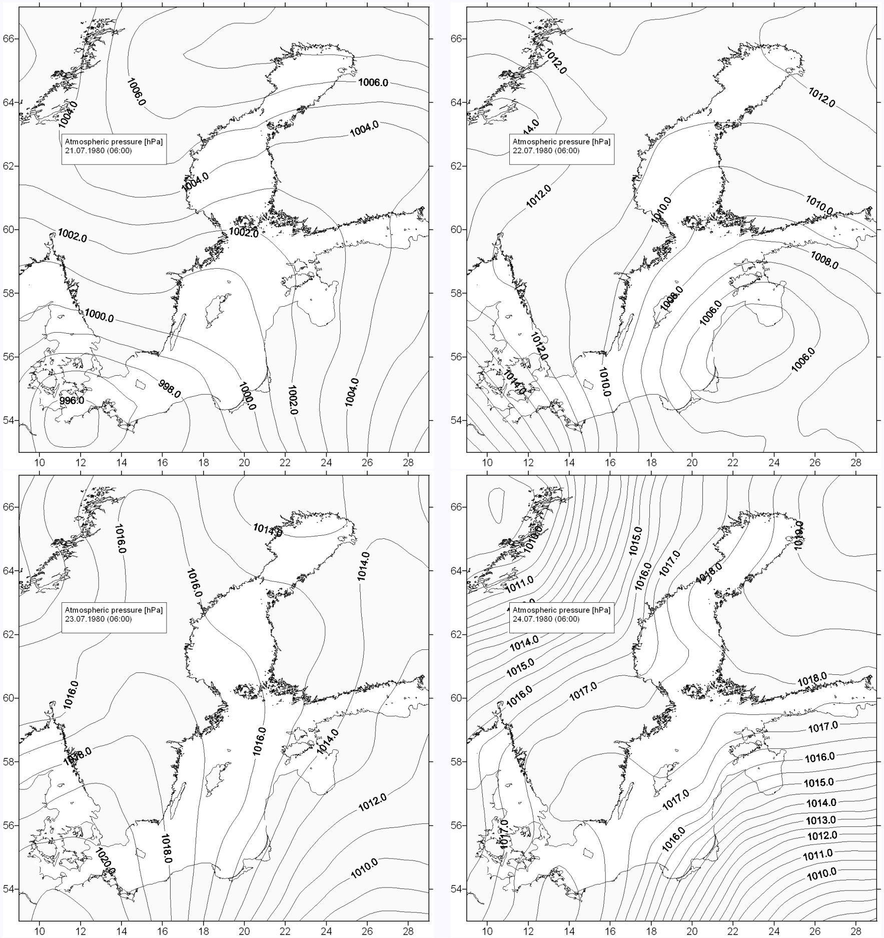


Figure 5 Atmospheric conditions above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isobars in [hPa].
Figure 5f - days: from 21.07 to 24.07).

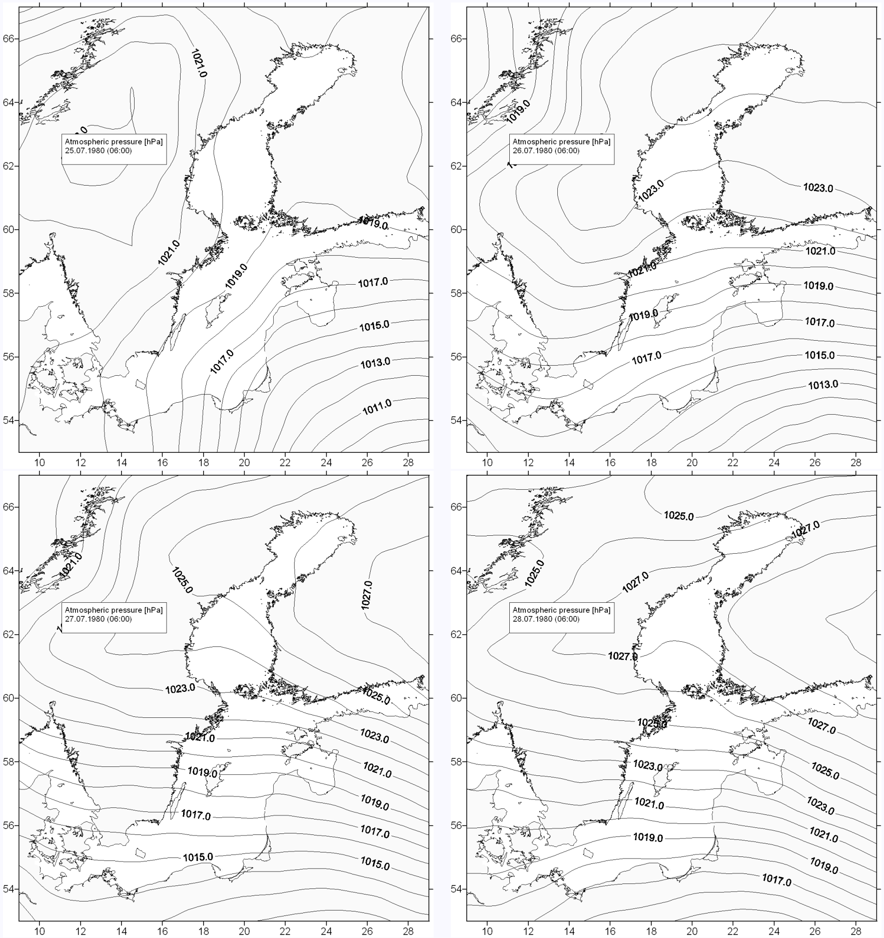


Figure 5 Atmospheric conditions above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isobars in [hPa].

Figure 5g - days: from 25.07 to 28.07).

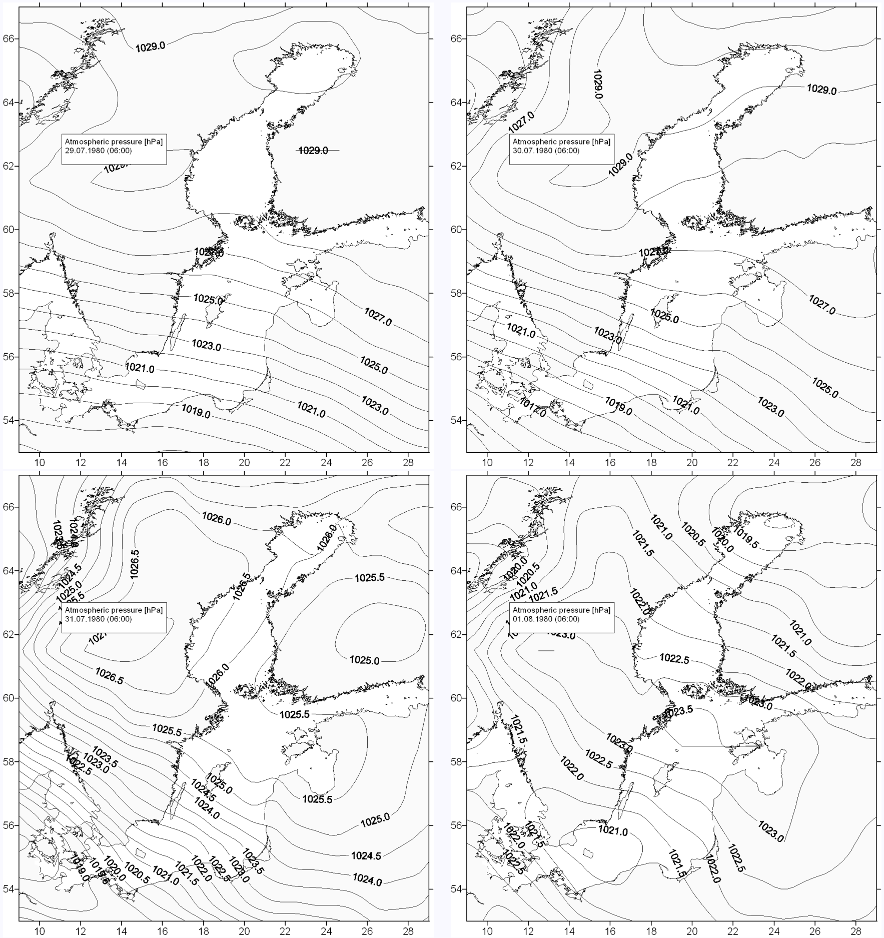


Figure 5 Atmospheric conditions above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isobars in [hPa].

Figure 5h - days: from 29.07 to 01.08).

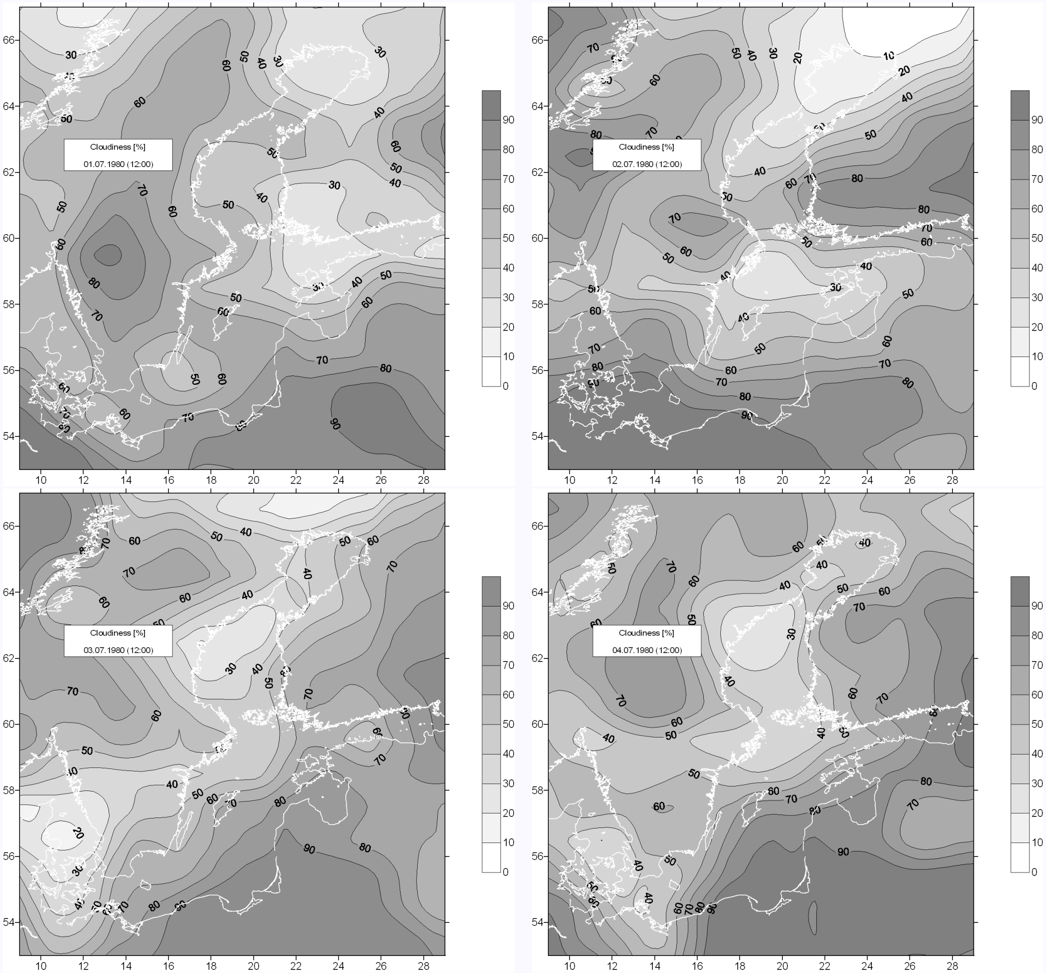


Figure 6 Cloudiness in [%] above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isolines in [%].
Figure 6a - days: from 01.07 to 04.07).

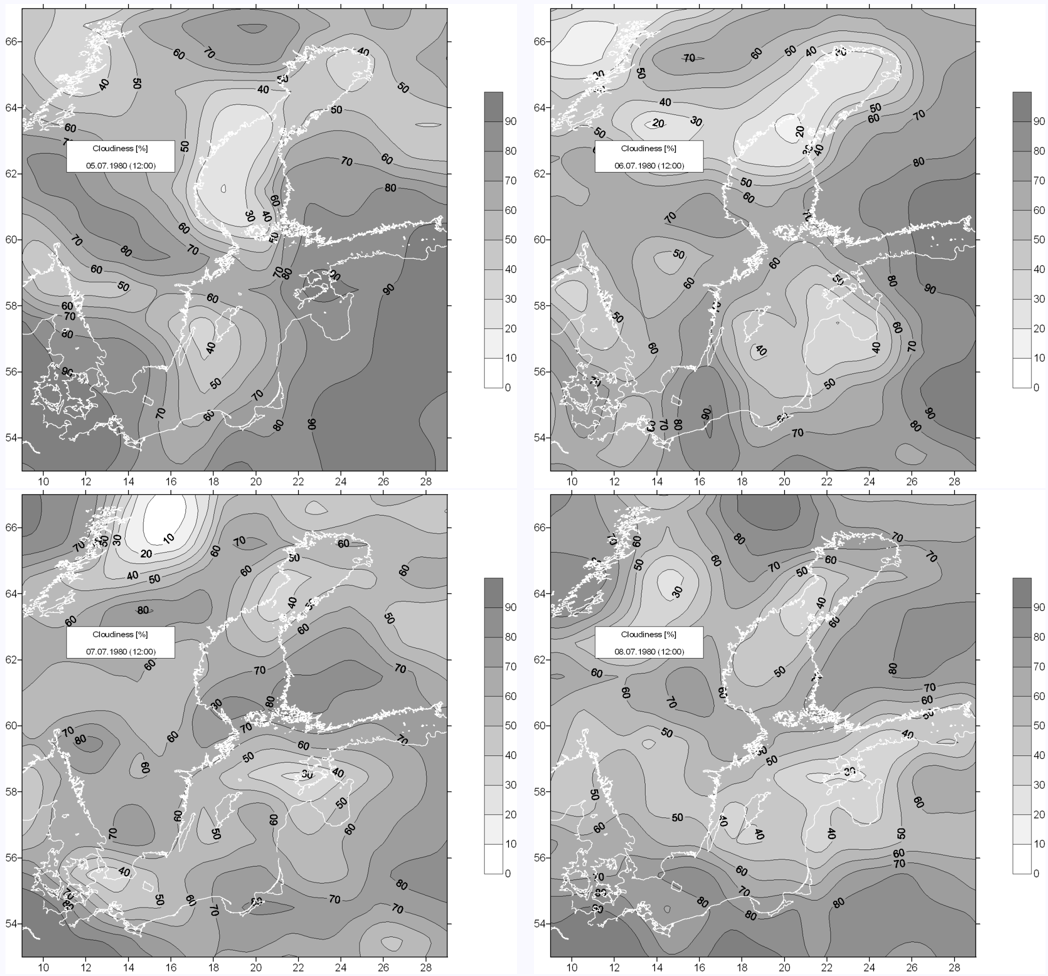
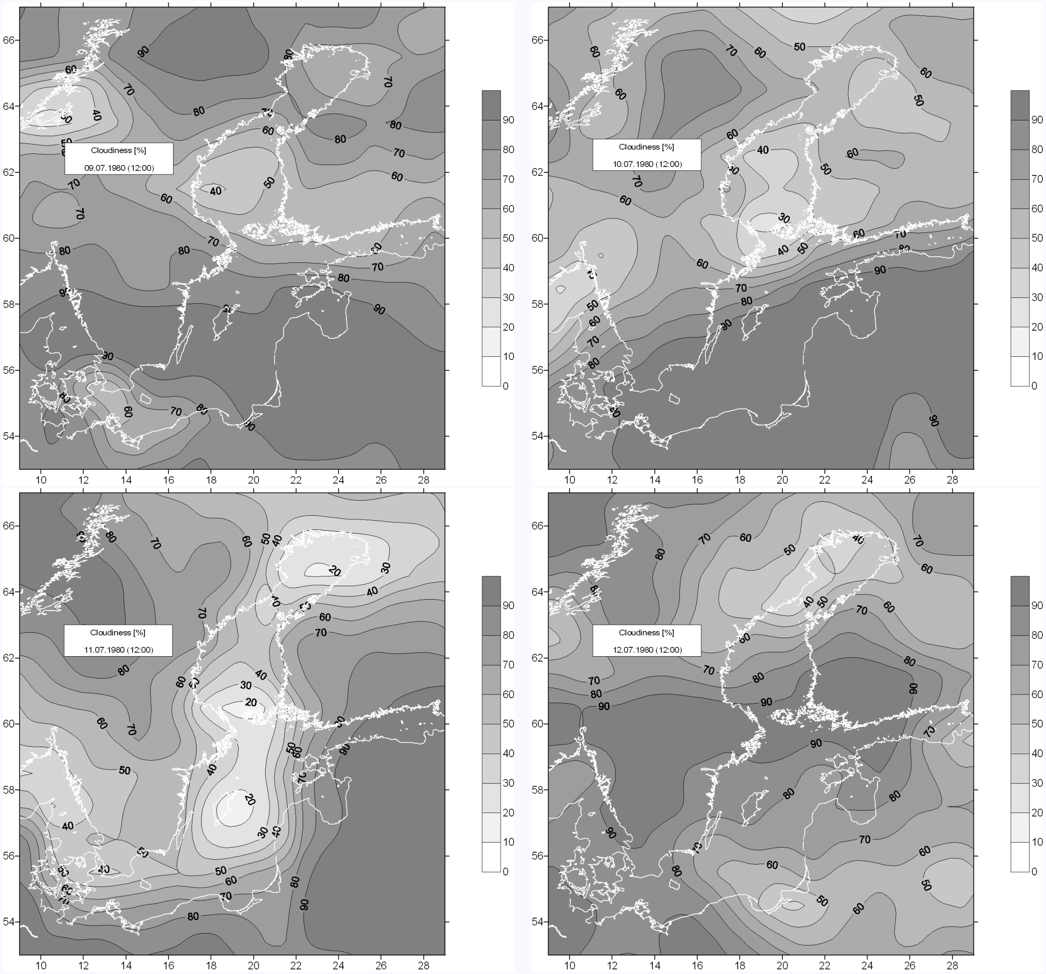


Figure 6 Cloudiness in [%] above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isolines in [%].
Figure 6b - days: from 05.07 to 08.07).



Cloudiness [%]
09.07.1980 (12:00)

Cloudiness [%]
10.07.1980 (12:00)

Cloudiness [%]
11.07.1980 (12:00)

Cloudiness [%]
12.07.1980 (12:00)

Figure 6 Cloudiness in [%] above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isolines in [%].
Figure 6c - days: from 09.07 to 12.07).

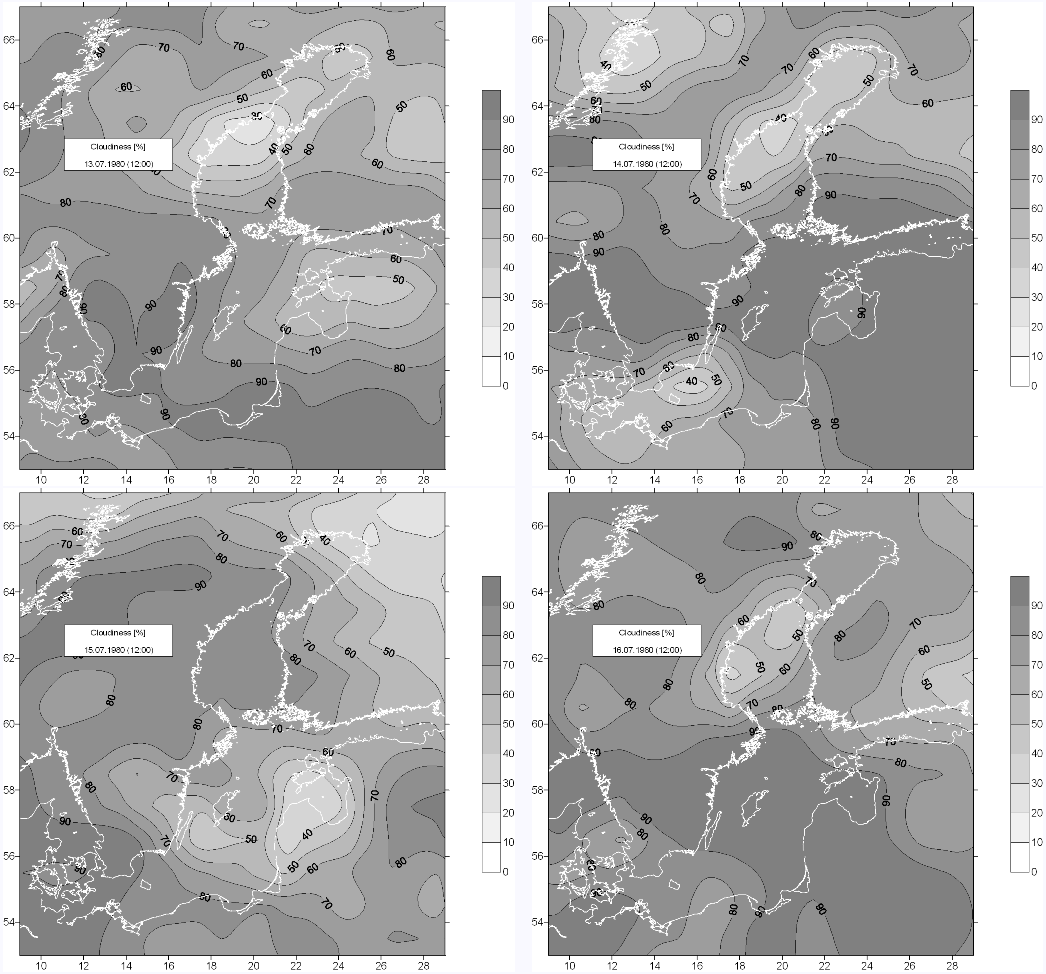


Figure 6 Cloudiness in [%] above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isolines in [%].
Figure 6d - days: from 13.07 to 16.07).

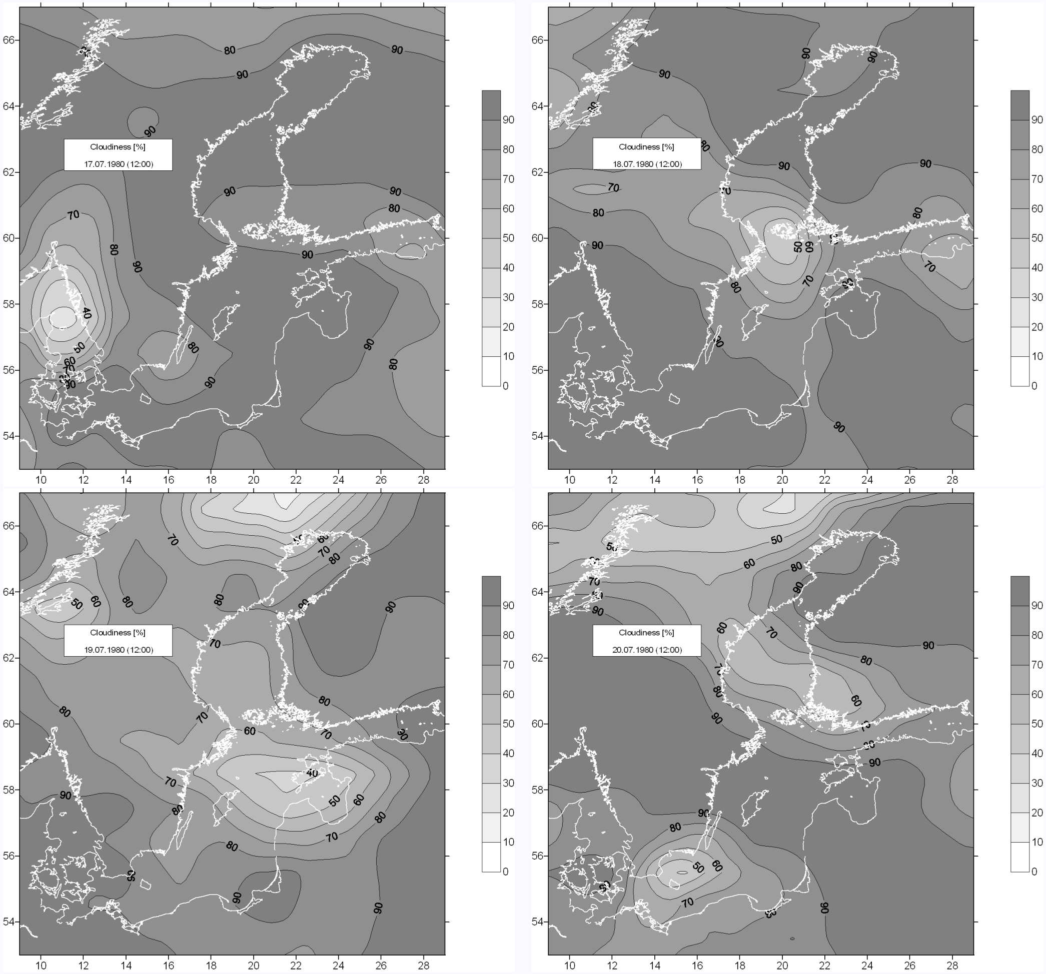


Figure 6 Cloudiness in [%] above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isolines in [%].
Figure 6e - days: from 17.07 to 20.07).

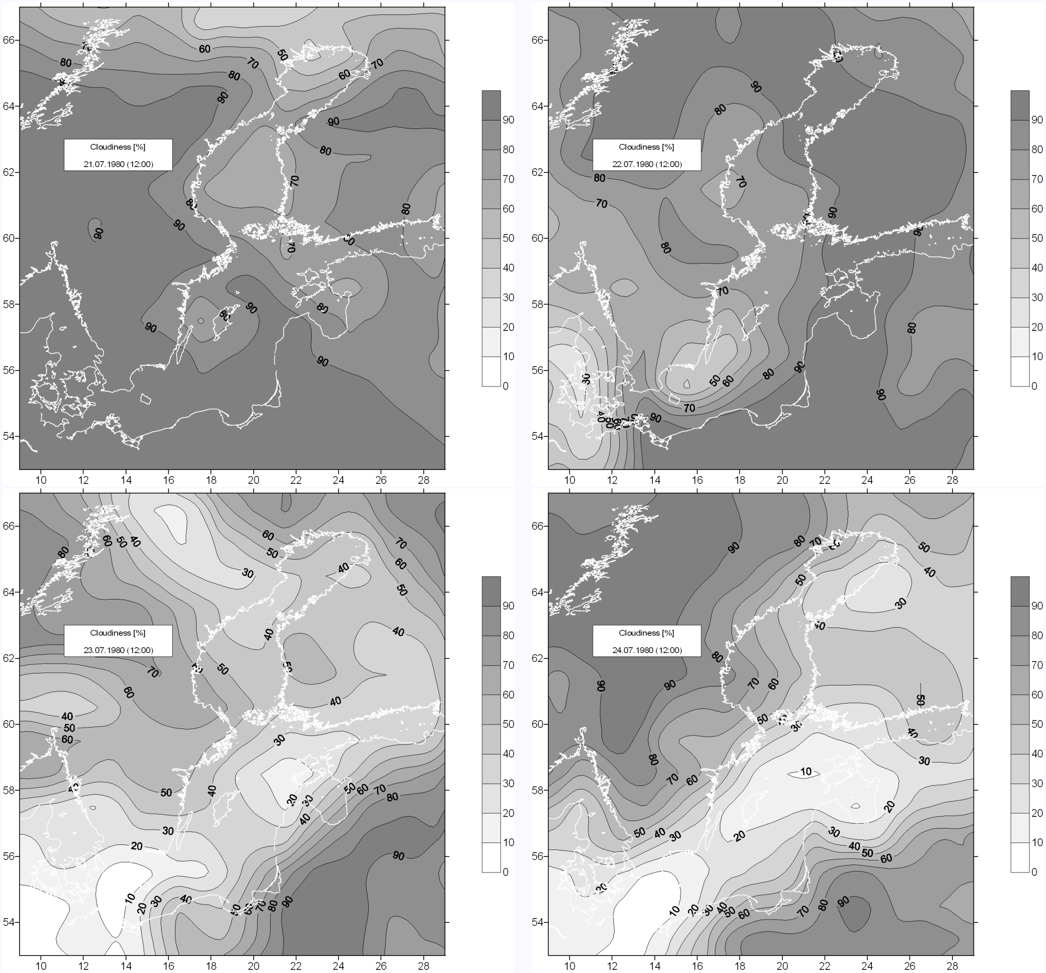


Figure 6 Cloudiness in [%] above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isolines in [%].
Figure 6f - days: from 21.07 to 24.07).

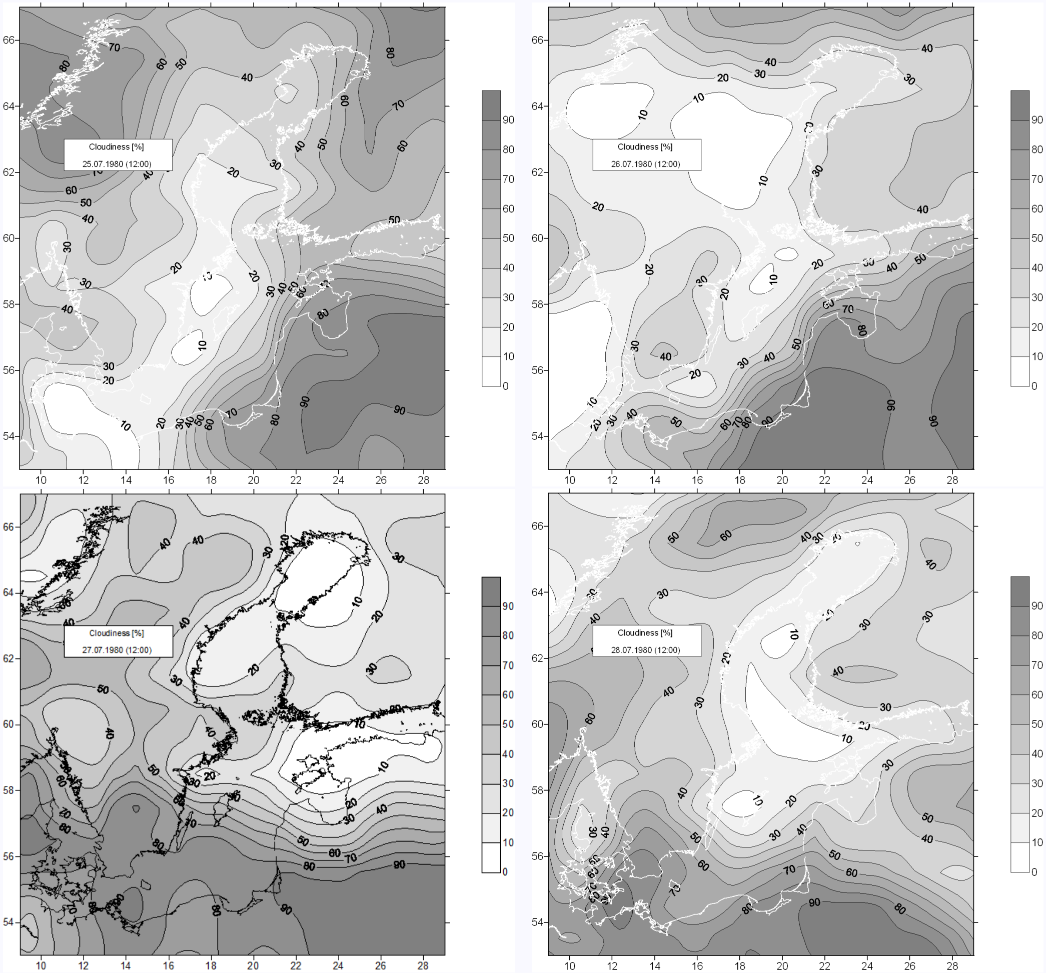


Figure 6 Cloudiness in [%] above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isolines in [%].
Figure 6g - days: from 25.07 to 28.07).

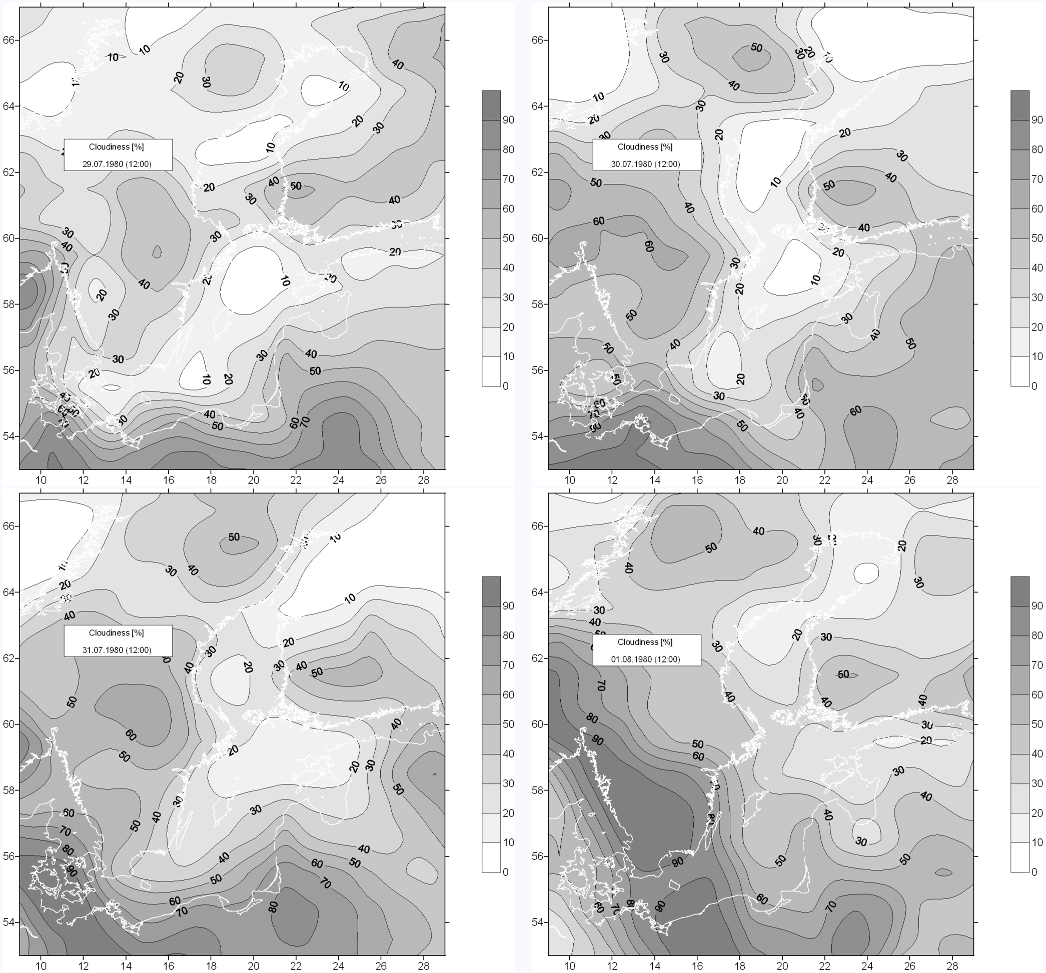


Figure 6 Cloudiness in [%] above the Baltic Sea in summer 1980 (from 01.07.1980 to 01.08.1980). Data taken from (BED, 2000)). Isolines in [%].
Figure 6h - days: from 29.07 to 01.08).