Extension of riverine water influence in the Gulf of Gdańsk and in the Pomeranian Bay during the flood event in summer 1980 - insight from model simulations [a]

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Abstract

The main bays in the coastal zone of Poland, i.e., the Gulf of Gdansk, situated in the southeastern part, and the Pomeranian Bay, located in the western part of the Polish coasts, belong to the ones of the Baltic's open gulfs. Their hydrological regimes are formed by atmospheric forcing and, due to wide connection with the open sea, under influence of the Baltic proper. Surface waters are influenced by riverine inflows among which the greater significance has those of the Wisła (Vistula) River in the Gulf of Gdansk and the Odra (Oder) River in the Pomeranian Bay, the biggest rivers in the regions. The mixed river waters can be observed at the open boundary of the gulfs or even futher after the strong flood events. The inflow of riverine waters substantially modifies the environmental conditions in the surface water of the Gulf by reducing its salinity as well as contaminating it with their pollution load.

The purpose of this work is to use computer simulation to better understand the fate of riverine water as it mixes and moves around with the currents and winds in the Southern Baltic in the coastal regions closed to the Gulf of Gdansk and the Pomeranian Bay during the flood event in summer 1980. The sea water salinity was used as a natural tracer for visualization of spreading of riverine waters. The results of the numerical experiments visualize the patterns of weak saline surface water (riverine plume) propagation on their way from the rivers mouth toward the open boundary of the bays. The results of simulations showed that the surface water plume can be particularly sensitive to the wind stress because it is thin. Its extent is influenced by the wind stress and varied dramatically depending on the orientation of the wind stress.

Introduction

The **Gulf of Gdansk** (see **Figure 1** for its location) is bordered by the Russian and Polish coasts in the east, south-east, south and west. It has wide (ca. 107 km) and deep (ca. 118 m) connection with the Baltic Proper in the north, while its mean depth is about 55 m. The area of the gulf, equals to about 4995 km^2 and its volume reaches about 236 km^3. Main river, the Vistula (Wisła) river, with its yearly mean runoff, equals to ca. 1026 m^3/s, introduces about 32 km^3 per year.
(cf e.g., Gulf of Gdansk, Majewski A. (ed), 1990).

The **Pomeranian Bay** (see **Figure 1** for its location) is bordered by the German and Polish coasts in the west, south and south-east, while in the north it is widely opened to the Arkona and Bornholm Basins. The two latter deep basins are the first recipients of salt water from the Danish Straits. The northern boundary of the entire Pomeranian Bay stretches approximately along the 20 m isobath. The area of the bay, calculated within this boundary, equals to ca. 6000 km^2, while its volume reaches 73 km^3. The bay is shallow and its depth drops even to 6 m on the Odra (Oder) Bank. The Odra (Oder) river, the biggest one in this region, with its yearly mean runoff, equals to ca. 570 m^3/s, introduces into the bay about 18 km^3 per year via the shallow Szczecin Lagoon. The most (60-70 %) of the Odra waters are transported into the Baltic Sea through the Swina canal so, herein, this point is utilized as a mouth of the Odra river.
(cf e.g., Majewski, 1974).

Model

Code - based on the Princeton Ocean Model (POM) (Blumberg and Mellor 1987; Mellor 1993), adapted to the Baltic Sea conditions (cf., Jankowski 2002)

Physical characteristics:

vertical coordinate - so-called terrain-following sigma–coordinate $\sigma = (z-\eta)/(H+\eta)$
vertical eddy viscosity and **diffusitivity** - computed using Mellor and Yamada (1974; 1982) formulation
horizontal eddy viscosity and **diffusivity** - computed using Smagorinsky (1963) formulation
model extension: $8^o\ 50^{'}$ E - $30^o\ 00^{'}$ E; $53^o\ 50^{'}$ N - $65^o\ 50^{'}$ N
bottom topography - is based on data from Seifert and Kayser (1995).
horizontal resolution - 5 km
vertical resolution - 24 sigma - levels

Numerical characteristics:

numerical grid - "C" grid (Mesinger and Arakawa 1976)
momentum equations and transport equations
time differencing - leap frog + time splitting
space differencing - centered scheme
open boundary conditions - radiation type

Simulations with realistic forcings - (July - August 1980)

First stage - model initialization - 20 days

forcings:
wind field - no wind
thermohaline - no heat and salt fluxes at the sea surface, real (climatic) temperature and salinity fields (July, August)
river runoff – no river inflow
initial fields: real climatic termohaline fields (July, August)
velocity components and **sea level** = 0

Second stage - prognostic simulations (31 days for each of month)

forcings:
wind field - from the atmospheric surface pressure charts
wind stress - standard formula (Large and Pond 1982)
thermohaline - surface heat fluxes at the sea surface estimated by bulk formula + "relaxation to climatology" (e.g., Lehmann 1995; Svendsen et al. 1996)
river runoff - yearly means of the 31 main rivers (1980-1993); data from Maier et al. (1999); (Vistula and Odra runoff (flood event values) - 3026 m^3/s and 2017 m^3/s, respectively)
initial fields: output from the first stage

Data

winds and heat fluxes - estimated on basis of 3-hourly atmospheric data taken from (BED 2000)

data (initial and **climatological forcing)** - from Lenz's (1971) and Bock's (1971) atlases, ICES Oceanographic Database and Regional Oceanographic Database of IO PAS, Sopot

Simulations with homogeneous wind fields

First stage - model initialization - 20 days

forcings:
wind field - no wind
thermohaline - no heat and salt fluxes at the sea surface, real (climatic) temperature and salinity fields (August)
river runoff – no river inflow
initial fields: real climatic termohaline fields (August)
velocity components and **sea level** = 0

Second stage - prognostic simulations (5 days)

forcings:
bf wind field - homogeneous fields with wind stress equal to 0.01, 0.05 and 0.10 N/m^2; winds from 8 directions (N, E, S, W, NE, NW, SW, SE)
thermohaline - no heat and salt fluxes at the sea surface, only "relaxation to climatology" (e.g., Lehmann 1995; Svendsen et al. 1996)
river runoff - yearly means of the 31 main rivers (1980-1993) from Maier eta al., (1999); (Vistula and Odra runoff (flood event values) - 3026 m^3/s and 2017 m^3/s, respectively)
initial fields: output from the first stage

Data

data (initial and **climatological forcings)** - from Lenz's (1971) and Bock's (1971) atlases, ICES Oceanographic Database and Regional Oceanographic Database of IO PAS, Sopot

Results of simulations with realistic forcings

(July - August 1980)

The hindcast calculations were performed along with the methodology and strategies described in the previous slides. The model was forced by the river runoff rates of the main 31 rivers (assumed as yearly means) as well as with real atmospheric forcings in July and August 1980.

Figure 2 displays monthly mean river discharge (1975-1985) of the Vistula River and the Odra River in period of 1975-1985. In summer of 1980 (July and August) high values of the river runoff can be observed for both rivers and they can be related to summer flood event in the Gulf of Gdansk as well as in the Pomeranian Bay.

Thus, in simulations, in order to mimic the flood event in summer 1980, higher values of river runoff for the Vistula River and Odra River i.e., values, related to the flood values, were used: i.e, 3026 m^3/s and 2017 m^3/s, respectively. The seawater salinity is used to trace spreading of riverine waters in the surface layer in the both bays.

Results of simulations with realistic forcings

(July - August 1980) ... continued

Next two figures: **Figure 3** and **Figure 4**, present selected atmospheric pressure fields over the Baltic Sea in July and August 1980, respectively for some chosen days (5th, 10th, 15th, 20th, 25th and 30th of each month).

Figure 5 illustrates exemplary time series of wind direction and wind speed at point **P4** (see **Figure 1** for the point location). Results of simulations of at the end of the first stage of calculations for July and August in the Gulf of Gdansk and the Pomeranian Bays have been shown in **Figure 6** and **Figure 7**. These figures display initial distrbution of seawater salinity and currents vectors in the surface layer.

The next some figures: **Figures: 8a,b; 9a,b** and **Figures: 10a,b; 11a,b**, display examplary results of the prognostic (hindcast) simulations with the realistic forcings in both gulfs in July and August 1980 in the bays. They show the distrbution of seawater salinity and currents vectors in the surface layer for some chosen days (5th, 10th, 15th, 20th, 25th and 30th of each month). Additional information on the time history of wind direction and its speed at point **P4** is also added to each of the figures.

Results of simulations with homogeneous wind forcings

summer (climatic) seawater stratification - for August

To complete description of the hydrodynamics of the surface waters in the both bays some additional hindcast calculations were performed along with the methodology and strategies described in the previous slides but now the model was forced by the uniform in space wind fields over the Baltic Sea and as well as in previous simulation, by the river runoff of the main 31 rivers (assumed as yearly means).

All calculations have been performed for the case of summer seawater stratificationas - real climatic thermohaline fields for August. Only higher values of river runoff for the Vistula River and the Odra River, i.e., values, related to the flood values, were used with the same values, as in the previous simulations, equal to 3026 m^3/s and 2017 m^3/s, respectively.

The prognostic (hindcast) calculations started with results of the output of the first stage (initial) of calculation: i.e. after 20 days of model time without wind and river inflow with realistc summer thermhaline fields - climatic (for August) - see the figures 6 and 7 for details. Duratino of all prognostic with spatially uniform wind stress was equal to 5 days. The simulations were performed with wind from 8 directions (E, N, S, W, NE, SE, SW and NW) with the wind stress equal to 0.01, 0.05 and 0.10 N/m^2. Exemplary results have been displayed in the **Figures 12 - 15**.

Results of simulations with homogeneous wind forcings

summer (climatic) seawater stratification - for August ... continued

The **Figures 12** and **Figure 13** ilustrate the extent of the influence of riverine waters on the seawater salinity in the suface layer in the Gulf of Gdansk and in the Pomeranian Bay as a response to the uniform wind, with the stress equal to 0.05 N/m^2 blowing 4.5 days from E, SE and W. Besides the simulated seawater salinity in the surface layer, the currents vectors at 0 m depth have been also shown as well as time history of the wind stress.

The last two figures: **Figures 14** and **Figure 15**, present examples of the extent of reverine waters in both bays under influence of the uniform wind from NE, but with different values of the wind stress equal to: 0.01, 0.05 and 0.10 N/m^2, respectively. Time history of the wind stress during calculations as well as the estimated currents vectors in the surface layer have been also displayed.

The results presented above complete simulations performed to show sensitivity of the riverine water plume to the wind stress strength and its variability. Its extent is influenced by the wind stress and varied depending on the wind stress direction.

Figures

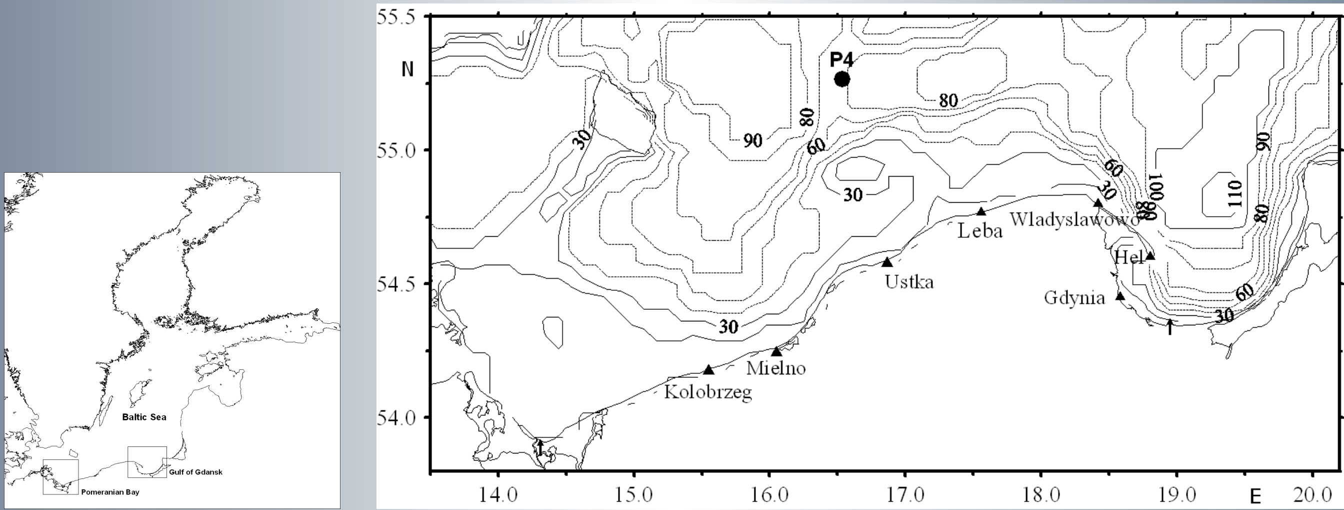

Figure 1 Location of the Pomeranian Bay and the Gulf of Gdansk in the Baltic Sea (left panel) and bottom topography in the Southern Baltic (right panel). Numbers on isolines indicate depth in meters. Symbol P4 indicates location of point used to visualize wind variability. Bottom topography was elaborated based on data from Seifert and Kayser (1995).
Arrows indicate location of the mouths of the Wisła river and the Odra river (Swina).

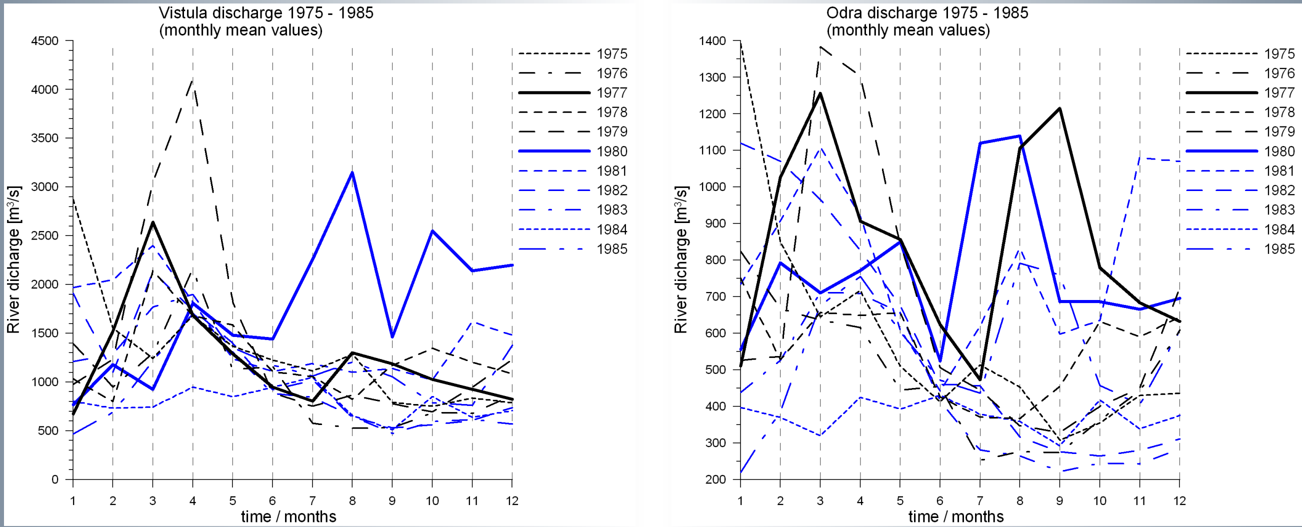

Figure 2 Monthly mean river discharge (1975-1985) of the Vistula (left figure) and the Odra (right figure) river, respectively. Data based on Vorosmarty et al. 1998 (Data set, available on-line [http://www.daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A., http://www-eosdis.ornl.gov/RIVDIS/rivdis.html

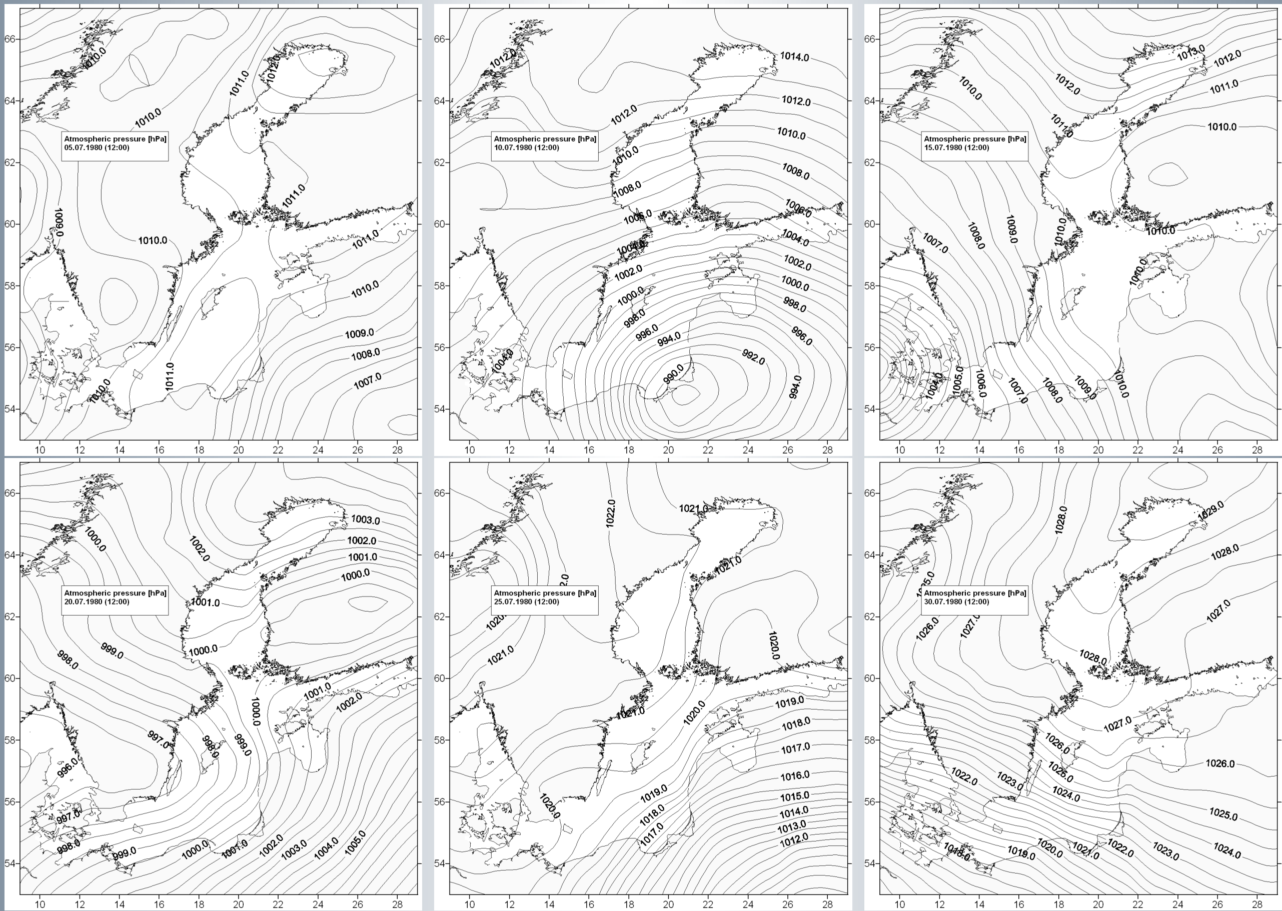

Figure 3 Anemobaric situation above the Baltic Sea related to the flood event in the Southern Baltic in July 1980 in a time sequence of 5 days (on selected days 05.07.1980 to 30.07.1980). Data taken from (BED, 2000)). Isobars in [hPa].

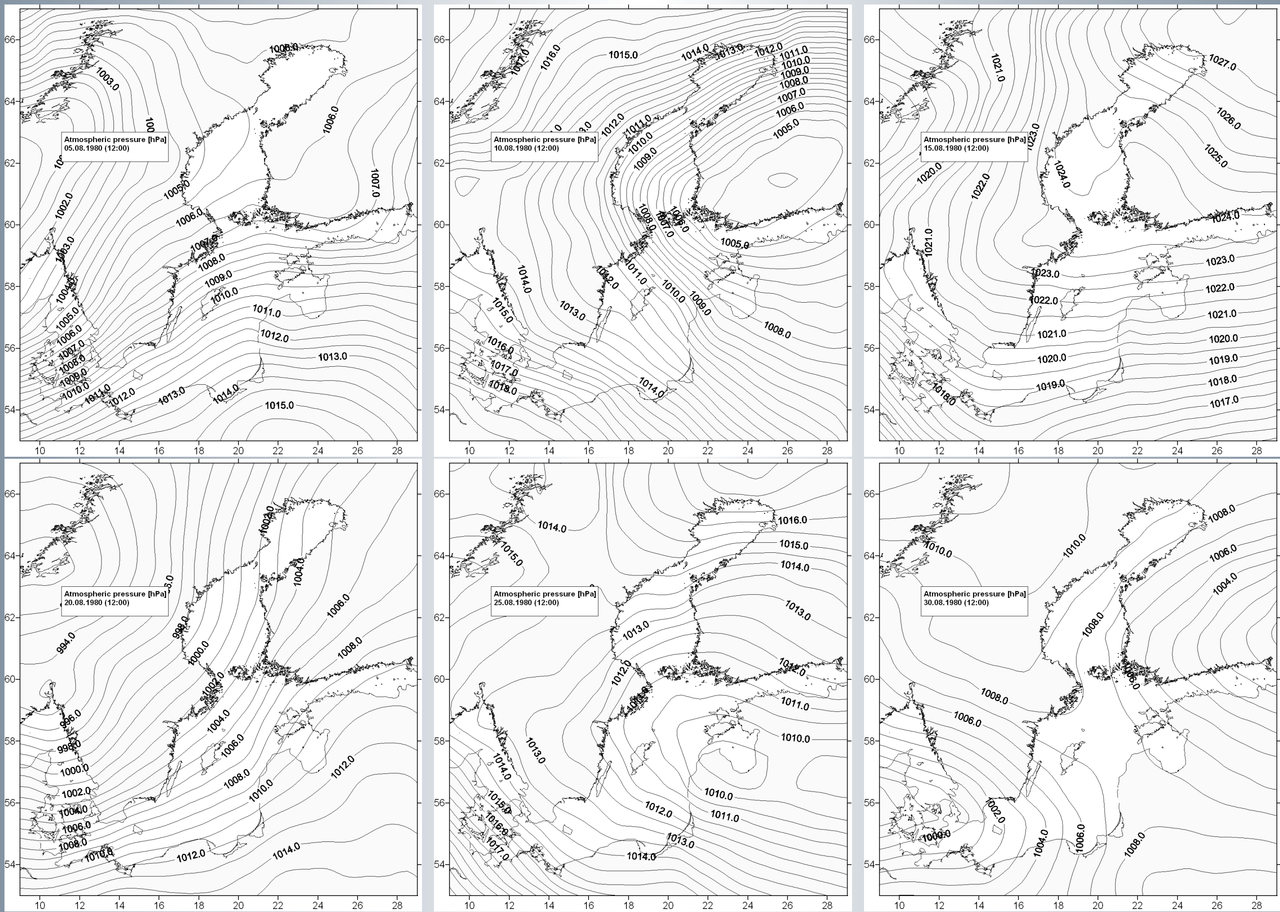

Figure 4 Anemobaric situation above the Baltic Sea related to the flood event in the Southern Baltic in August 1980 in a time sequence of 5 days (on selected days 05.08.1980 to 30.08.1980). Data taken from (BED, 2000)). Isobars in [hPa].

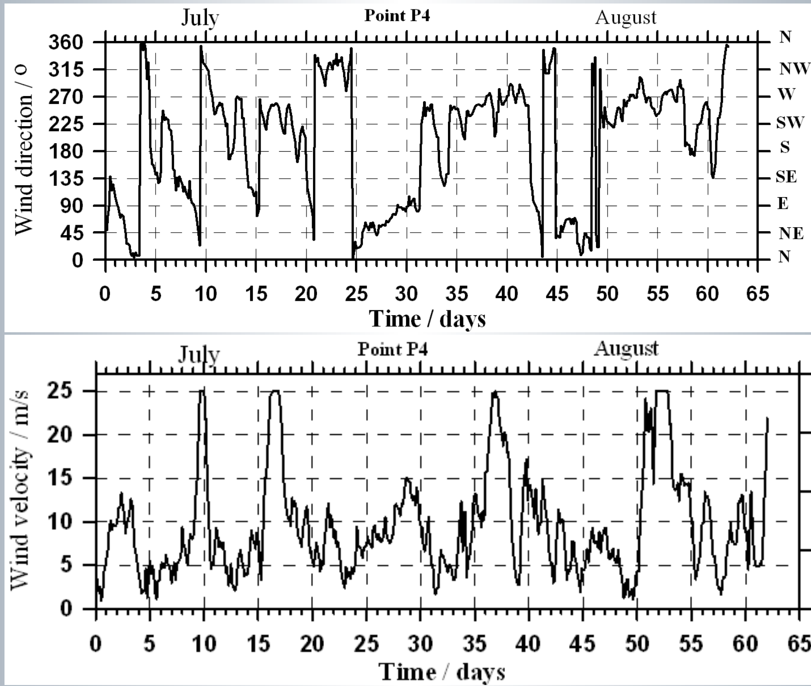

Figure 5 Time evolution of the wind direction [o] and the wind velocity module [m/s] at point P4. Location of point P4 - see Figure 1.

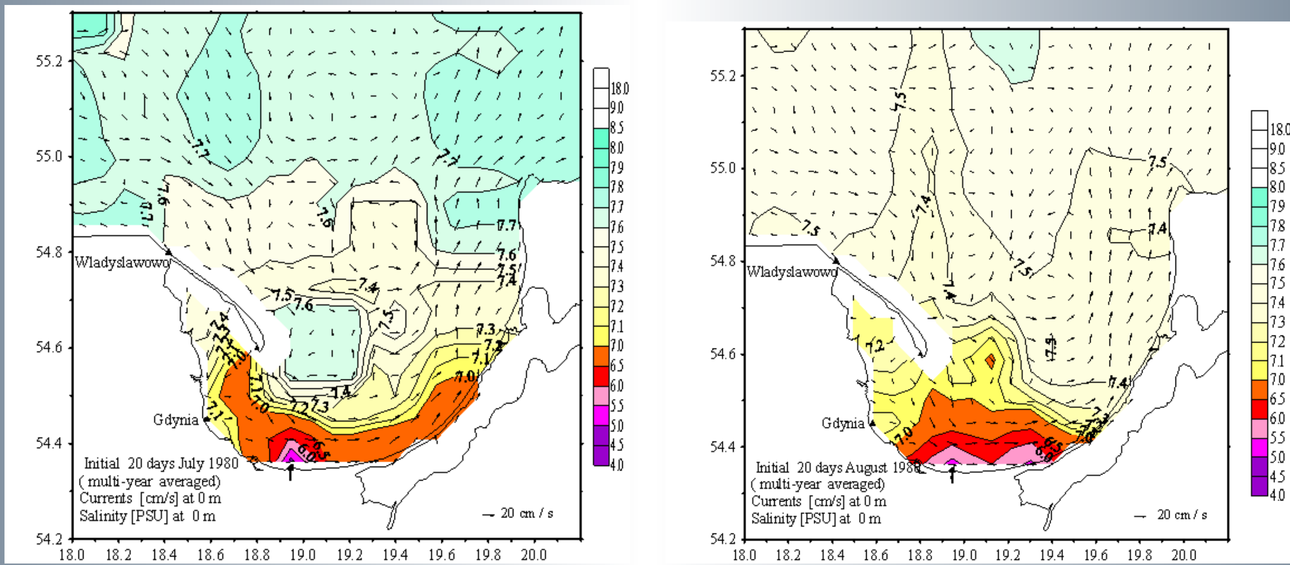

Figure 6 The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) at the end of the first (initial) stage of calculation) - after 20 days of simulations without wind and river runoff: (left figure) July ; (right figure) August

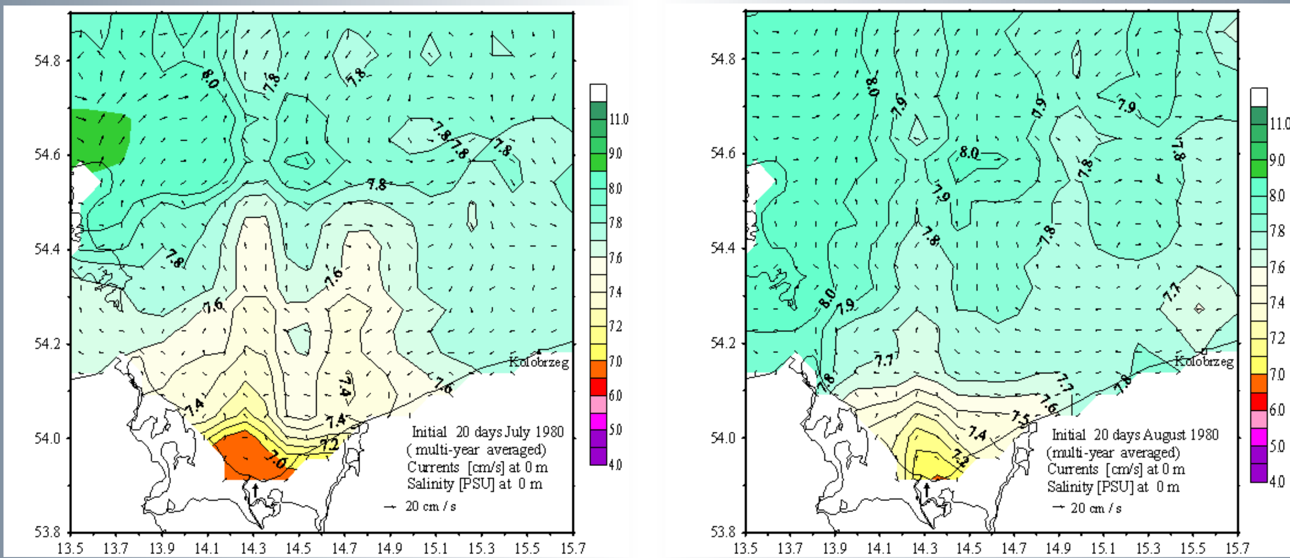

Figure 7 Pomeranian Bay - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) at the end of the first (initial) stage of calculation) - after 20 days of simulations without wind and river runoff: (left figure) July ; (right figure) August.

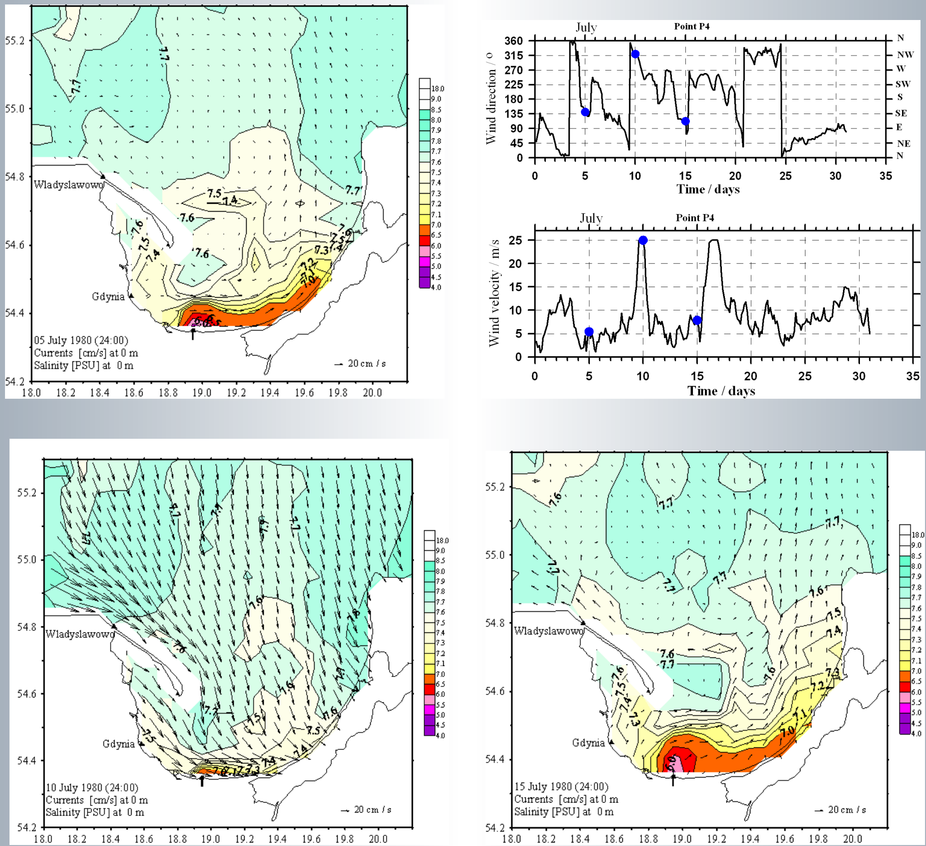

Figure 8a The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.07.1980 to 30.07.1980:
(left upper figure) - on 05.07.1980; (left lower figure) - on 10.07.1980; (right lower figure) - on 15.07.1980; (right upper figure) - time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

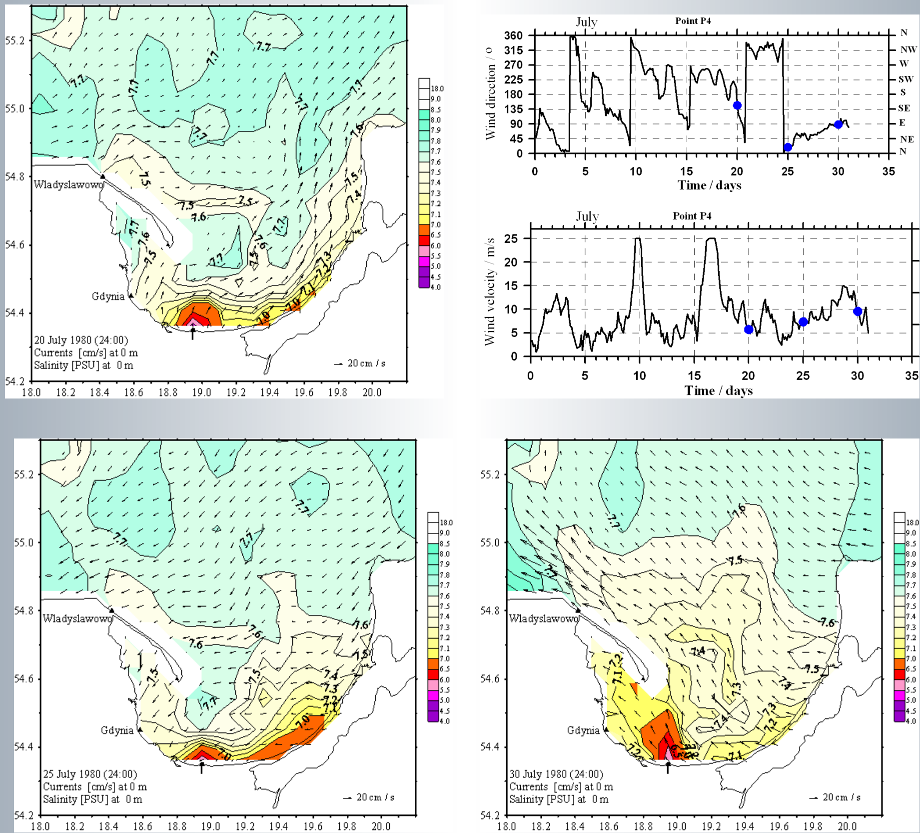

Figure 8b The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.07.1980 to 30.07.1980:
(left upper figure) - on 20.07.1980; (left lower figure) - on 25.07.1980; (right lower figure) - on 30.07.1980; (right upper figure) - time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

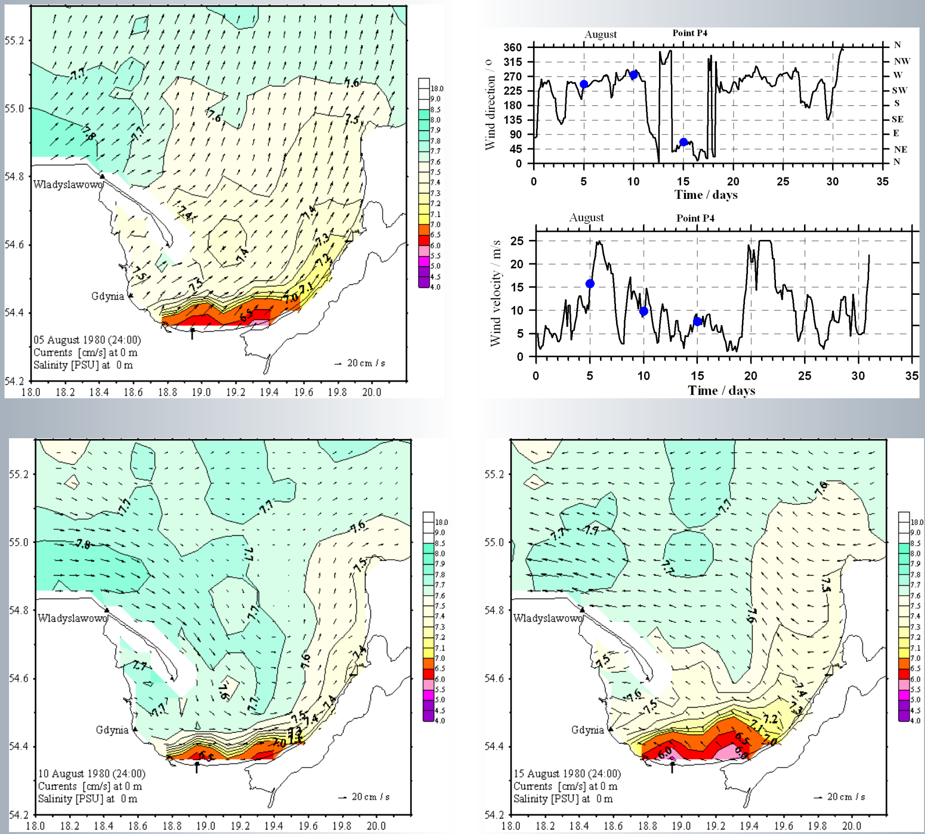

Figure 9a The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.08.1980 to 30.08.1980:
(left upper figure) - on 05.08.1980; (left lower figure) - on 10.08.1980; (right lower figure) - on 15.08.1980; (right upper figure) - time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

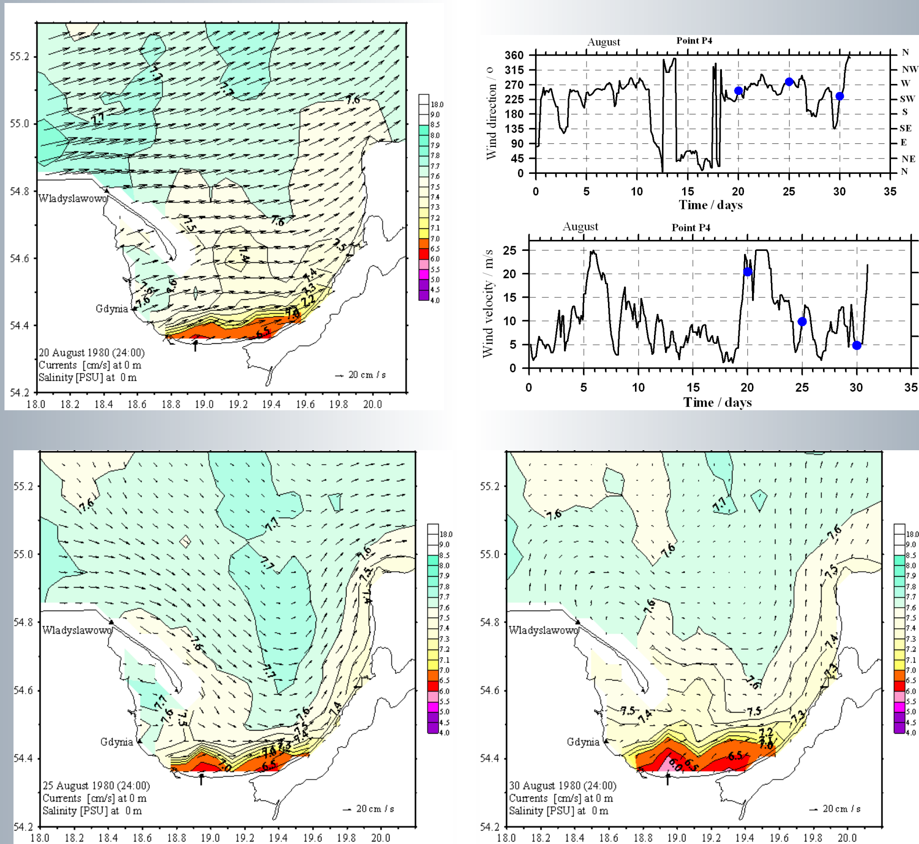

Figure 9b The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 20.08.1980 to 30.08.1980:
(left upper figure) - on 20.08.1980; (left lower figure) - on 25.08.1980; (right lower figure) - on 30.08.1980; (right upper figure) - time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

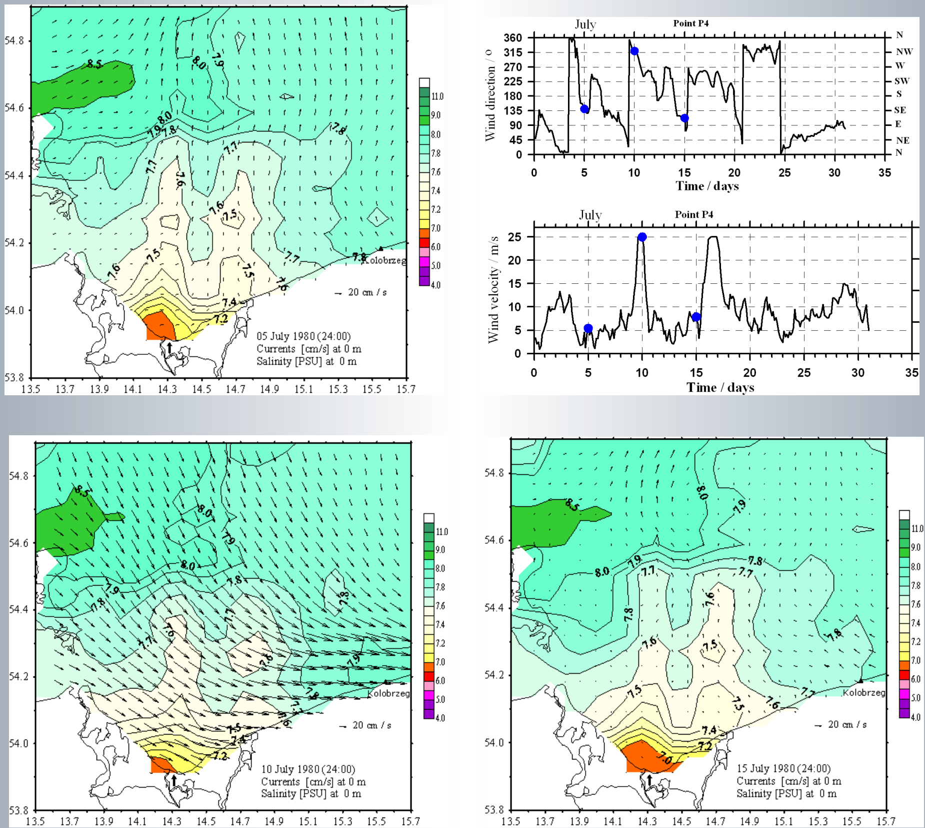

Figure 10a The Pomeranian Bay - simulated seawater salinity [PSU] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.07.1980 to 30.07.1980:
(left upper figure) - on 05.07.1980; (left lower figure) - on 10.07.1980; (right lower figure) - on 15.07.1980; (right upper figure) - time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

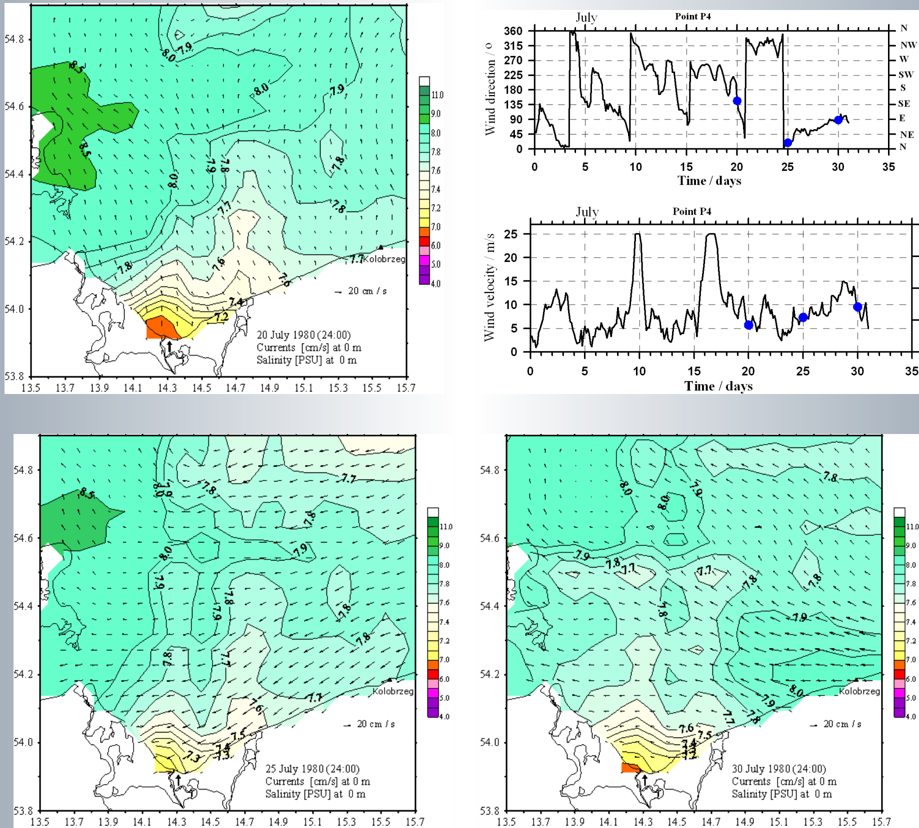

Figure 10b The Pomeranian Bay - simulated seawater salinity [PSU] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.07.1980 to 30.07.1980:
(left upper figure) - on 20.07.1980; (left lower figure) - on 25.07.1980; (right lower figure) - on 30.07.1980; (right upper figure) -time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

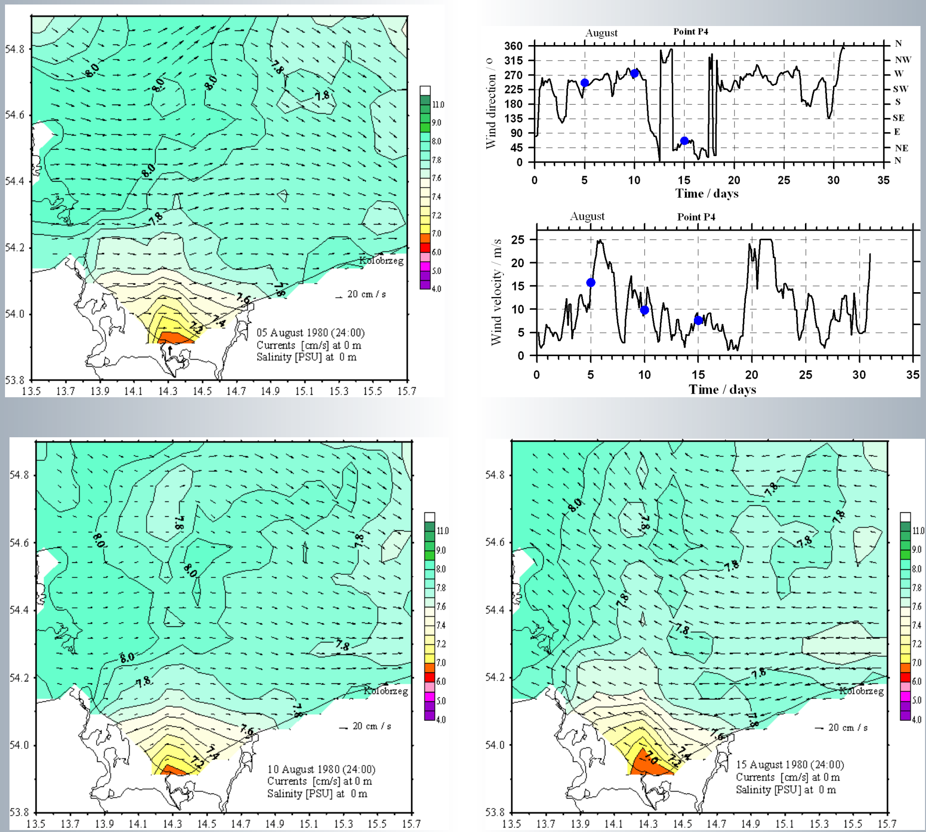

Figure 11a The Pomeranian Bay - simulated seawater salinity [PSU] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.08.1980 to 30.08.1980:
(left upper figure) - on 05.05.1980; (left lower figure) - on 10.08.1980; (right lower figure) - on 15.08.1980; (right upper figure) -time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

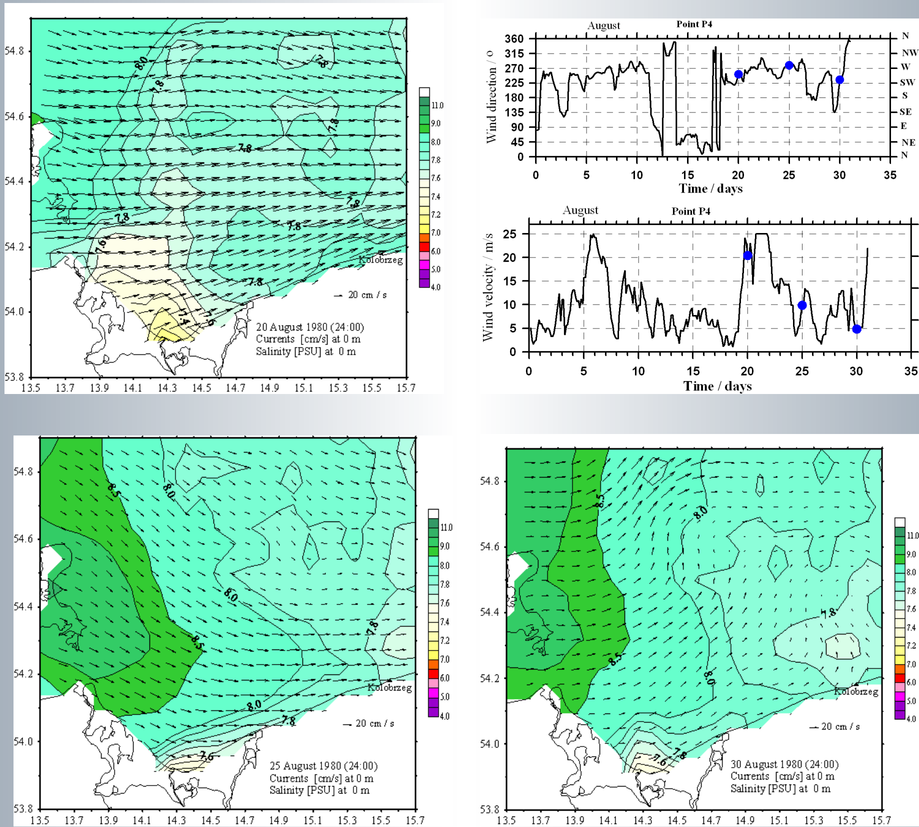

Figure 11b The Pomeranian Bay - simulated seawater salinity [PSU] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.08.1980 to 30.08.1980:
(left upper figure) - on 20.08.1980; (left lower figure) - on 25.08.1980; (right lower figure) - on 30.08.1980; (right upper figure) -time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

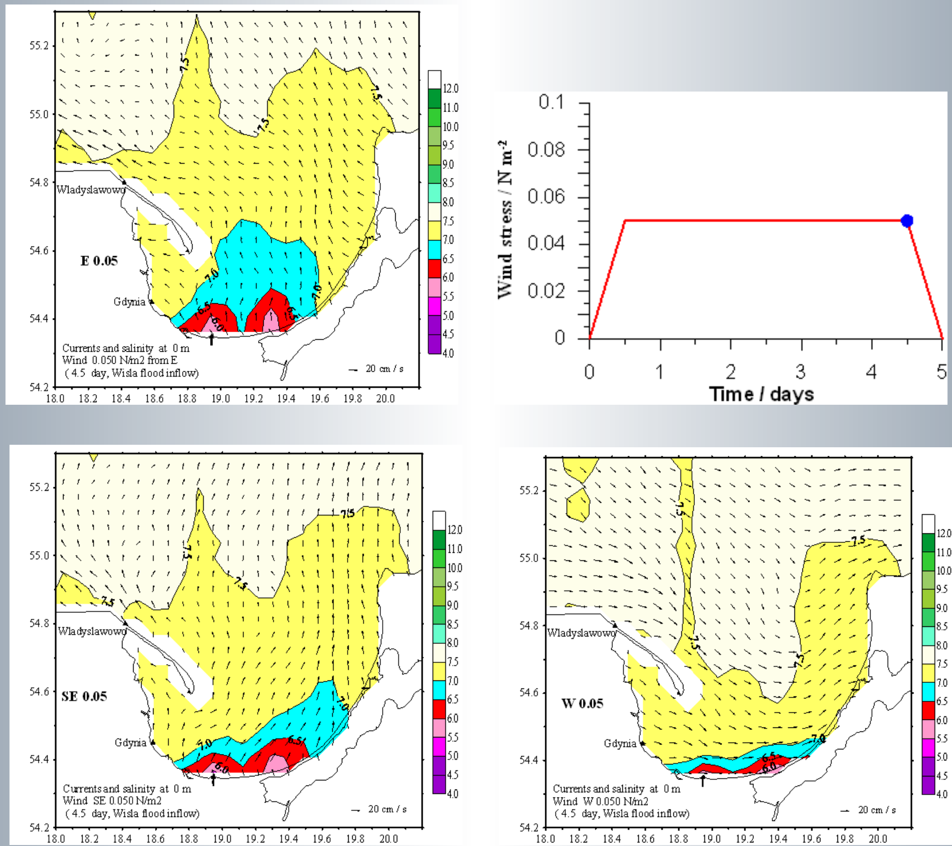

Figure 12 The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) after 4.5 days of simulation with homogeneous wind fields over the Baltic Sea with wind stress equal to 0.05 N/m^2 from direction: E (left upper figure), SE (left lower figure) and W (right lower figure), respectively. Time history of the wind stress N/m^2 is shown at right upper figure.

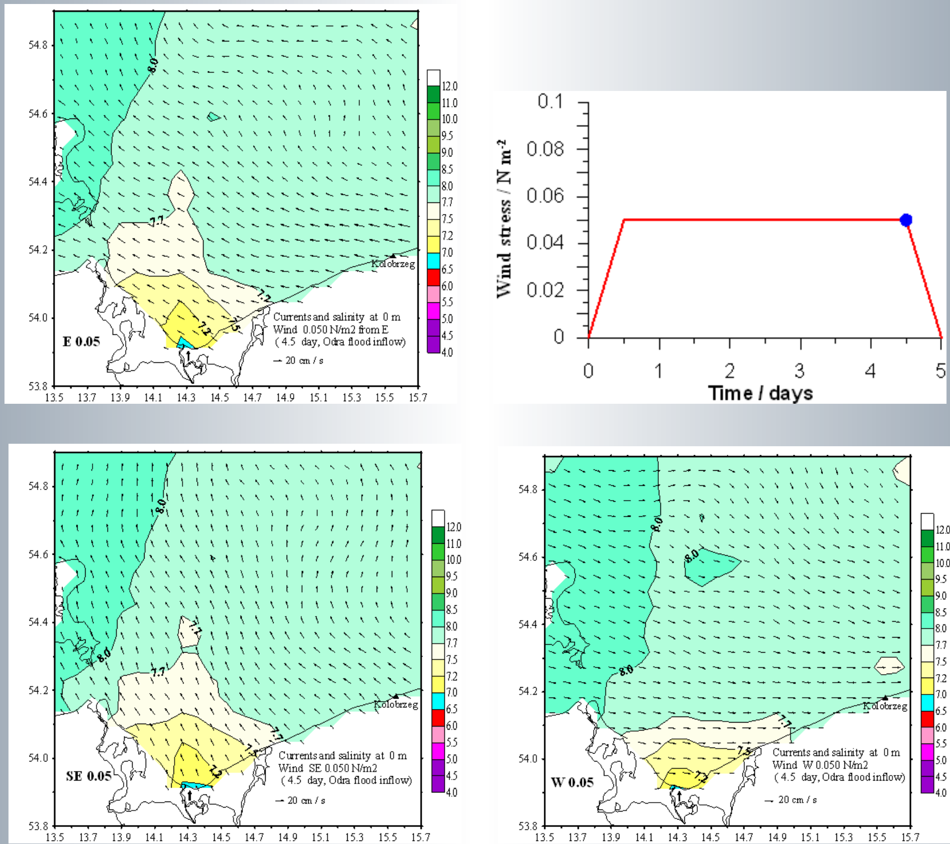

Figure 13 The Pomeranian Bay - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) after 4.5 days of simulation with homogeneous wind fields over the Baltic Sea with wind stress equal to 0.05 N/m^2 from direction: E (left upper figure), SE (left lower figure) and W (right lower figure), respectively. Time history of the wind stress N/m^2 is shown at right upper figure.

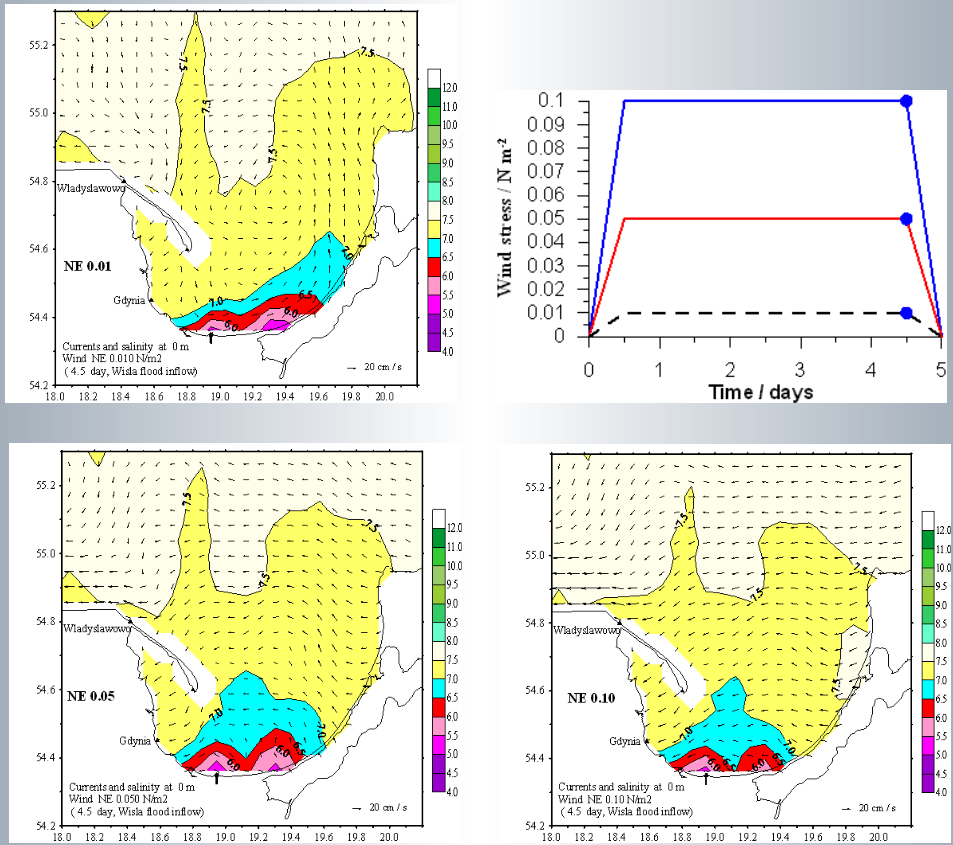

Figure 14 The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) after 4.5 days of simulation with homogeneous wind fields over the Baltic Sea blowing from NE with diffrent values of wind stress equal to: 0.01 N/m^2 (left upper figure), 0.05 N/m^2 (left lower figure) and 0.10 N/m^2 (right lower figure), respectively. Time history of the wind stress N/m^2 is shown at right upper figure.

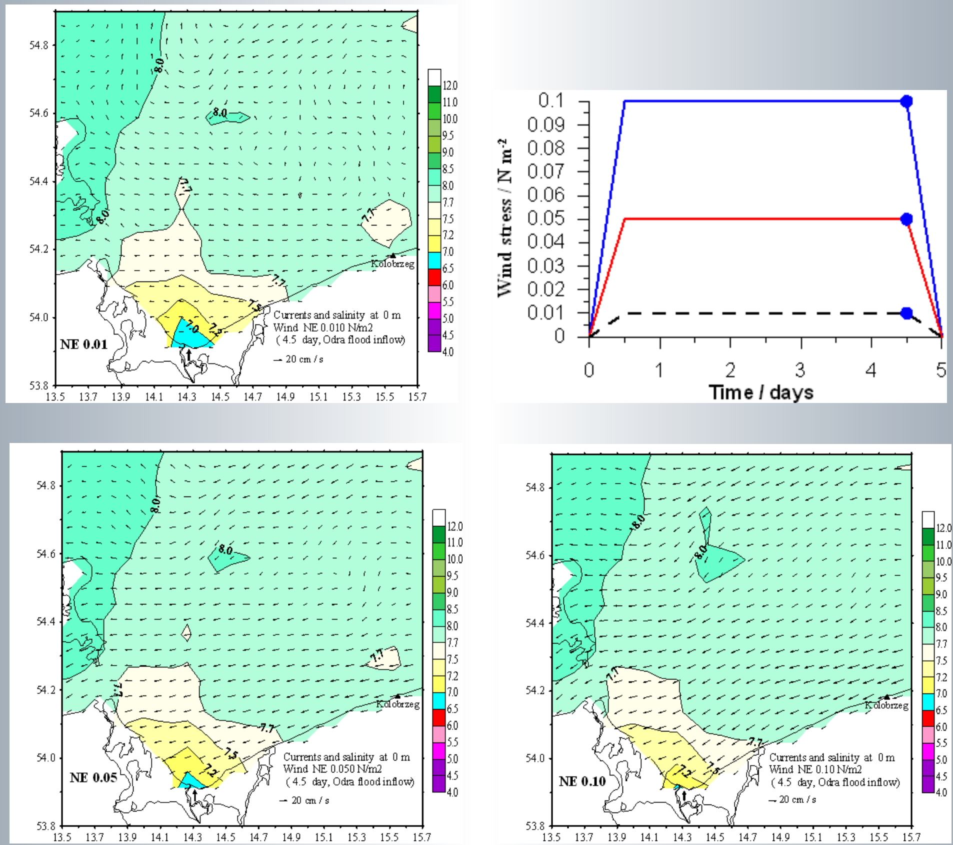

Figure 15 The Pomeranian Bay - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) after 4.5 days of simulation with homogeneous wind fields over the Baltic Sea blowing from NE with diffrent values of wind stress equal to: 0.01 N/m^2 (left upper figure), 0.05 N/m^2 (left lower figure) and 0.10 N/m^2 (right lower figure), respectively. Time history of the wind stress N/m^2 is shown at right upper figure.

Final comments

A 3D baroclinic model was applied to study wind- and river inflow-induced hydrodynamic conditions in the Gulf of Gdańsk and in the Pomeranian Bay for summer period. The model was forced by the uniform in space wind fields and the river runoff rates of the main 31 rivers (assumed as yearly means) as well as with real atmospheric forcings in July and August 1980. Only for the Vistula River and Odra River values related to the flood values were used. The sea water salinity was used as a natural tracer for visualization of spreading of riverine waters in the both bays.

The results of the numerical experiments visualize the patterns of weak saline surface water (riverine plume) propagation on their way from the Vistula River and the Odra River mouths toward the open boundary of the Gulf of Gdańsk and the Pomeranian Bay, respectively. The results of simulations showed that the surface water plume can be particularly sensitive to the wind stress values as well as to its variability in space and time.

In general response of surface waters to river run-off and winds are in agreement with in situ measurements (e.g. Cyberska 1989, Cyberska and Krzyminski 1988) in a case of the Gulf of Gdansk and Siegel et al. (1998); Lass et al. (2001) - in the case of the Pomeranian Bay; as well as with theoretical and numerical investigations (cf. Fennel and Mutzke 1997, Robakiewicz and Walkowiak 1998), and Siegel et al., 1999).

In companion files to this presentation more detailed visualization of the results of simulations is presented in form of animated gifs files:

atm_pressure_jul80.gif and **atm_pressure_aug80.gif** - present the anemobaric situation above the Baltic Sea in July and August 1980 in a time sequence of 1 day,

Gbay_jul80.gif and **Gbay_aug80.gif** - present the distribution of the surface salinity and currents at the 0 m (in the surface layer) in the Gulf of Gdańsk during the flood event in July and August 1980 in a time sequence of 1 day,

Pbay_jul80.gif and **Pbay_aug80.gif** - present the distribution of the surface salinity and currents at the 0 m (in the surface layer) in the Pomeranian Bay during the flood event in July and August 1980 in a time sequence of 1 day.

It is believed that results of the numerical simulation and model visualization help to understand the distribution and temporally changes of the surface waters as well as the hydrodynamics of the river plume during the flood event in different wind conditions.

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Figures captions

Figure 1 Location of the Pomeranian Bay and the Gulf of Gdansk in the Baltic Sea (left panel) and bottom topography in the Southern Baltic (right panel). Numbers on isolines indicate depth in meters. Symbol P4 indicates location of point used to visualize wind variability. Bottom topography was elaborated based on data from Seifert and Kayser (1995).
Arrows indicate location of the mouths of the Wisła river and the Odra river (Swina).

Figure 2 Monthly mean river discharge (1975-1985) of the Vistula (left figure) and the Odra (right figure) river, respectively. Data based on Vorosmarty et al. 1998 (Data set, available on-line [http://www.daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A., http://www-eosdis.ornl.gov/RIVDIS/rivdis.html

Figure 3 Anemobaric situation above the Baltic Sea related to the flood event in the Southern Baltic in July 1980 in a time sequence of 5 days (on selected days 05.07.1980 to 30.07.1980). Data taken from (BED, 2000)). Isobars in [hPa].

Figure 4 Anemobaric situation above the Baltic Sea related to the flood event in the Southern Baltic in August 1980 in a time sequence of 5 days (on selected days 05.08.1980 to 30.08.1980). Data taken from (BED, 2000)). Isobars in [hPa].

Figure 6 The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) at the end of the first (initial) stage of calculation) - after 20 days of simulations without wind and river runoff: (left figure) July ; (right figure) August

Figure 7 Pomeranian Bay - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) at the end of the first (initial) stage of calculation) - after 20 days of simulations without wind and river runoff: (left figure) July ; (right figure) August.

Figure 8a The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.07.1980 to 30.07.1980:
(left upper figure) - on 05.07.1980; (left lower figure) - on 10.07.1980; (right lower figure) - on 15.07.1980; (right upper figure) - time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

Figures captions ... continued

Figure 8b The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.07.1980 to 30.07.1980:
(left upper figure) - on 20.07.1980; (left lower figure) - on 25.07.1980; (right lower figure) - on 30.07.1980; (right upper figure) - time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

Figure 9a The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.08.1980 to 30.08.1980:
(left upper figure) - on 05.08.1980; (left lower figure) - on 10.08.1980; (right lower figure) - on 15.08.1980; (right upper figure) - time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

Figure 9b The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 20.08.1980 to 30.08.1980:
(left upper figure) - on 20.08.1980; (left lower figure) - on 25.08.1980; (right lower figure) - on 30.08.1980; (right upper figure) - time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

Figure 10a The Pomeranian Bay - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.07.1980 to 30.07.1980:
(left upper figure) - on 05.07.1980; (left lower figure) - on 10.07.1980; (right lower figure) - on 15.07.1980; (right upper figure) - time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

Figure 10b The Pomeranian Bay - simulated seawater salinity [PSU] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.07.1980 to 30.07.1980:
left upper figure - on 20.07.1980; (left lower figure) - on 25.07.1980; (right lower figure) - on 30.07.1980; (right upper figure) -time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

Figures captions ... continued

Figure 11a The Pomeranian Bay - simulated seawater salinity [PSU] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.08.1980 to 30.08.1980:
(left upper figure) - on 05.08.1980; (left lower figure) - on 10.08.1980; (right lower figure) - on 15.08.1980; (right upper figure) -time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

Figure 11b The Pomeranian Bay - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) in a time sequence of 5 days from 05.08.1980 to 30.08.1980:
(left upper figure) - on 20.08.1980; (left lower figure) - on 25.08.1980; (right lower figure) - on 30.08.1980; (right upper figure) -time history of the wind direction and the wind velocity module at the point P4 (for its location see Fig. 1).

Figure 12 The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) after 4.5 days of simulation with homogeneous wind fields over the Baltic Sea with wind stress equal to 0.05 N/m^2 from direction: E (left upper figure), SE (left lower figure) and W (right lower figure), respectively. Time history of the wind stress N/m^2 is shown at right upper figure.

Figure 13 The Pomeranian Bay - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) after 4.5 days of simulation with homogeneous wind fields over the Baltic Sea with wind stress equal to 0.05 N/m^2 from direction: E (left upper figure), SE (left lower figure) and W (right lower figure), respectively. Time history of the wind stress N/m^2 is shown at right upper figure.

Figure 14 The Gulf of Gdansk - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) after 4.5 days of simulation with homogeneous wind fields over the Baltic Sea blowing from NE with diffrent values of wind stress equal to: 0.01 N/m^2 (left upper figure), 0.05 N/m^2 (left lower figure) and 0.10 N/m^2 (right lower figure), respectively. Time history of the wind stress N/m^2 is shown at right upper figure.

Figure 15 The Pomeranian Bay - simulated seawater salinity [psu] and currents vectors [cm/s] at 0 m depth (in surface layer) after 4.5 days of simulation with homogeneous wind fields over the Baltic Sea blowing from NE with diffrent values of wind stress equal to: 0.01 N/m^2 (left upper figure), 0.05 N/m^2 (left lower figure) and 0.10 N/m^2 (right lower figure), respectively. Time history of the wind stress N/m^2 is shown at right upper figure.