Riverine water influence in the Gulf of Gdańsk (Baltic Sea) under different wind conditions – by the σ –coordinate model

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Abstract

The Gulf of Gdańsk, situated in the southern part of the Gdańsk Basin, belongs to one of the Baltic's open gulfs. Its hydrological regime is formed by atmospheric forcing and, due to wide and deep 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 Vistula River, the biggest river in the region. The mixed river waters can be observed at the open boundary of the Gulf of Gdańsk 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.

Abstract cdn…

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 Gulf of Gdańsk. A three-dimensional sigma-coordinate Baltic Sea model, based on the Princeton Ocean Model code, was used to simulate wind- and river inflow-induced hydrodynamic conditions in the Gulf of Gdańsk.

Model has a horizontal resolution of 5 km and 24 sigma - levels in vertical and its domain comprises the whole Baltic with its main basins and a simplified boundary conditions of the radiation type were applied at the open boundary of the model in Skagerrak.

Abstract cdn…

The numerical experiments were started from a three-dimensional summer mean distribution of temperature and salinity.
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).

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 Gulf of Gdańsk.

Abstract cdn…

The results of the numerical experiments visualize the patterns of weak saline surface water (riverine plume) propagation on their way from the Vistula mouth toward the open boundary of the Gulf of Gdańsk.

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.

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

Model

code - based on the **P**rinceton **O**cean **M**odel (POM) (Blumberg and Mellor, 1987; Mellor, 1993), adapted to the Baltic Sea conditions

Physical characteristics

vertical coordinate - so-called terrain-following sigma – coordinate sigma = (z-η)/(H+η)

vertical eddy viscosity and diffusitivity - computed using Mellor and Yamada (1974; 1982) formulation

horizontal eddy viscosity and diffusivities - computed using Smagorinsky (1963) formulation

model extension: 8º 50' E - 30º 00' E; 53º 50' N - 65º 50' N

bottom topography - is based on data from Seifert and Kayser (1995).

horizontal resolution - 5 km

vertical resolution - 24 sigma - levels

Model - continuation ...

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 homogeneous wind fields

First stage - model initialization - 20 days
forcings:
wind field - no wind
thermohaline - no heat and salt fluxes at the sea surface, temperature and salinity fields fixed

river runoff – now river inflow

initial fields:
real climatic termohaline fields
velocity components and sea level = 0

Simulations with homogeneous wind fields - continuation ...

Second stage - prognostic simulations (5 days)

forcings:

wind field - homogeneous fields with wind stress equal to 0.25, 0.5 and 1 dyne/ cm^2;
winds from 8 directions (N, E, S, W, NE, NW, SW, SE)

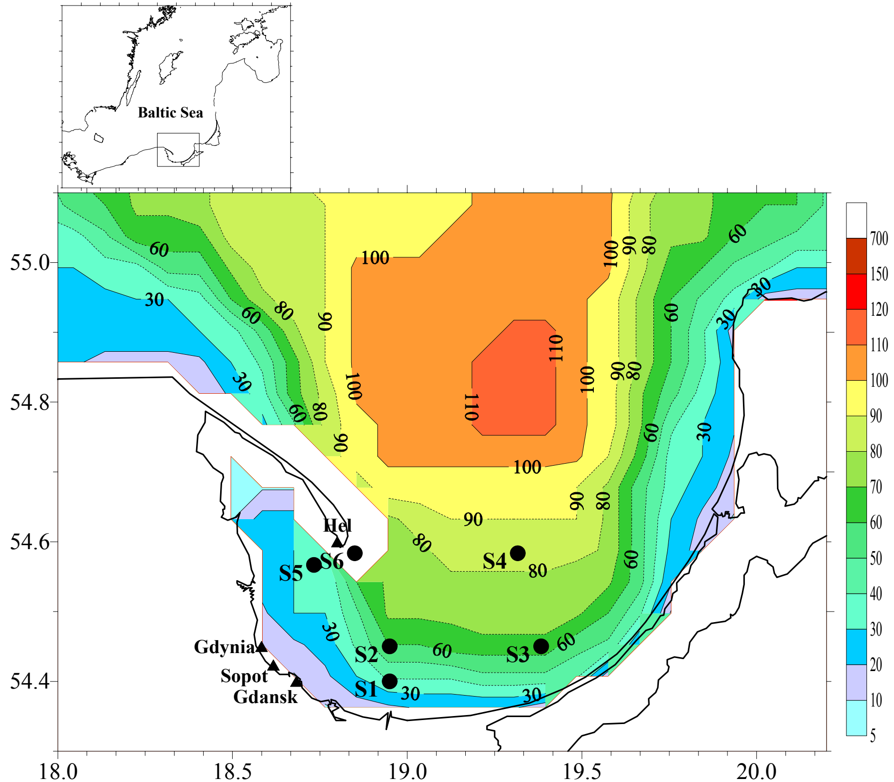
thermohaline - no heat and salt fluxes at the sea surface, only "relaxation to climatology" (Lehmann, 1995; Svendsen et al., 1996)

river runoff - yearly means of the 31 main rivers
(Odra and Vistula rivers: 1-3 times yearly-means)

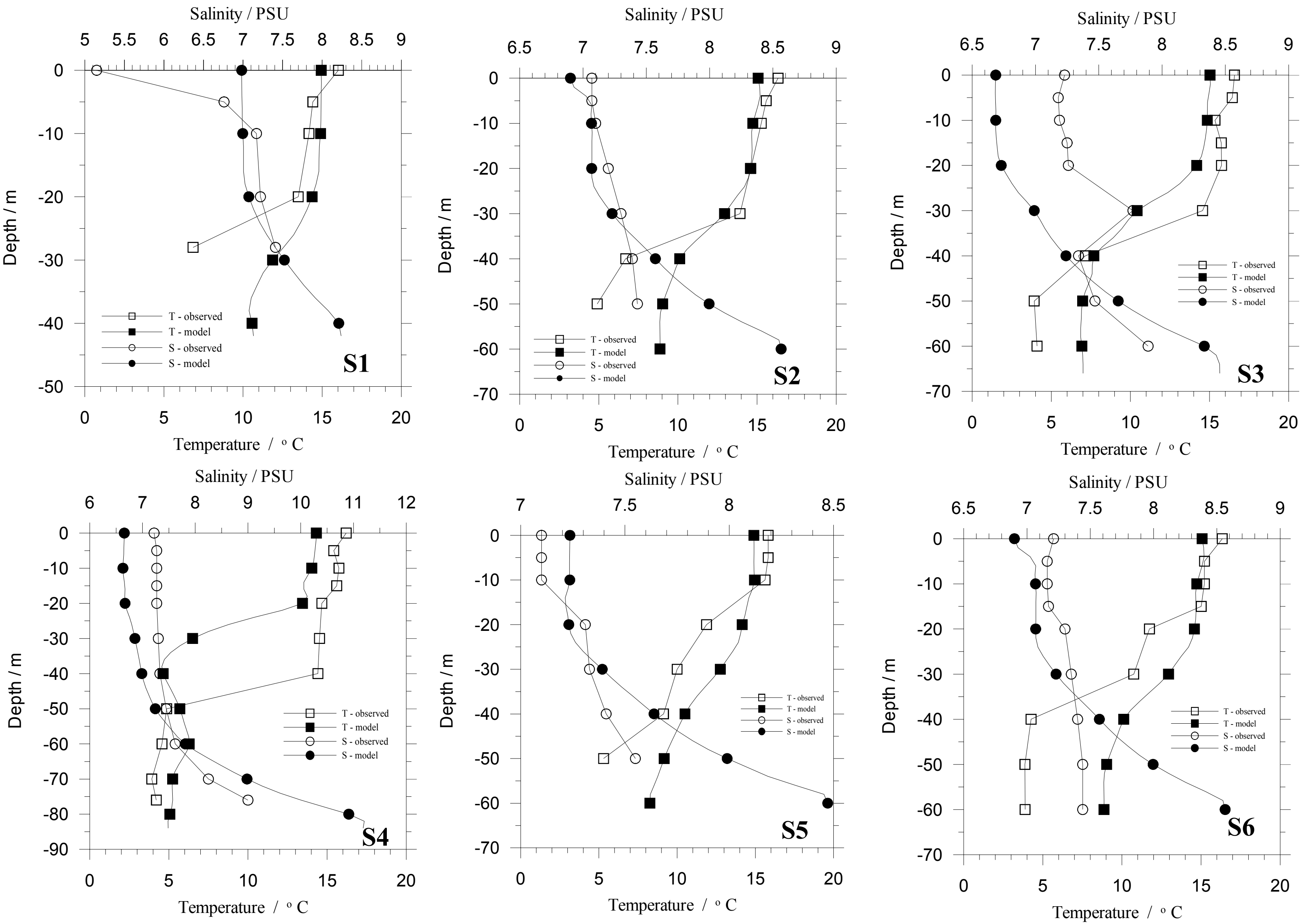
initial fields: output from the first stage

Data

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

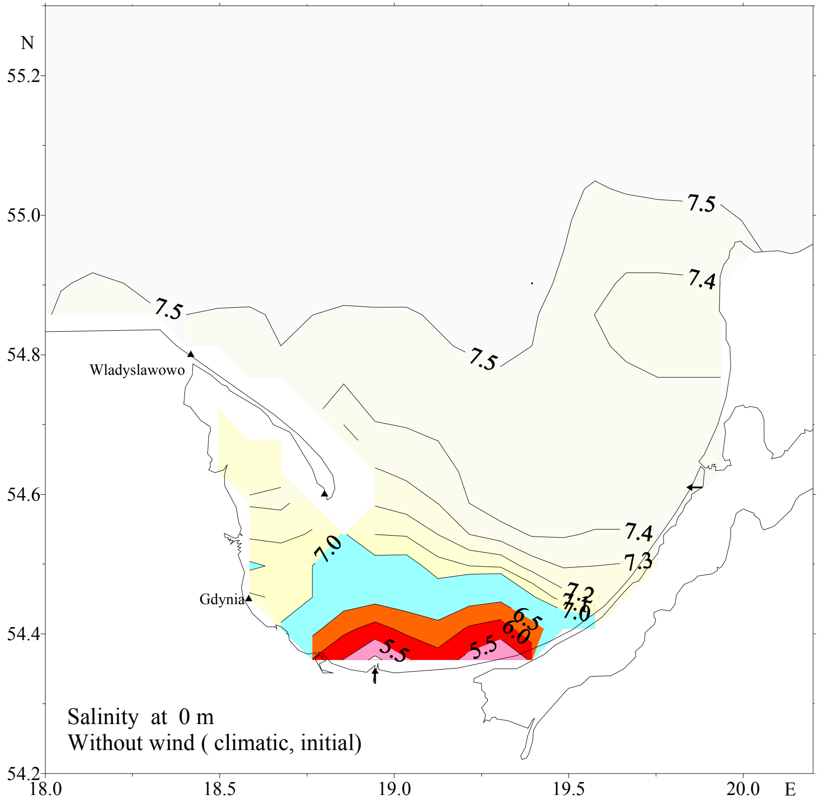


Bottom topography in the Southeastern Baltic. Numbers on isolines indicate depth in meters. Points S1-S6 indicate locations of selected points used to compare the modelled and measured T,S data

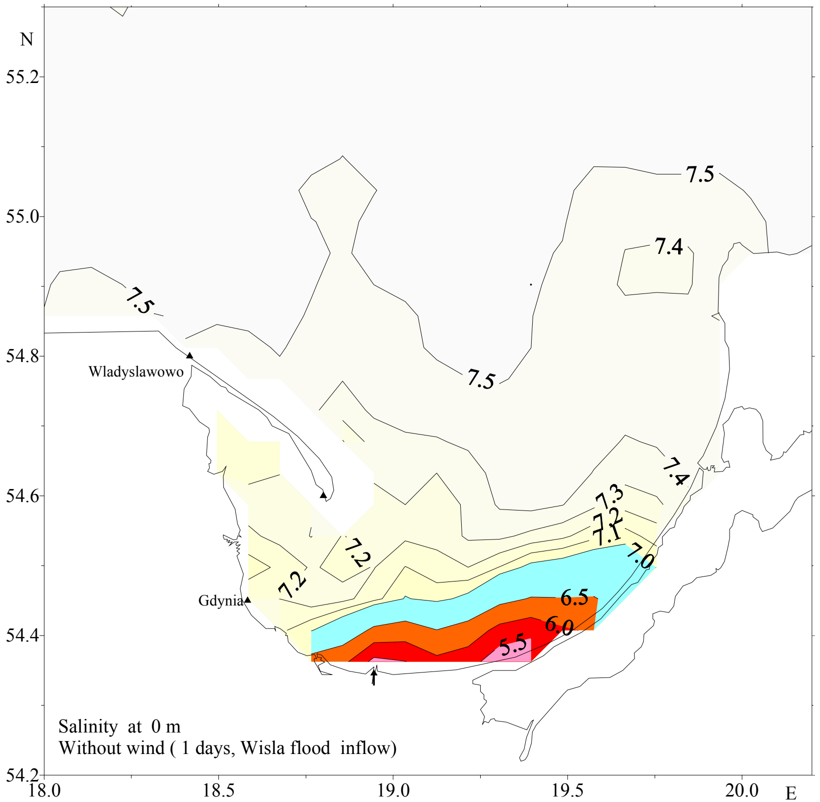


Modelled and *in situ* measured temperature and salinity at selected points

Response to river run-off



Simulated surface water salinity [PSU] in a time sequence of 1 day.
Run 1: Without wind, only Vistula flood inflow . Day 0



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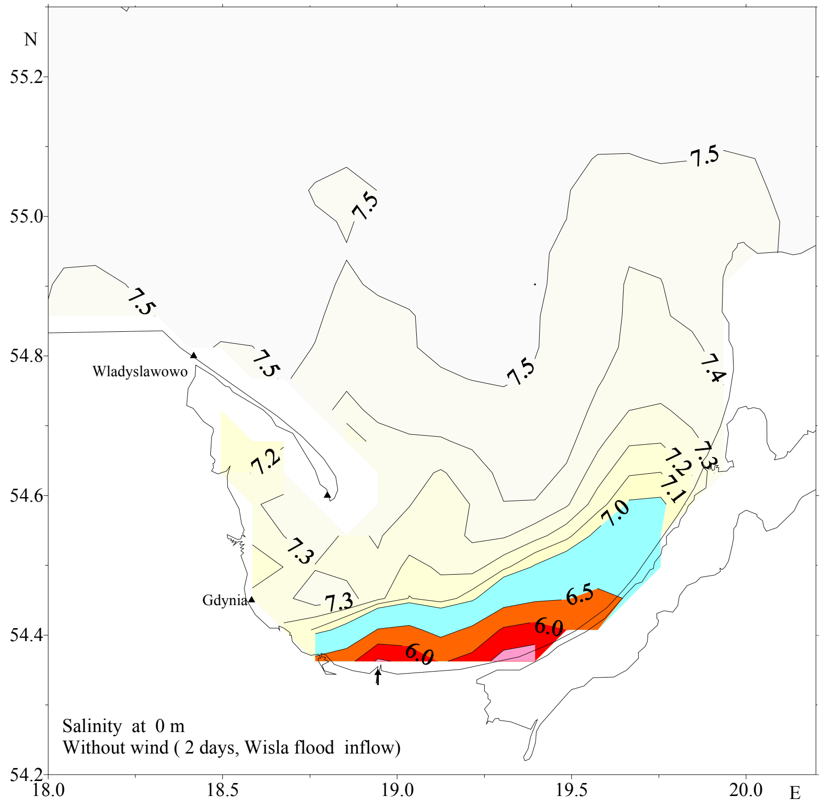
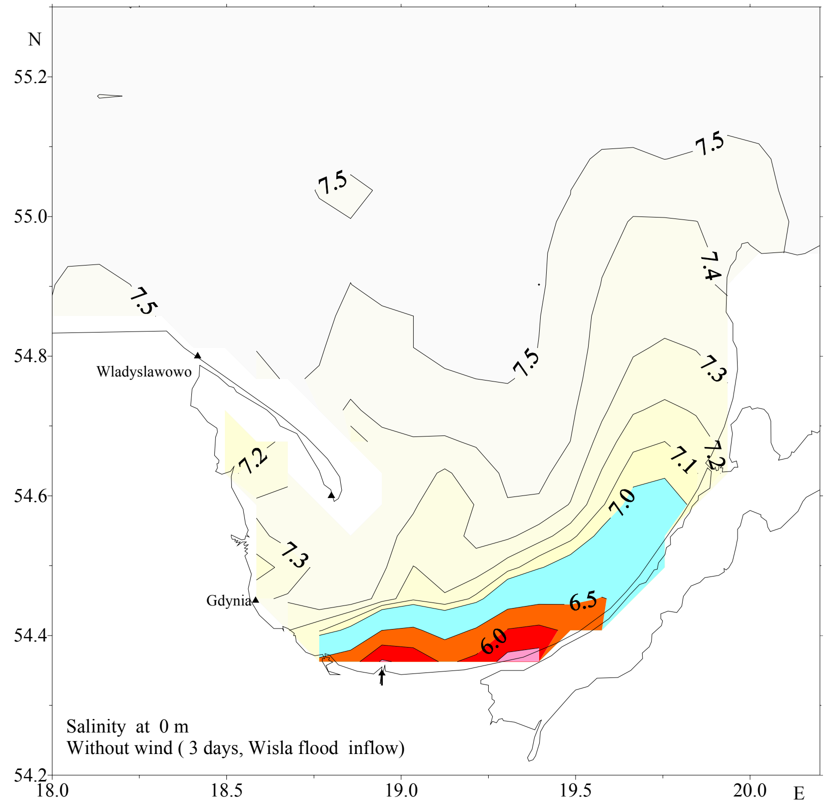
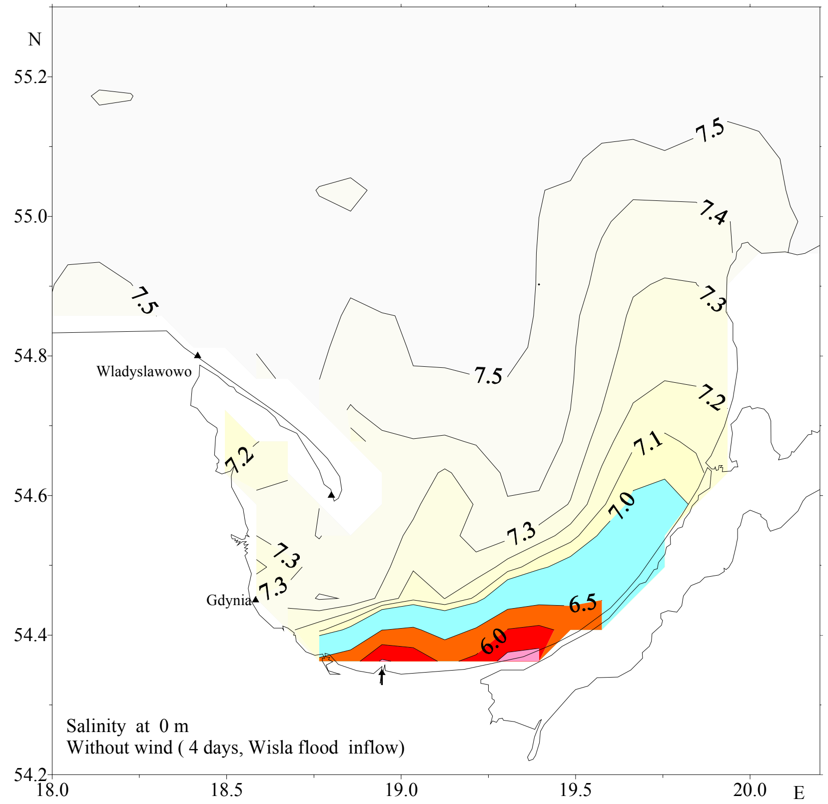
Run 1: Without wind, only Vistula flood inflow. Day 1



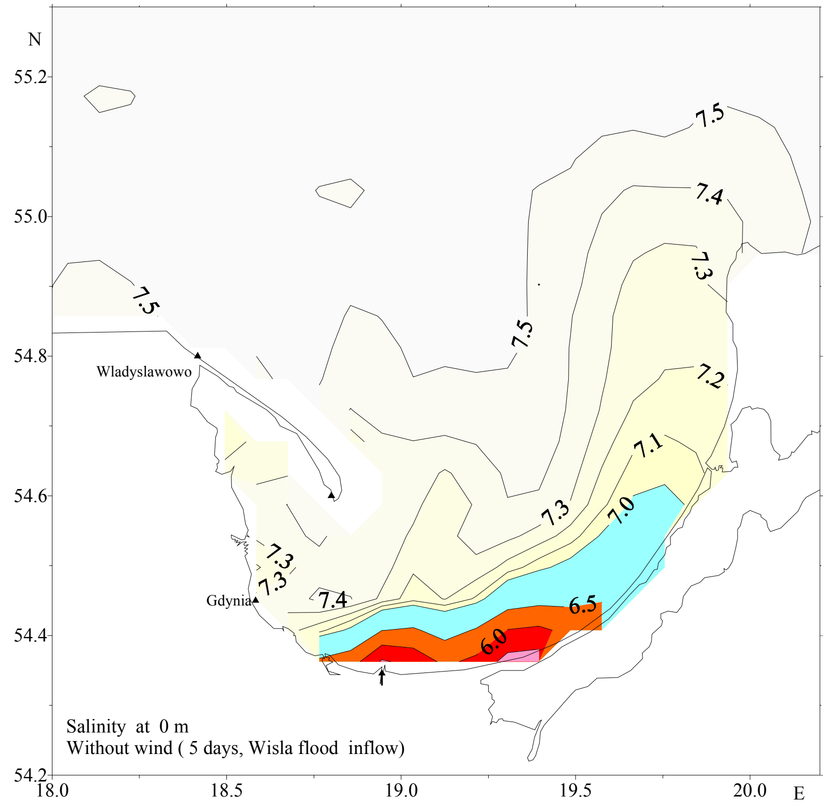
Simulated surface water salinity [PSU] in a time sequence of 1 day.
Run 1: Without wind, only Vistula flood inflow. Day 2



Simulated surface water salinity [PSU] in a time sequence of 1 day.
Run 1: Without wind, only Vistula flood inflow. Day 3

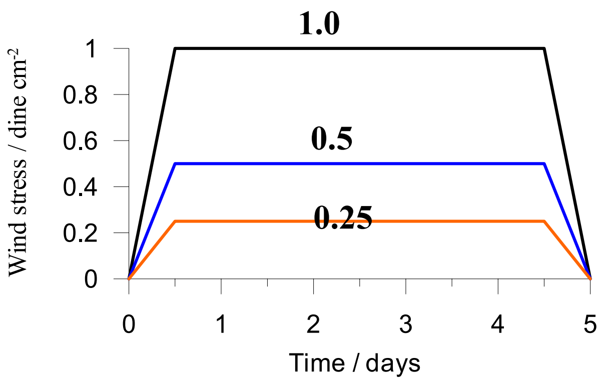


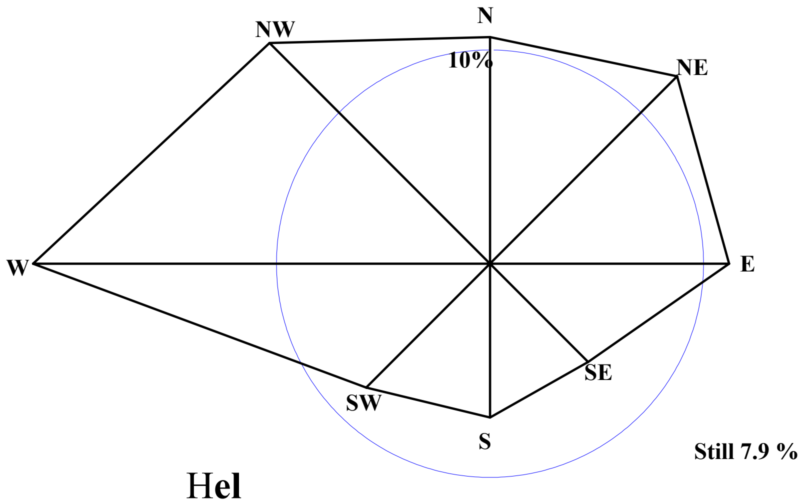
Simulated surface water salinity [PSU] in a time sequence of 1 day.
Run 1: Without wind, only Vistula flood inflow. Day 4

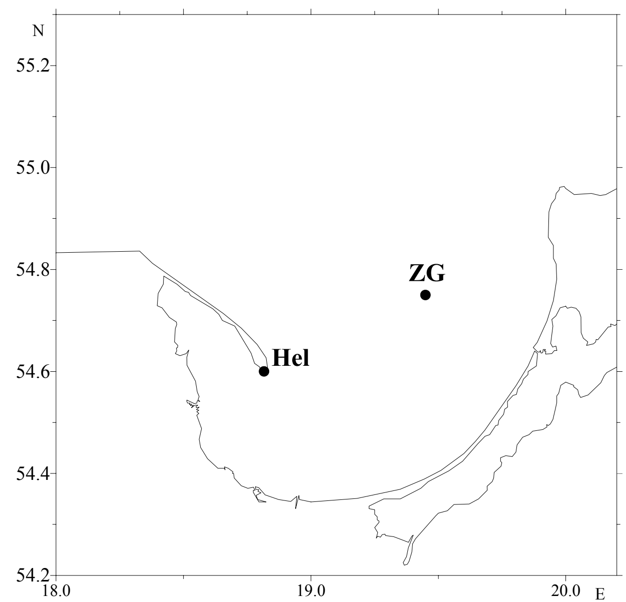


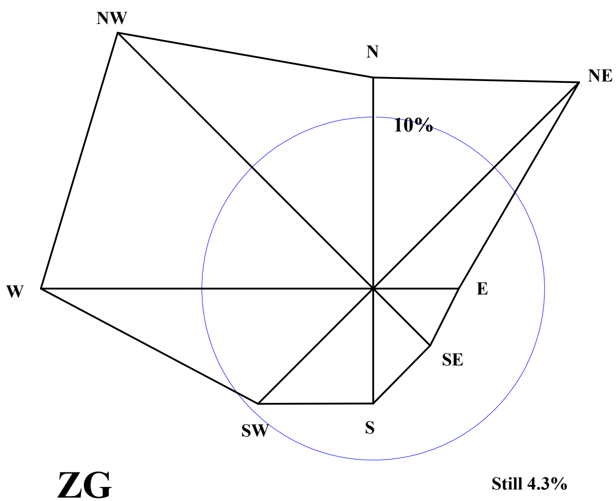
Simulated surface water salinity [PSU] in a time sequence of 1 day.
Run 1: Without wind, only Vistula flood inflow. Day 5

Response to winds and river run-off

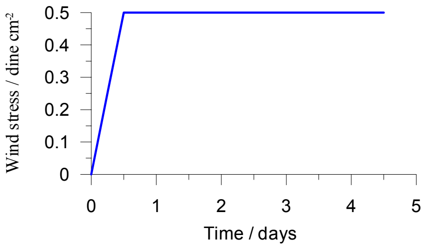


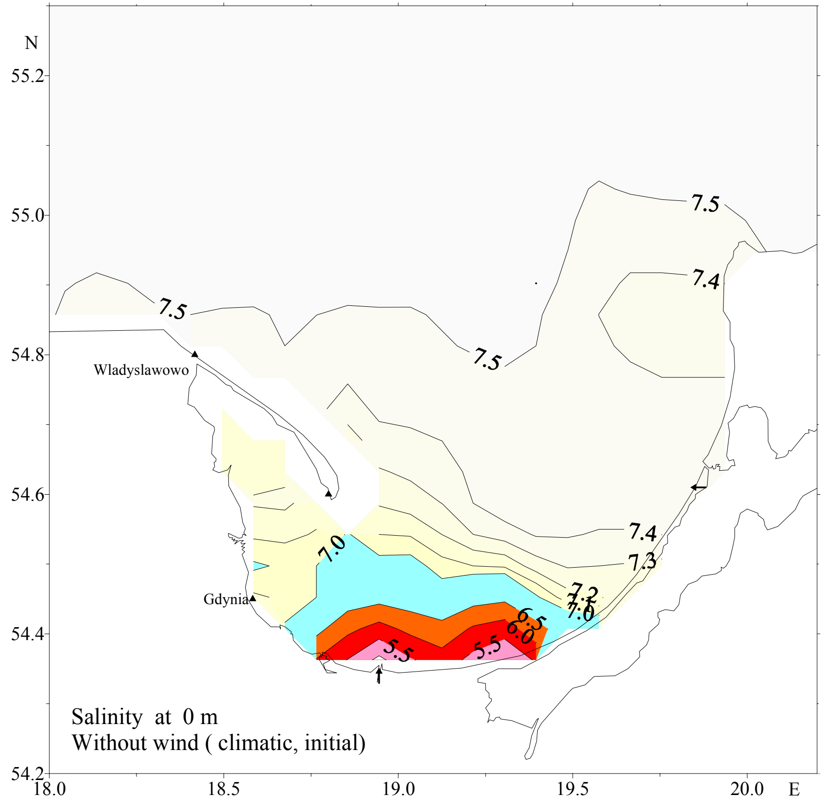




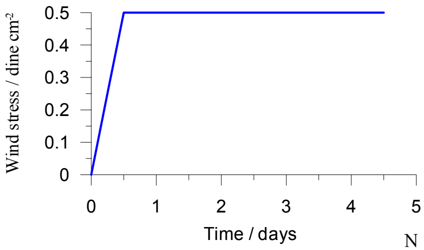


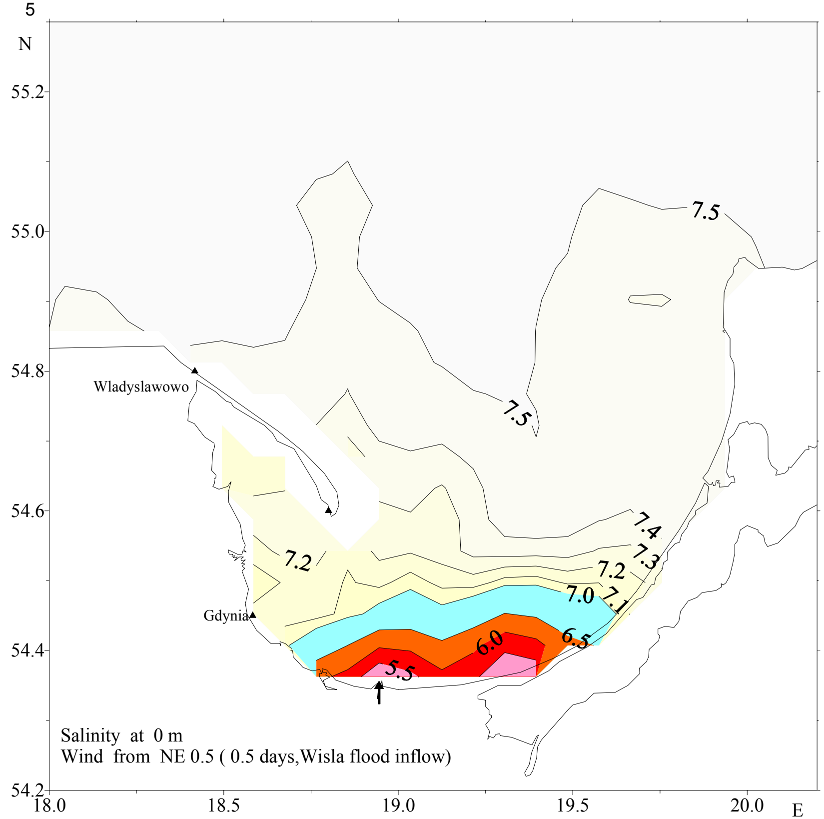
Frequency of wind direction [%] in summer period (VI-VIII) 1951-1975 (Majewski, 1990)



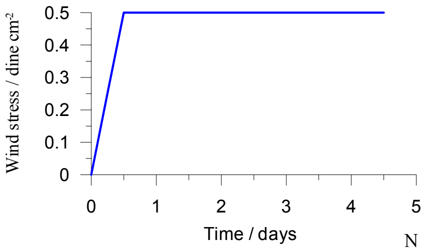


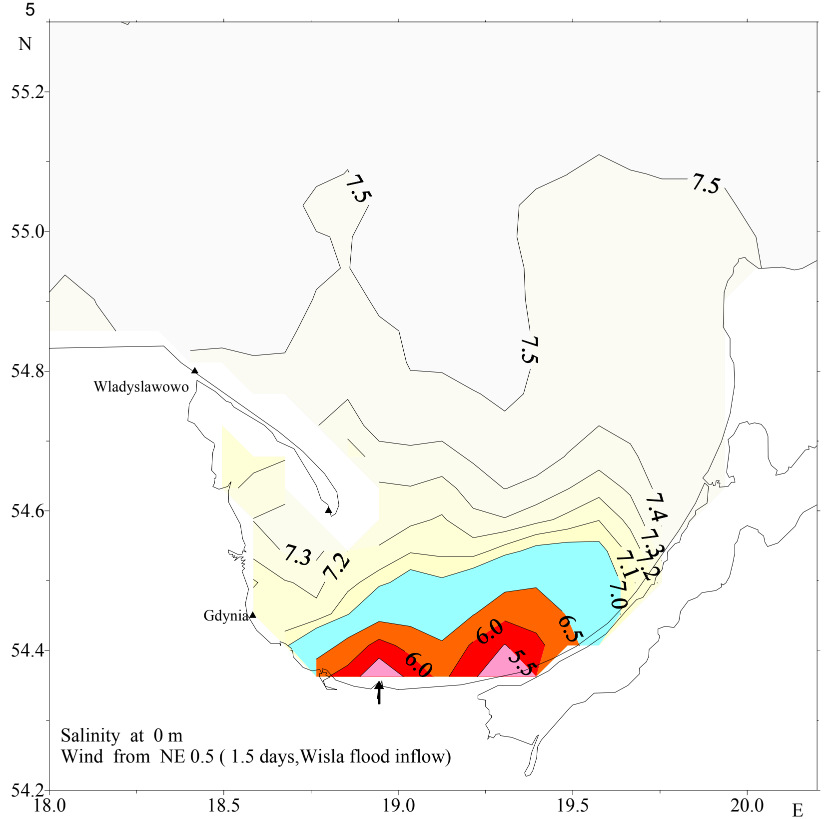
Simulated surface water salinity [PSU] in a time sequence of 1 day.
Run 2: Wind from NE 0.5, Vistula flood inflow. Day 0



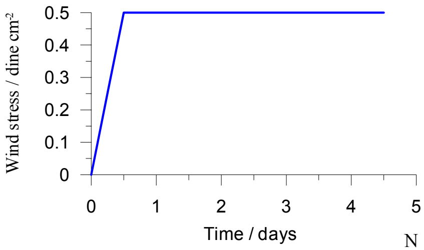


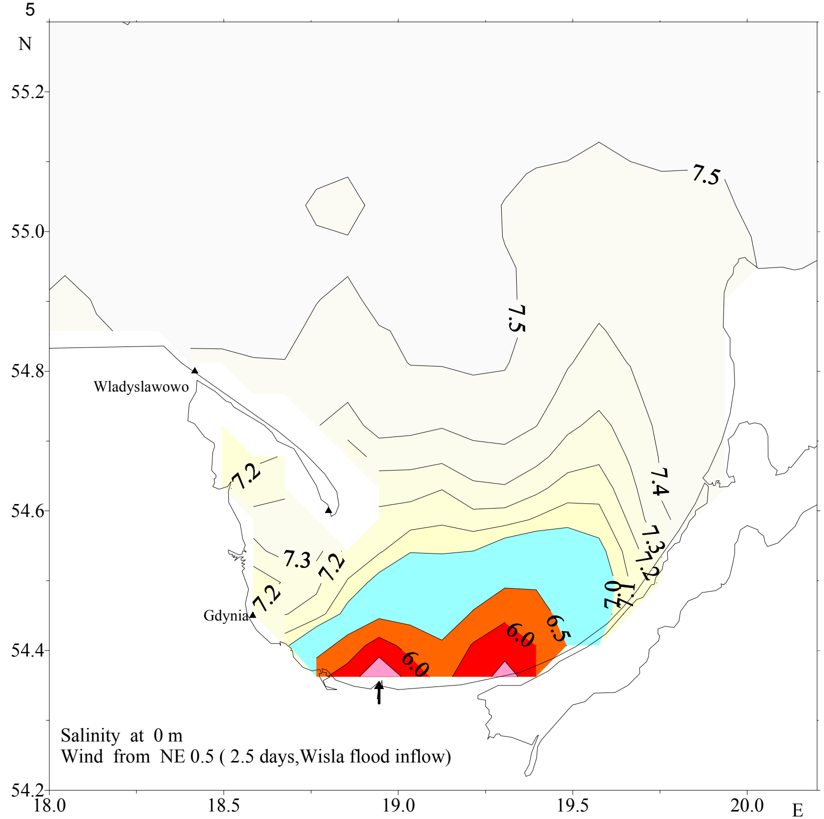
Simulated surface water salinity [PSU] in a time sequence of 1 day.
Run 2: Wind from NE 0.5, Vistula flood inflow. Day 0.5



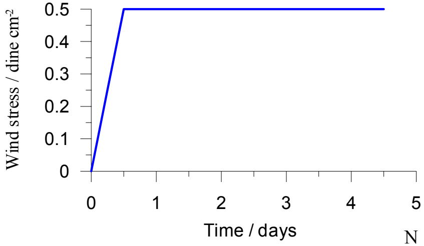


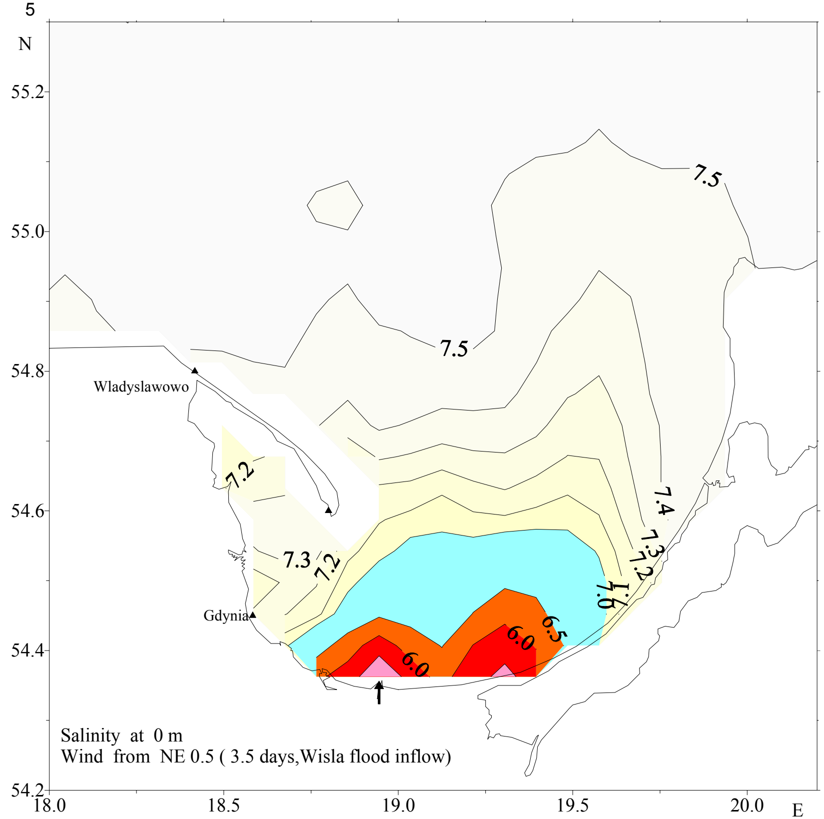
Simulated surface water salinity [PSU] in a time sequence of 1 day.
Run 2: Wind from NE 0.5, Vistula flood inflow. Day 1.5



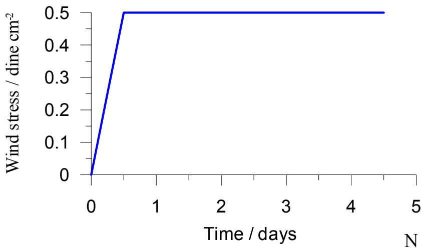


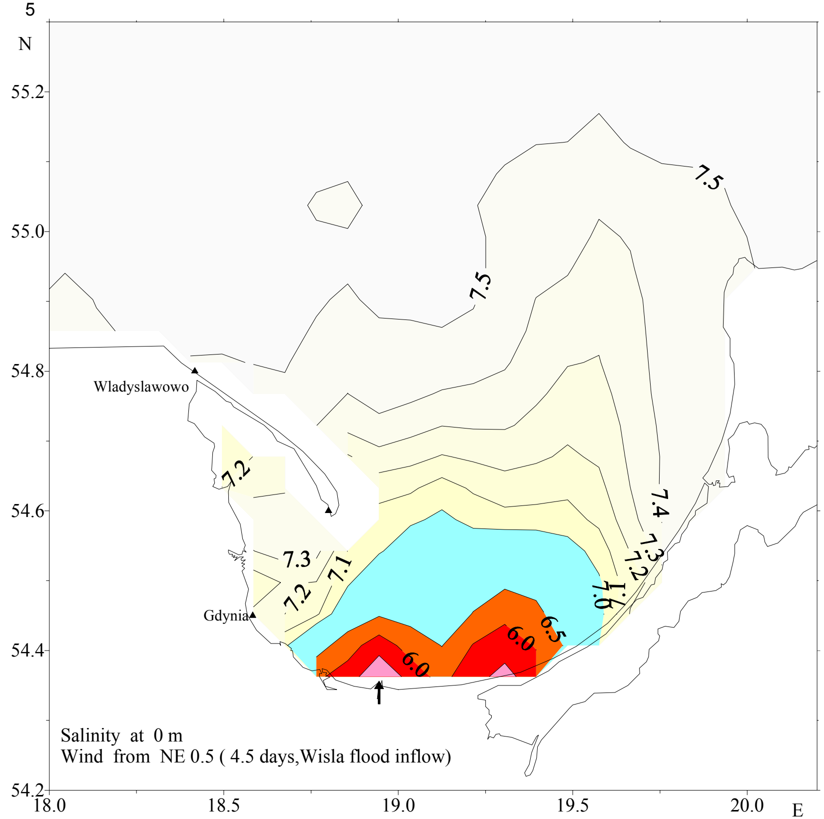
Simulated surface water salinity [PSU] in a time sequence of 1 day.
Run 2: Wind from NE 0.5, Vistula flood inflow. Day 2.5



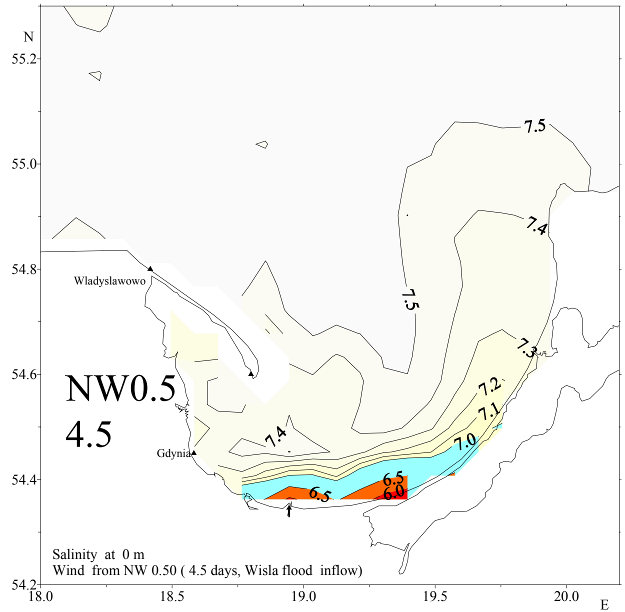


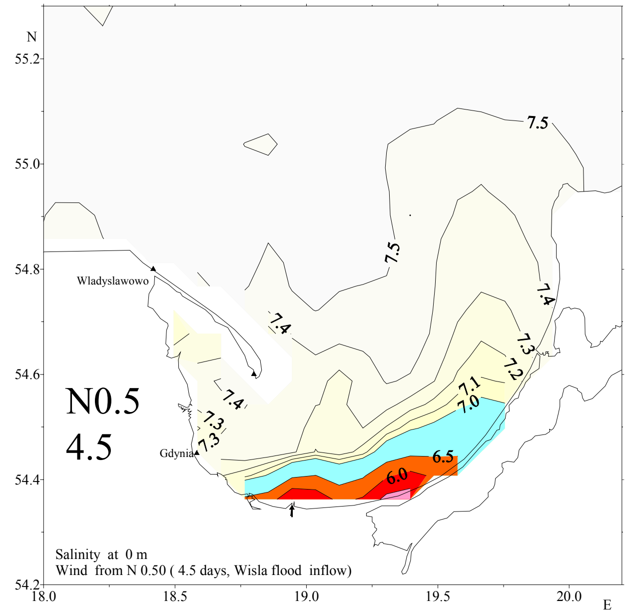
Simulated surface water salinity [PSU] in a time sequence of 1 day.
Run 2: Wind from NE 0.5, Vistula flood inflow. Day 3.5

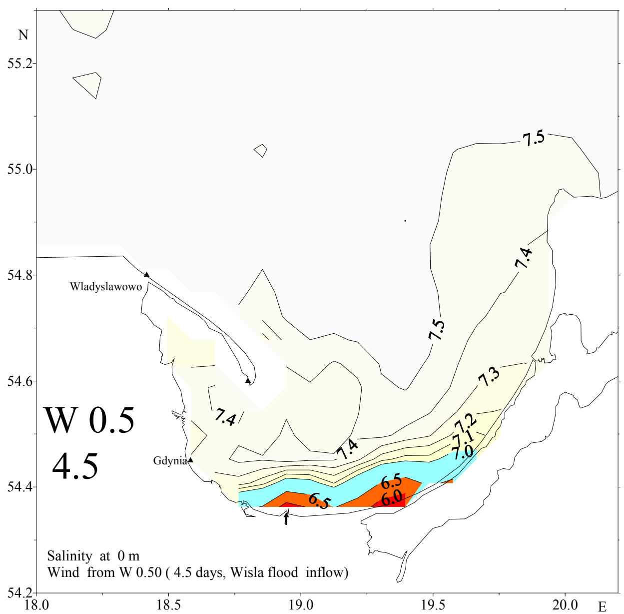


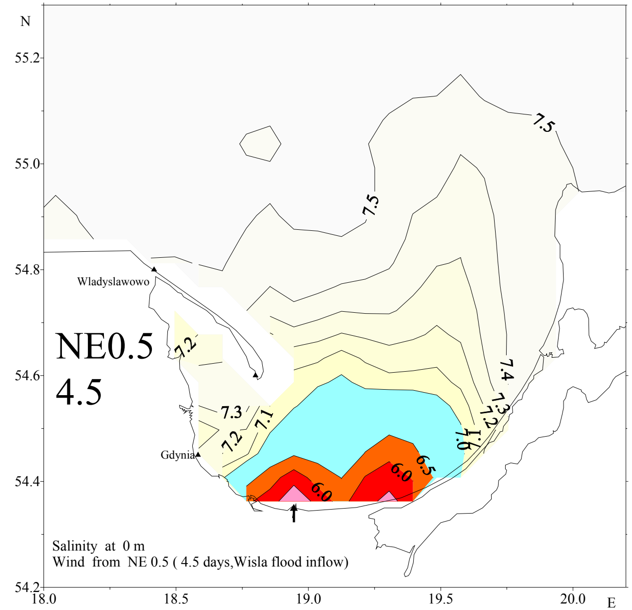


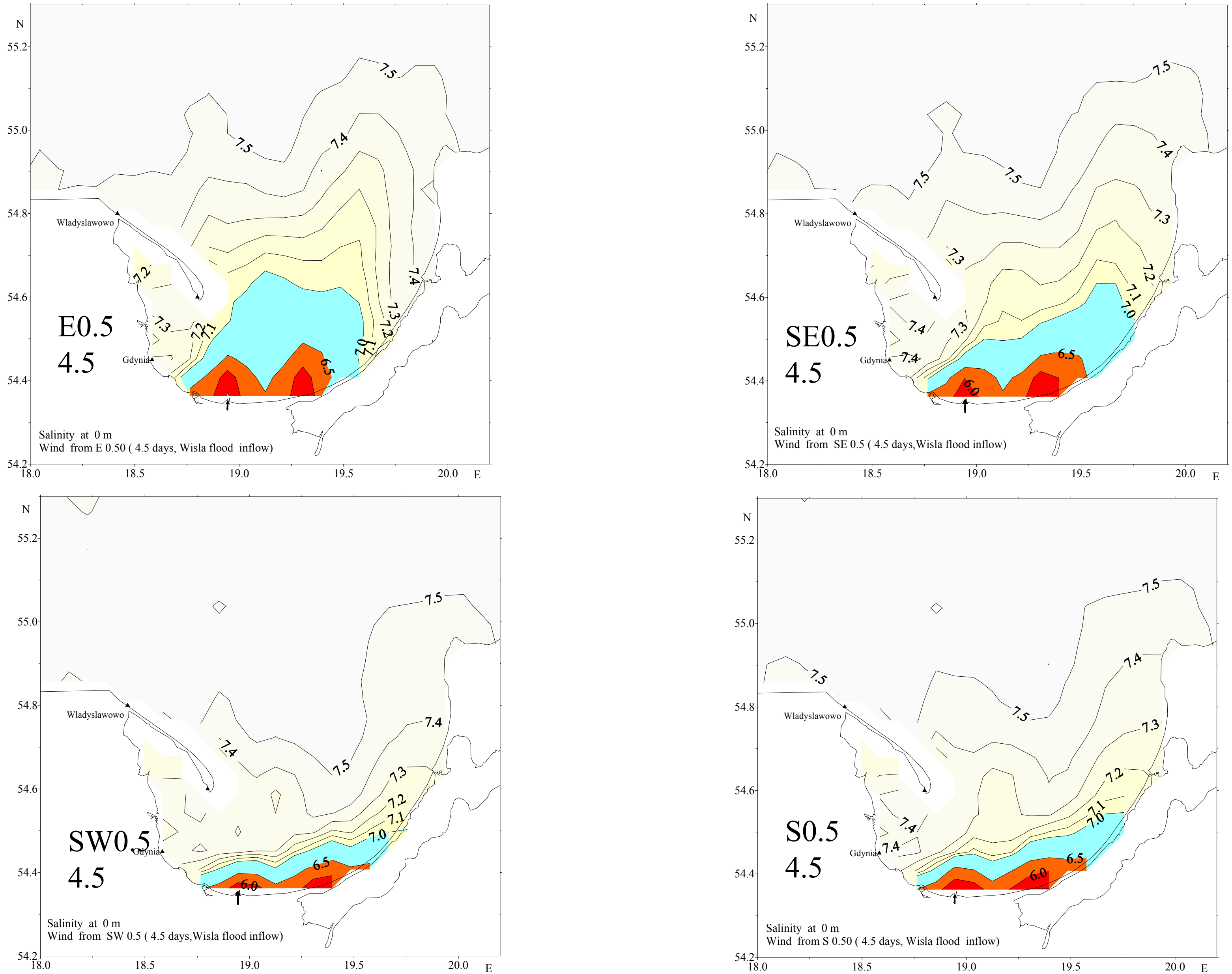
Simulated surface water salinity [PSU] in a time sequence of 1 day.
Run 2: Wind from NE 0.5, Vistula flood inflow. Day 4.5

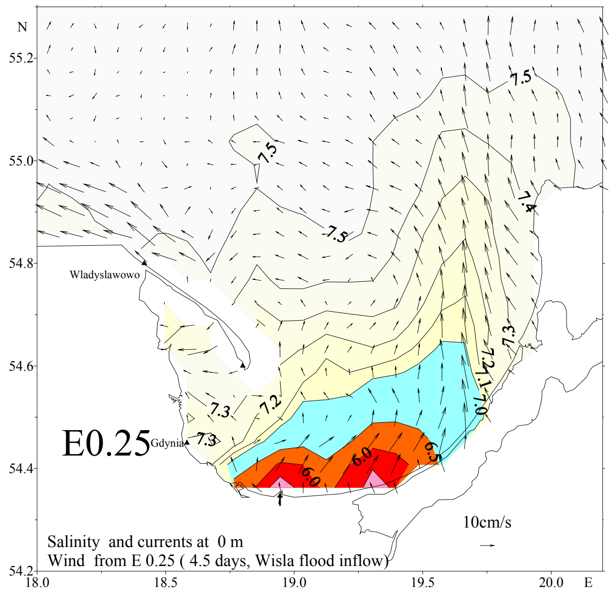

NW0.5
4.5
Wladyslawowo
Gdynia
Salinity at 0 m
Wind from NW 0.50 (4.5 days, Wisla flood inflow)

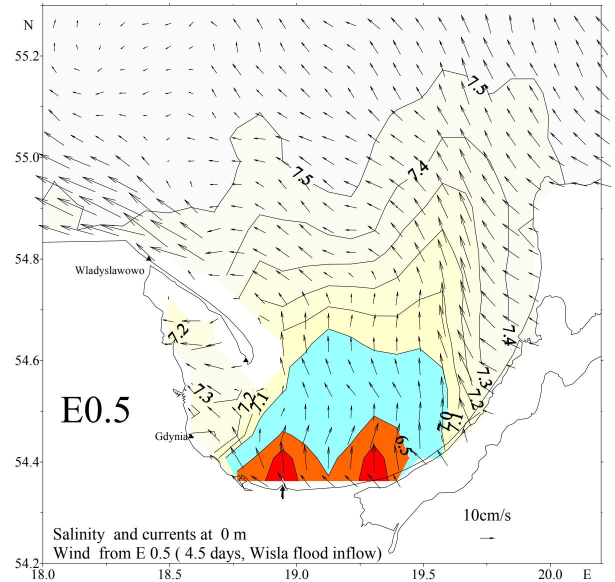

N0.5
4.5
Wladyslawowo
Gdynia
Salinity at 0 m
Wind from N 0.50 (4.5 days, Wisla flood inflow)

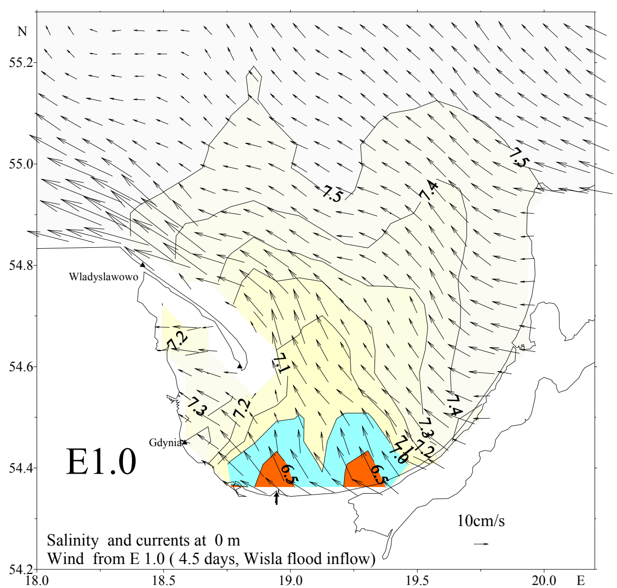

W 0.5
4.5
Wladyslawowo
Gdynia
Salinity at 0 m
Wind from W 0.50 (4.5 days, Wisla flood inflow)


NE0.5
4.5
Wladyslawowo
Gdynia
Salinity at 0 m
Wind from NE 0.5 (4.5 days,Wisla flood inflow)

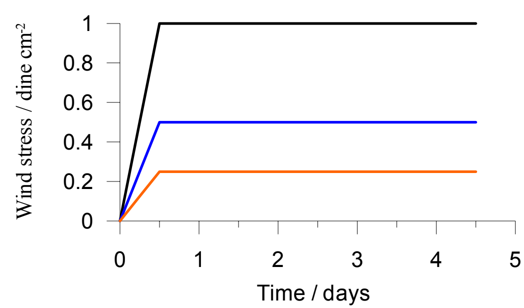

E0.5
4.5
Salinity at 0 m
Wind from E 0.50 (4.5 days, Wisla flood inflow)
SE0.5
4.5
Salinity at 0 m
Wind from SE 0.5 (4.5 days,Wisla flood inflow)
SW0.5
4.5
Salinity at 0 m
Wind from SW 0.5 (4.5 days,Wisla flood inflow)
S0.5
4.5
Salinity at 0 m
Wind from S 0.50 (4.5 days, Wisla flood inflow)
Wladyslawowo
Gdynia
N
E
55.2
55.0
54.8
54.6
54.4
54.2
18.0
18.5
19.0
19.5
20.0

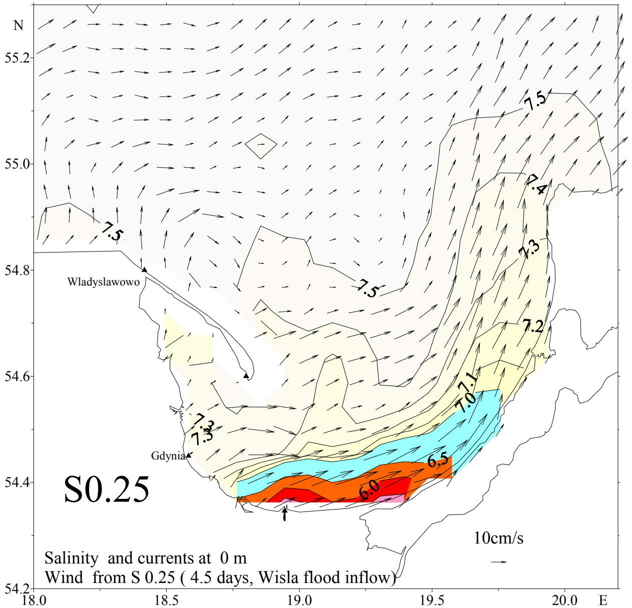


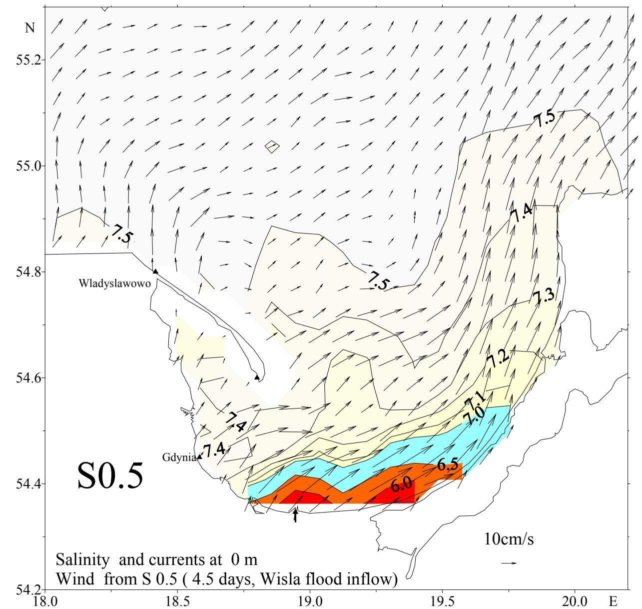


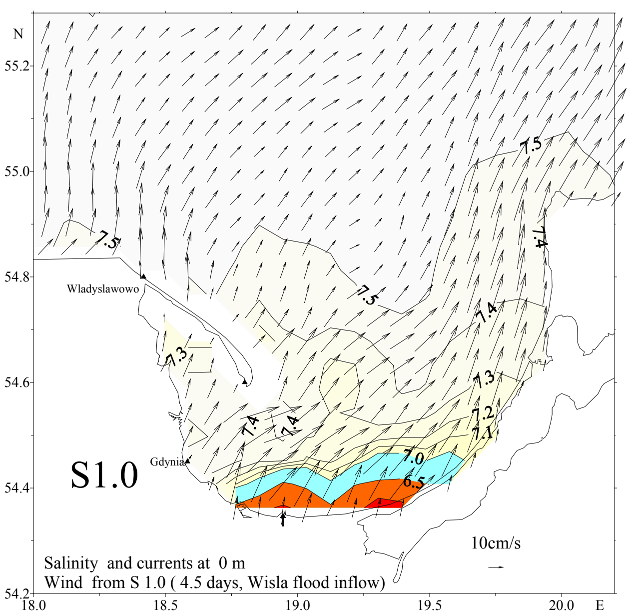


Simulated surface water salinity [PSU] and currents for wind from E 0.25, 0.5 and 1.0, Vistula flood inflow. Day 4.5

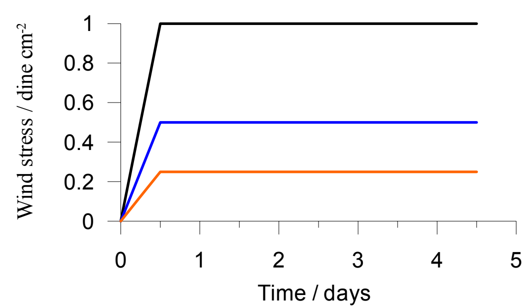






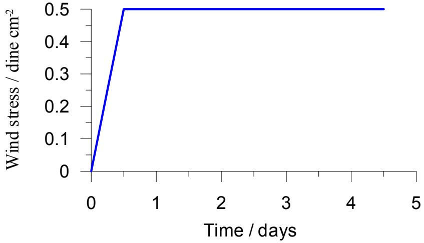


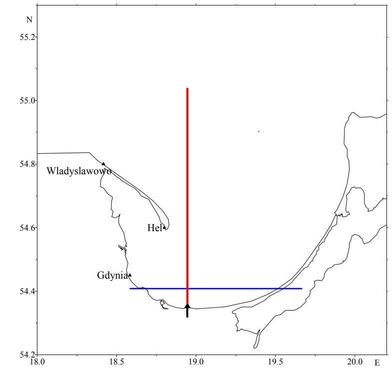
Simulated surface water salinity [PSU] and currents for wind from S 0.25, 0.5 and 1.0, Vistula flood inflow. Day 4.5

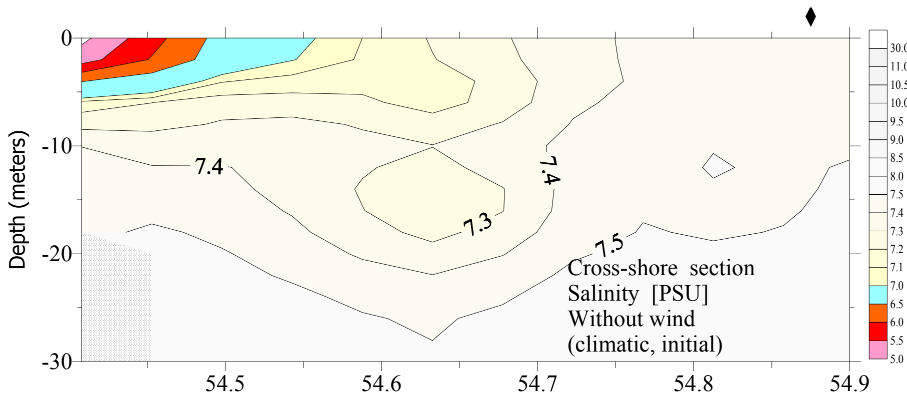


Wind stress Area [km²] of mixing zone (salinity < 7 PSU)

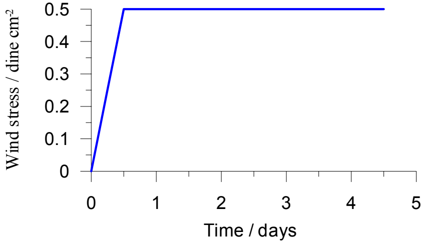
Wind stress [dyne/cm²]	Wind direction							
	N	NE	E	SE	S	SW	W	NW
0.5	700	1050	1225	1075	675	575	425	450
1.0	525	825	550	525	500	400	350	325

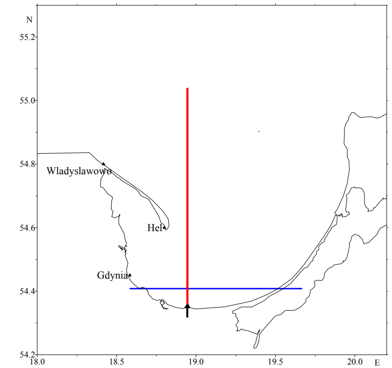


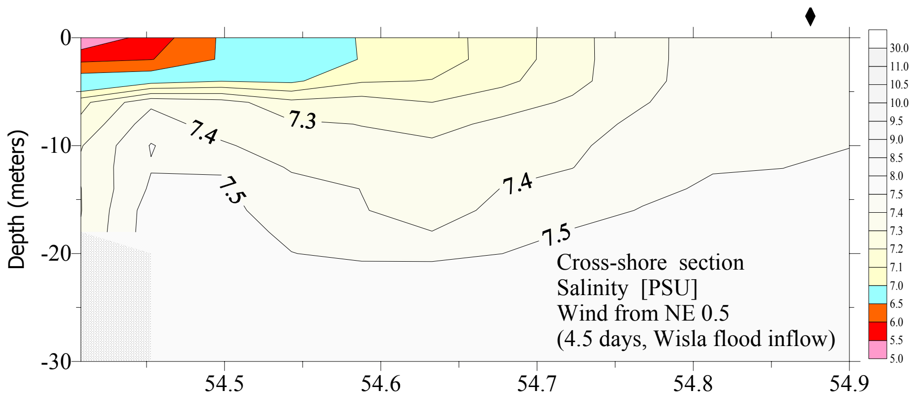


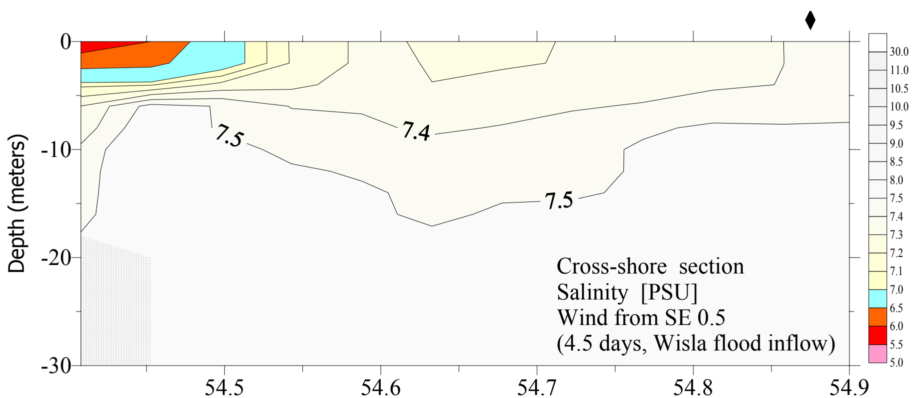


Simulated water salinity [PSU] along cross-shore vertical section (climatic, initial)

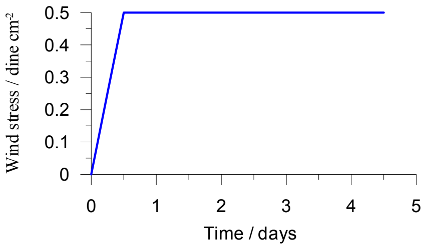


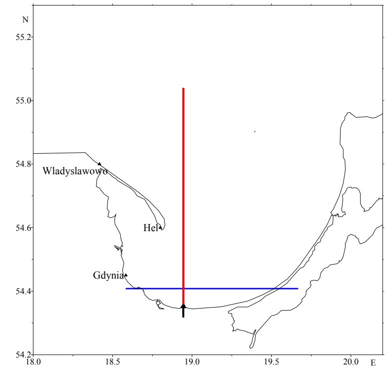


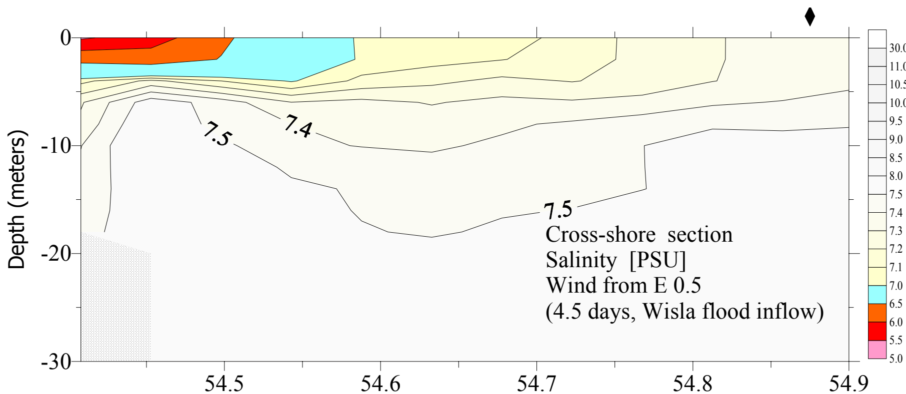


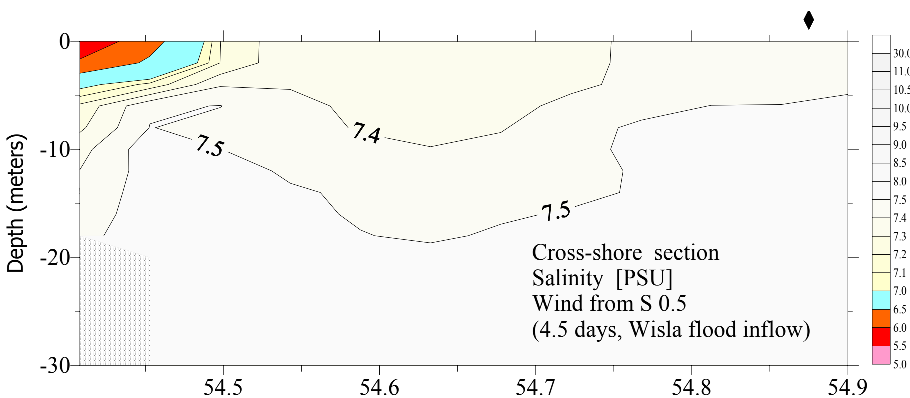


Simulated water salinity [PSU] along cross-shore vertical section for wind from NE 0.5 and SE 0.5, Vistula flood inflow. Day 4.5

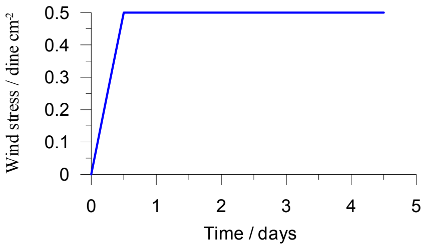


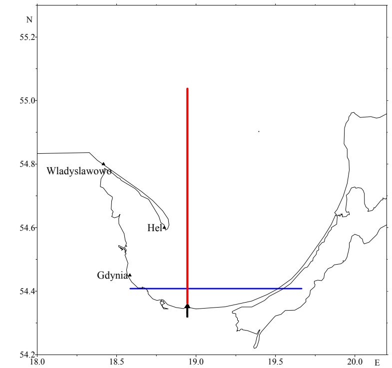


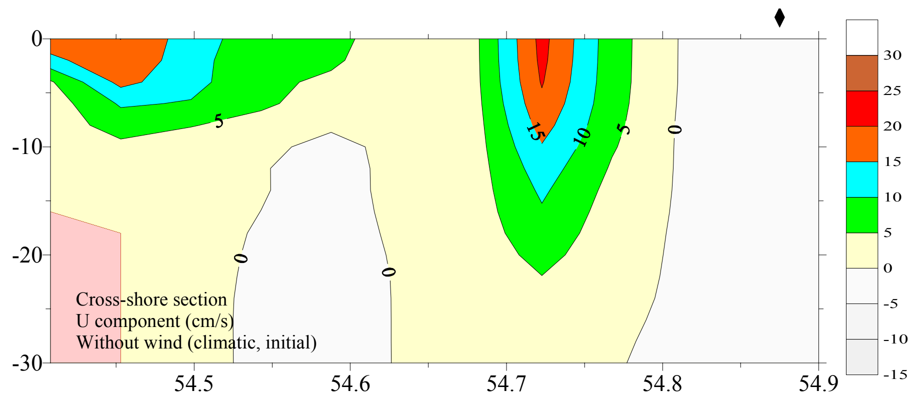




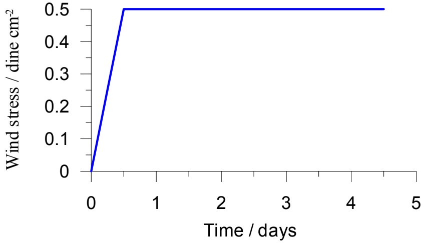
Simulated water salinity [PSU] along cross-shore vertical section for wind from E 0.5 and S 0.5, Vistula flood inflow. Day 4.5

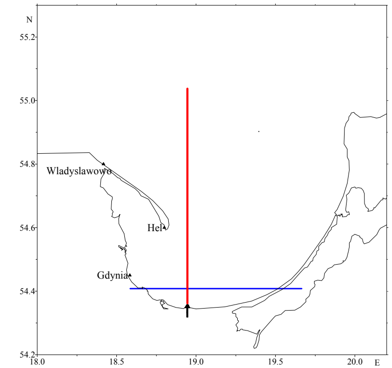


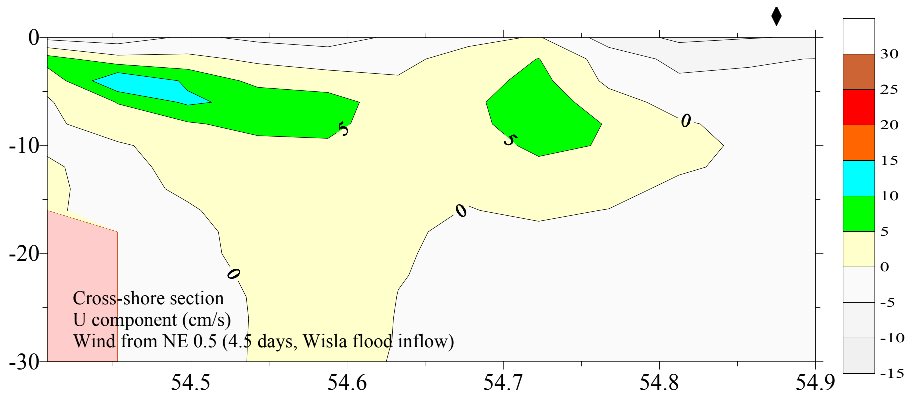


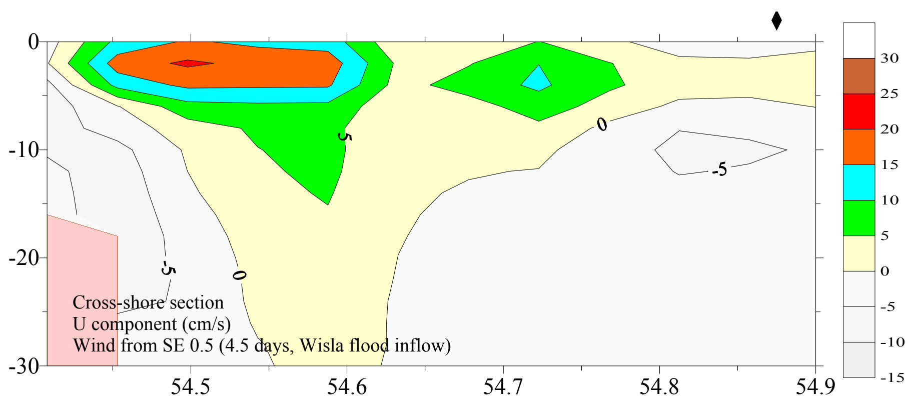


Simulated velocity component [cm/s] along cross-shore vertical section (climatic, initial)

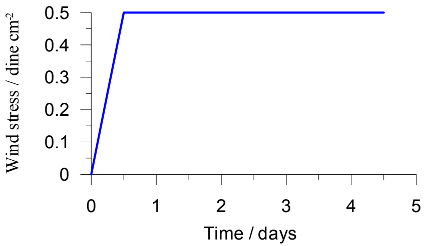


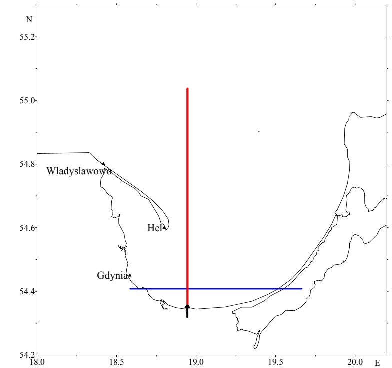


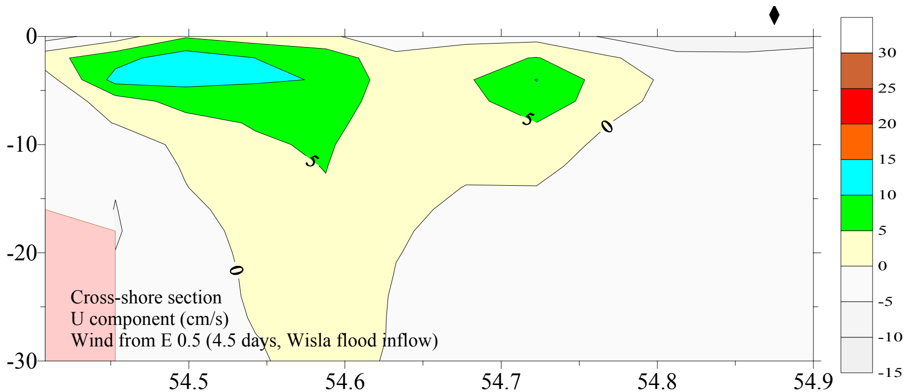


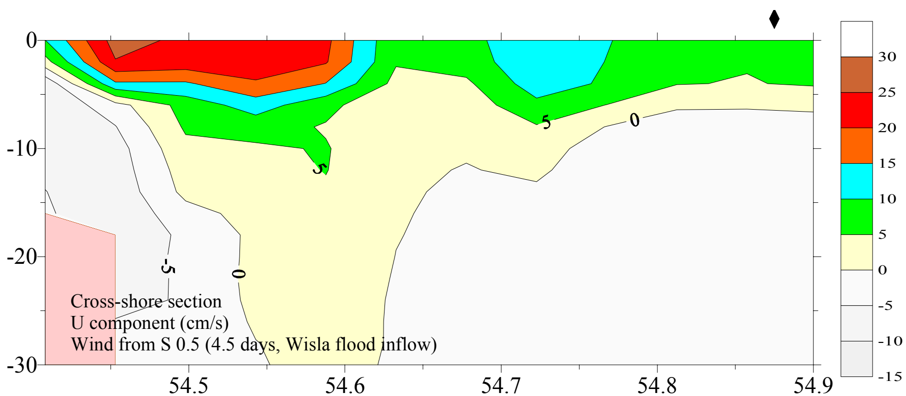


Simulated velocity component [cm/s] along cross-shore vertical section for wind from NE 0.5 and SE 0.5, Vistula flood inflow. Day 4.5

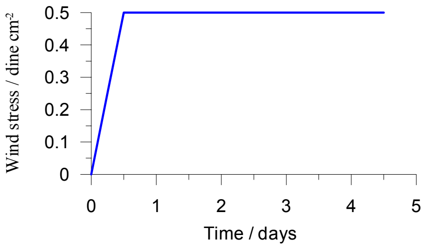


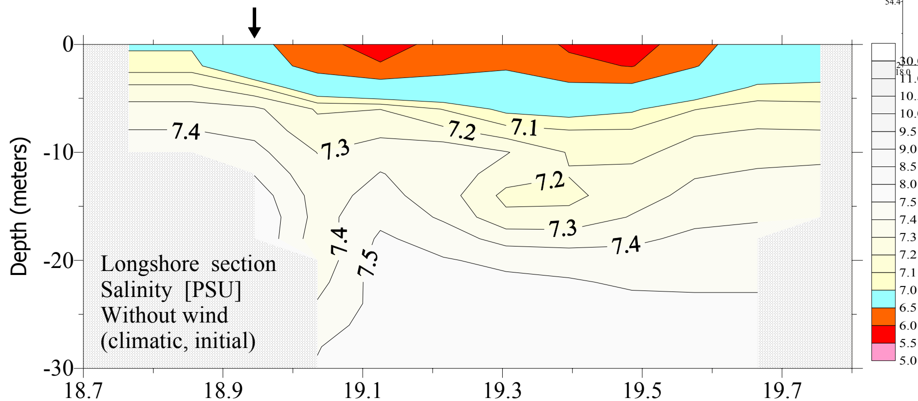


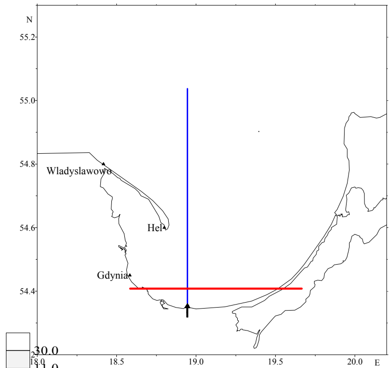




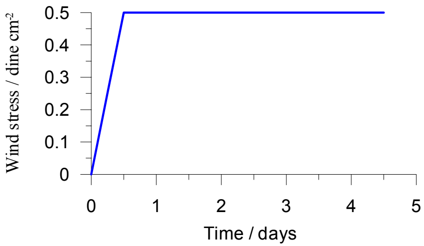
Simulated velocity [cm/s] along cross-shore vertical section for wind from E 0.5 and S 0.5, Vistula flood inflow. Day 4.5

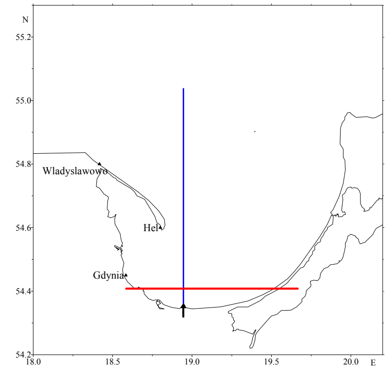


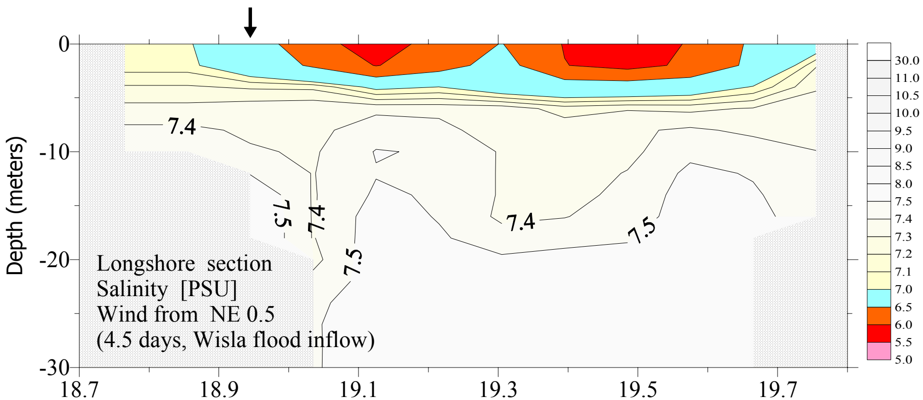


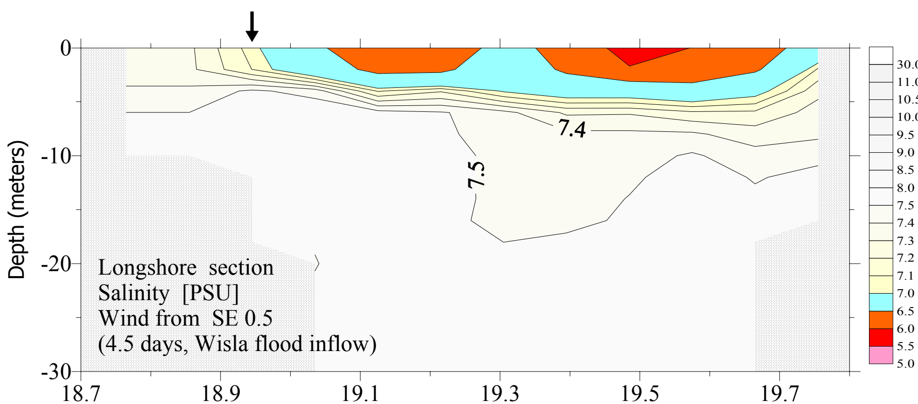


Simulated water salinity [PSU] along longshore vertical section for wind from NE 0.5, Vistula flood inflow. Day 0

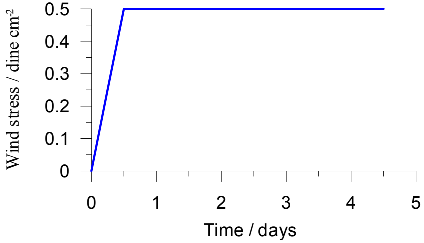


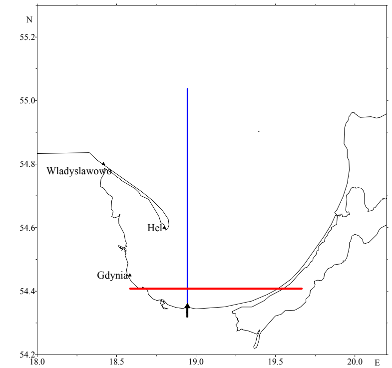


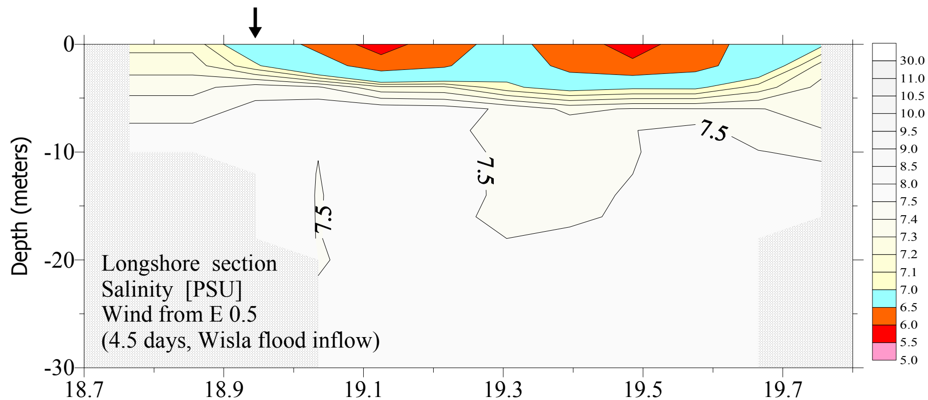


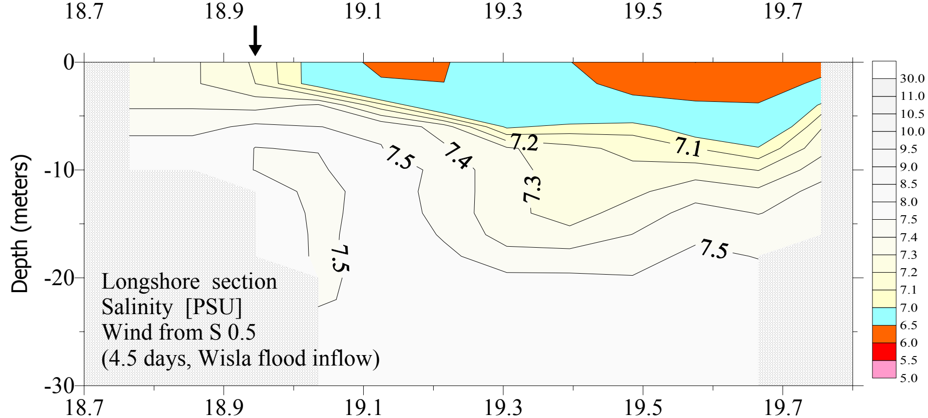


Simulated water salinity [PSU] along longshore vertical section for wind from NE 0.5and SE 0.5, Vistula flood inflow. Day 4.5









Simulated water salinity [PSU] along longshore vertical section for wind from E 0.5 and S 0.5, Vistula flood inflow. Day 4.5

Final remarks

A 3D baroclinic model was applied to study wind- and river inflow-induced hydrodynamic conditions in the Gulf of Gdańsk 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). 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 Gulf of Gdańsk.

The results of the numerical experiments visualize the patterns of weak saline surface water (riverine plume) propagation on their way from the Vistula mouth toward the open boundary of the Gulf of Gdańsk. The results of simulations showed that the surface water plume can be particularly sensitive to the wind stress. Its extent is influenced by the wind stress and varied depending on the orientation of the wind stress.

The values of area of mixing zone (salinity < 7 PSU) vary from 1100-1200 km^2 (wind from E and NE) to 400-500 km2 (winds from W and SW). Under stronger winds the area of mixing zone decrease almost twice. These findings and 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) as well as with theoretical and numerical investigations (cf. Fennel and Mutzke 1997, Robakiewicz and Walkowiak 1998).

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

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