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

Andrzej Jankowski, Institute of Oceanology of PAS
Powstańców Warszawy 55, 81-712 Sopot, Poland

e-mail: jankowsk@iopan.gda.pl

[a]Based on poster presented at Baltic Sea Science Congress 2003, Helsinki, 24-28 August 2003 with some corrections - IO PAN 2004-2008

Abstract

The upwelling of cold coastal water during summer period is a common phenomenon in the vicinity of the Hel Peninsula frequently observed on satelite images. Krezel (1995) and Urbanski (1995), based on the analysis of events related to the wind observation concluded that occurance of upwelling in this area cannot be easily explained by the Ekman's theory.

The main aim of this study is to reconstruct, with the aid of numerical model, the hydrological conditions in the coastal area of the southeastern Baltic and related to the real atmospheric conditions. The objective of this presentation is to describe and make a preliminary analysis of the dynamic processes related to this upwelling-like event, in the vicinity of the Hel Peninsula.

The 3-D (sigma - coordinate) model has been used here for hindcast simulations. The model is based on the Princeton Ocean Model code known as POM, and was adapted to the Baltic Sea conditions. Model, with horizontal resolution of ca. 5 km and with 24 sigma - levels in vertical, allows to reproduce variability and main features of currents and thermohaline fields in the southern Baltic Sea. From the model simulation, the specific conditions for the occurrence and development of upwelling at the eastern end of the Polish coast (in the vicinity of the Hel Peninsula) can be deduced.

It is believed that the results of numerical simulations have supplied some new insight into the dynamics of the upwelling induced by real atmospheric forcing along the Polish Baltic coast.

Introduction

Infrared satellite images provide compelling evidence for upwelling occurrence along the Polish Baltic coast (Gidhagen 1984, Siegel et al. 1994, Bychkova and Victorov 1987, Bychkova et al. 1988, Urbanski 1995, Krezel 1997). The upwelling of cold coastal water in the area off the open sea coast of the Hel Peninsula (Fig. 1) occurs each year, often during summer period (July - September). Krężel (1997) and Urbański (1995), based on the analysis of events related to the wind observation concluded that occurence of upwelling in this area cannot be easily explained by the Ekman's theory.
There have been some in situ observations (Malicki and Miętus 1994, Matciak et al. 2001) of upwelling events occurring in the vicinity of the Hel Peninsula. 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.

Introduction ..... cont.

Only few 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 and Seifert 1995, Kowalewski 1998, Jankowski 2000, 2002). In latter study, in which upwelling was investigated under real anemobaric conditions in September 1989 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.

Introduction ..... cont.

Main intention of this investigation is to verify these findings under different atmospheric conditions. Reported here hindcast numerical simulations were performed to reconstruct the hydrological conditions in the coastal area of the southeastern Baltic and related to the real atmospheric conditions in July and August 1980. Model results exhibit occurrence and development of an intense upwelling-like event in the area off the Hel Peninsula (cf. Fig. 1). The objective of this presentation is to describe and make a preliminary analysis of this hydrological event.

Model

A three-dimensional (sigma coordinate model), based on the Princeton Ocean Model (POM) code (Blumberg and Mellor 1987) adapted to the Baltic Sea was applied for hindcast modelling of the variability of hydrodynamic conditions in the southeastern Baltic Sea due to real anemobaric situation in July and August 1980. 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).

Model ..... cont.

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 ..... cont.

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).

Model ..... cont.

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.

Model verification

In order to test the reliability of the model calculations, the results were compared with the in situ measurements (vertical sounding of temperature and salinity at a number hydrographic stations in the Southern Baltic (taken from the ICES Oceanographic Database and Service (http://www.ices.dk/ocean). Their distribution in the Gulf of Gdansk is shown in Fig. 1.

Fig. 2 depicts exemplary vertical profiles of the modelled sea water temperature and salinity at two points S1 and S2 for period of 17-20 July 1980 and 20-27 July 1980, respectively. The model produces acceptable vertical profiles of the seawater temperature and its salinity. The profiles variability in time is similar to in situ measured data. Thus the model results can be used for a more detailed analysis of the water dynamics in the Gdańsk Basin.

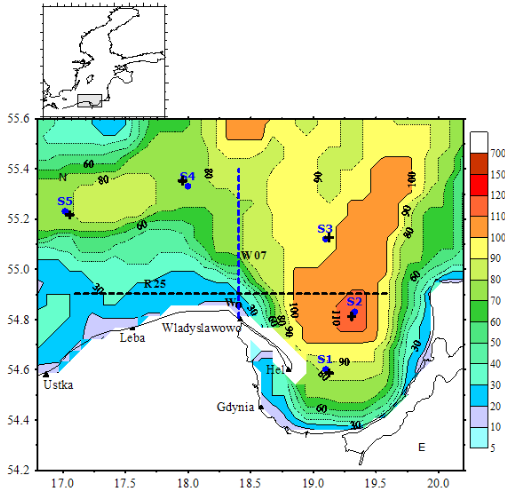

Figure 1 The study area and location of points and hydrographic sections used to visualize the results and for verification of the model calculations. Bottom topography was elaborated based on data from Seifert and Kayser (1995). The numbers on the isolines indicate the depth in meters.

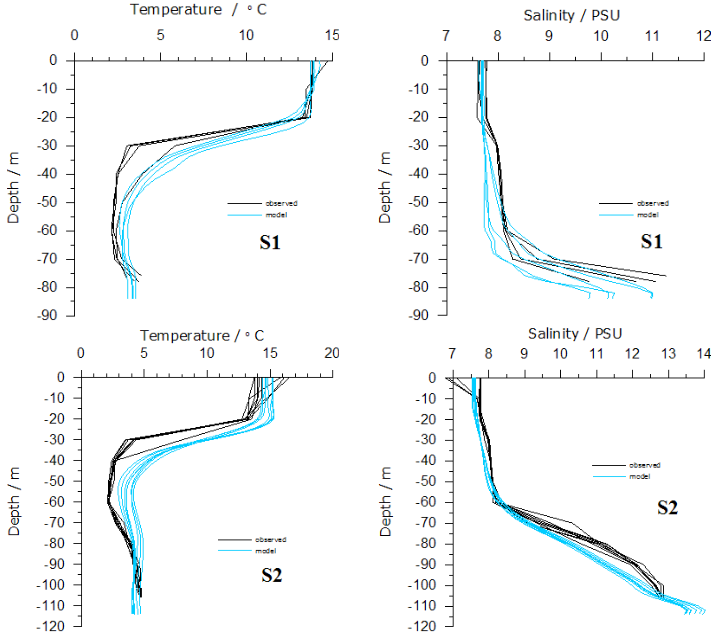

Figure 2 Time evolution of modelled and in situ measured vertical distributions of temperature and salinity at the hydrographic stations S1 and S2. For details of their locations, see Fig. 1

Results of simulations

Fig. 3 illustrates exemplary time series of wind direction, wind speed and calculated seawater temperature and salinity in surface layer at selected depths at point W (off Wladyslawowo, see Fig. 1 for point location). From this figure it follows that more intense upwelling event occurrs on days 27-33 of simulations (from 27 July to 02 August 1980). Two weaker ones occurr on days 3 to 6 and on 49 to 56, respectively. All of them are related to characteristic anemobaric situations: rapid changes in wind direction to upwelling favourable (winds from N-E sector). The maximum of upwelling event occurrs 2-4 days after.

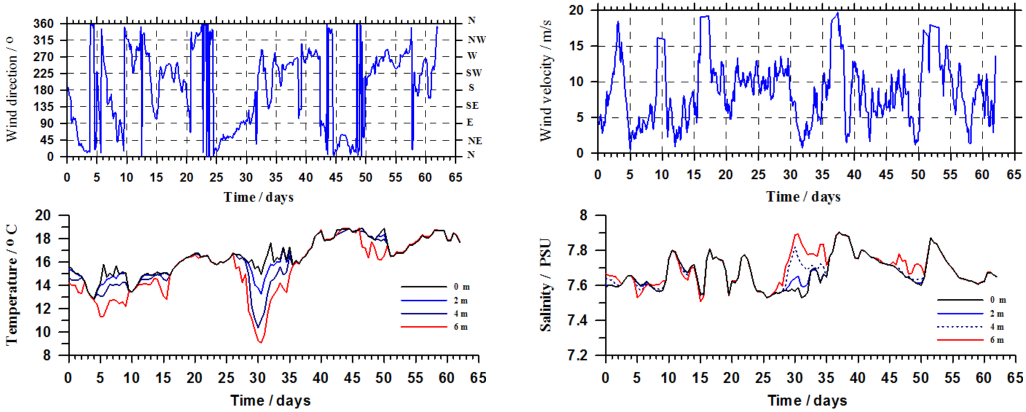

Figure 3 Time evolution of wind direction [o], wind velocity [m/s], simulated seawater temperature [o C] and seawater salinity [PSU] at point W in the vicinity of the Hel Peninsula. Location of point see Fig. 1.

Results of simulations ... cont.

The response of stratified sea water to upwelling favourable winds in sea surface temperature are shown in Fig. 4. Snapshots of surface temperature on four succesive days depict development of the stronger upwelling event (on 27 July 02 August). They demonstrate the temporal history of the occurrence of coastal upwelling, its evolution and its disappearance in the vicinity of the Hel Peninsula. Peak upwelling response in the surface seawater temperature fields (as with salinity field) appears on days 30-31 (on 30-31 July 1980).

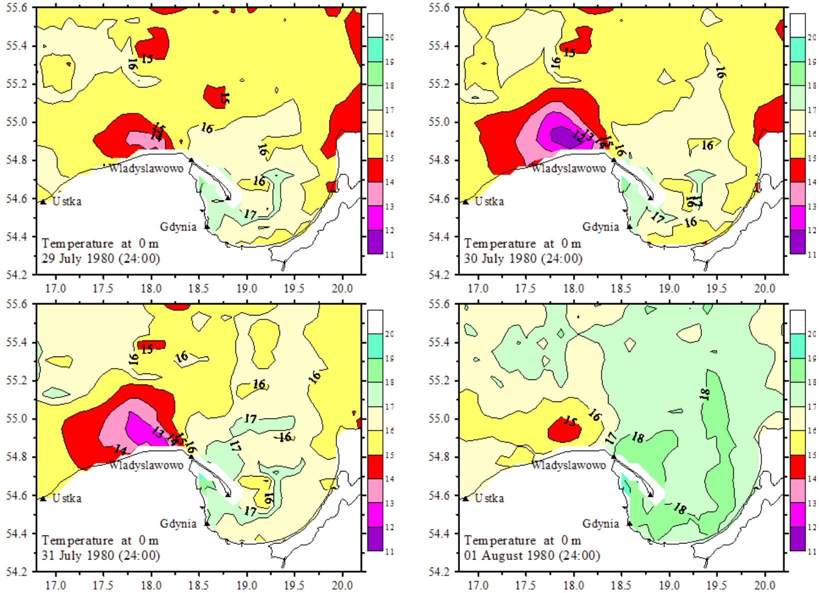

Figure 4 Simulated sea water temperature [o C] in surface layer in a time sequence of 1 day from 29.07.1980 to 01.08.1980. For time history of wind direction at point W see Fig. 3.

Results of simulations ... cont.

Some details of the vertical structure of the hydrological fields are presented for the peak of upwelling on 30 July. Figs. 5 and 6 depict spatial distribution of seawater temperature, salinity and velocity component along the vertical hydrographic cross-shore section W07 and alongshore one R25, respectively (location of sections see Fig. 1).

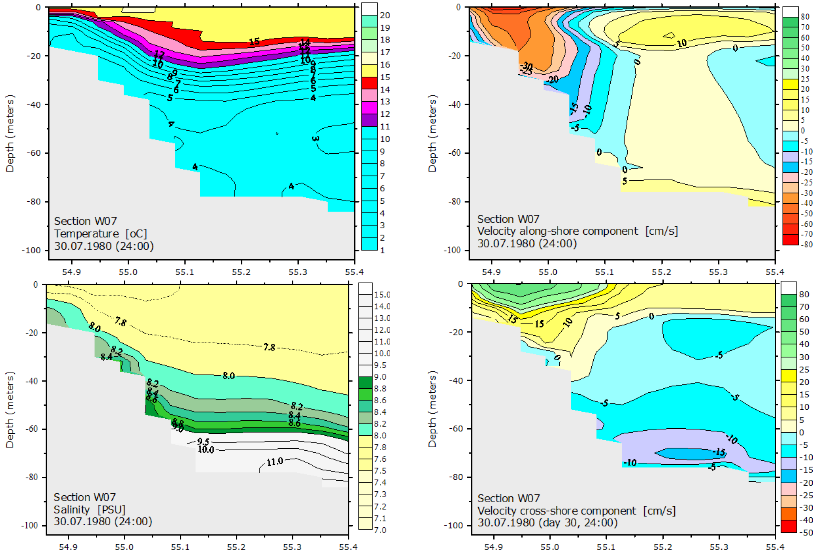

Figure 5 Vertical cross-shore section W07 results of model simulations on 30 July of: seawater temperature [oC] (left top), seawater salinity [PSU] (left bottom), alongshore, zonal current velocity component [cm/s] (positive values of velocity indicate eastward flow) (right top), cross-shore, latitudinal current velocity component [cm/s] (positive values of velocity indicate northward flow) (right bottom). Location of section see Fig. 1.

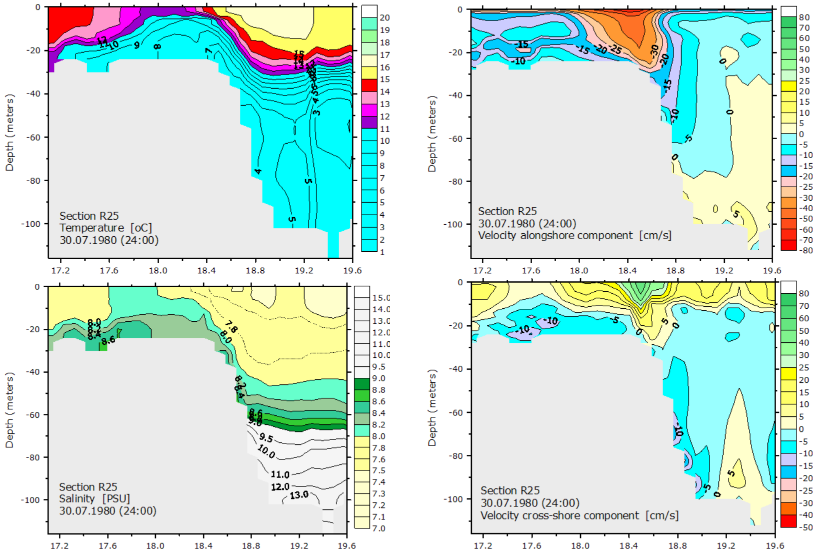

Figure 6 Vertical alongshore section R25 - results of model simulations on 30 July of: seawater temperature [oC] (left top), seawater salinity [PSU] (left bottom), alongshore, zonal current velocity component [cm/s] (positive values of velocity indicate eastward flow) (right top), cross-shore, latitudinal current velocity component [cm/s] (positive values of velocity indicate northward flow) (right bottom). Location of section see Fig. 1.

Results of simulations ... cont.

Next figure (Fig. 7) presents the series of snapshots of sea-water salinity at 10 m depth and the mean-depth current patterns in a time sequence of 1 day from 27 July to 01 August. Mean-depth current vectors illustrate the overall picture and the variability of water exchange between the coastal zone and the open sea. The simulated circulation patterns complete the description of hydrodynamic conditions related to the reported upwelling event.

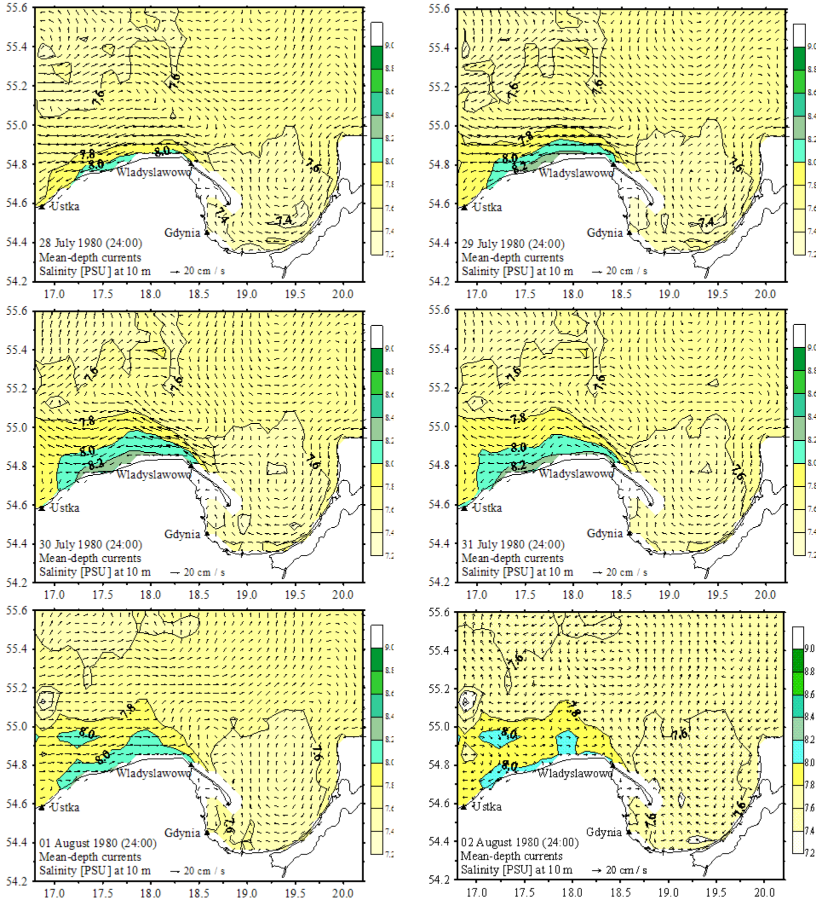

Figure 7 Simulated seawater salinity [PSU] at 10 m depth and mean-depth currents vector [cm/s] in a time sequence of 1 day from 28.07.1980 to 02.08.1980. For time history of wind direction at point W see Fig. 3.

Conclusions

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 in July and August 1980.

The results of hindcast simulations show that under the real atmospheric forcing in summer period of 1980, near the southeastern Polish Baltic coast intensive time- variable upwelling developed and, as a result of which the hydrological conditions in the area off the Hel Peninsula were substantially modified.

Specific conditions for the occurence and development of the upwelling processes in this area are observed. The results of present investigations confirm peculiar features of hydrodynamics in the region of the Hel Peninsula.

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