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Simulation of water circulation in the Baltic Sea for selected months form April to November
(Symulacja cyrkulacji wód Baltyku dla wybranych miesięcy: od kwietnia do listopada),

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Summary

The monograph presents the results of modelling the steady - state wind - and density - driven circulation in the density - heterogeneous Baltic Sea for selected months from April to November. They illustrate the mean 'seasonal', climatic variability in the water dynamics in the Baltic Sea in the
same manner that the mean (multi - year averaged) fields of atmospheric pressure (or sea water temperature, salinity and density) characterize the seasonal variability of baric fields (or seawater thermology).

Though simplified, this set of typical mean 'states' of the model describes with sufficient accuracy the spatial structural patterns of water movements in the Baltic Sea, thereby enabling non - modellers, e.g. ecologists, geochimists or biologists, to apply the results of mathematical models, not yet described in oceanographic literature. As the monograph was conceived as a kind of atlas, the results of computations are presented in the form of charts and diagrams. The description of the model itself and of the investigations performed its use was restricted to an indispensable minimum.

Following a general introduction, the first chapter outlines the aims and scope of study, and the second provides the theoretical basis of the diagnostic model i.e. equations, boundary conditions and methods of solution. Chapter three describes the methods of estimating of physical model parameters and the forcing functions fields, that is to say, wind and density fields considered as climatic, long - term mean for each month. Making up the bulk of the work, chapter four includes the results of model computations. In chapter five the validation of computations is commented on with respect to the results of field studies written up in the oceanological literature. The monograph concludes with the some final comments on the results.

The model is based on the linearized set of steady equations of motion for horizontal components of current vector and continuity equation, with vertical eddy viscosity coefficient (assumed constant with z- axis), written with the hydrostatic and Boussinesq approximations (section 2.1).

The horizontal current velocity components are calculated from the analytical Ekman - type solution (section 2.2). The vertical component of the current velocity vector is estimated with the aid (help) of model based on the equation for the z-th vorticity component of the water shear stress (section 2.3).

The sea level,essential in estimation of the current velocity vector components, is calculated from the numerical solution of the set of equal to non - stationary equations for mass transport

and sea level (section 2.4). The finite - difference H - N scheme of Hansen with the space and time steps equal to $h_x = 7{,}5'$, $h_y = 5'$ and $\tau = 60$ sec, respectively, was applied (section 2.5). In numerical calculations the Baltic Sea was assumed as closed basin without taking into account the river inflows.
The wind stress and baroclinic stress, expressing the joint effects of spatial heterogenity of sea water density and bottom relief, stand as forcing functions for water circulation (chapter 3). In figs. 3.2 - 3.9 the fields of wind velocity vectors (calculated with the aid of the model of gradient wind) for each months are shown and respectively, in figs. A1.1 - A1.8 and A2.1 - A2.8 (Appendix 1 and 2), the fields of baroclinic stress vectors are depicted.

The results of numerical calculations for selected months have been presented in the form of schematic charts with isolines of stream function for mass transport Psi (figs. 4.1 - 4.8), vectors of mean - depth currents (figs. 4.9 - 4.16), isolines of sea level (figs. 4.17 - 4.24) and with vectors of horizontal currents at the sea surface (figs. 4.25 - 4.32), and at the depths of 20 m (figs. 4.33 - 4.40) and of 40 m (figs. 4.41 - 4.48).

The fields with isolines of the vertical vector velocity component at the selected depths: 30 m (figs. 4.49 - 4.56) and 50 m (figs. 4.57 - 4.64) and the distributions of the vertical velocity along five vertical longitudinal sections (figs. 4.66 - 4.70) in some of the Baltic Proper (location of longitudinal sections - see fig. 4.65) complete the picture of the water circulation in the sea.

Cyclonic gyres - like structures prevail in the fields of horizontal flow characteristics and their location are related to the deepest regions of the sea - baltic deeps. Intensity and location of the gyres changes from month to month but some specific tendency for each seasons, especially, for spring and autumn months, when the variability and amplitudes flows are the highest, may be observed. "Seasonality" of variability of the water circulation parameters are closely correlated with the spatial and temporal variability of the fields of the forcing functions.

The results of calculations confirmed the results of the previous investigations of water circulation in the Baltic (Sarkisyan et al., 1975; Kowalik and Staskiewicz, 1976; Simons, 1978; Kielmann, 1981; Funkquist and Gidhagen, 1984; Staskiewicz, 1988; Kullas and Tamsalu, 1975; Mälkki and Tamsalu, 1985), concern on the important role of the baroclinic of sea water and the bottom topography (JEBAT - the Joint Effect of Baroclinicity and Topography of the sea bottom, (Sarkisyan, 1977a,b)) in forming climaic, seasonal wind and density - driven flows in the Baltic Sea Wind force play minor role and its influence on circulations can be seen only for the autumn months, when the wind velocities approach their maximal values.

Confrontation of the results of modelling, made only qualitatively for the case of horizontal currents, because of lack of the results of the *in situ* measurements, confirmed that the model patterns of water circulation in the Baltic Sea are in general agreement with the known schemas of the layout of the surface current vectors so in the Baltic itself as in its Gulfs (section 5.1). Quantative verification of the results of calculations of the sea level zeta (based on paper of Lazarenko (1961), section 5.2, tab. 10 and figs. 5.4 - 5.14) showed good agreements so in values of zeta as in seasonal variability of that flow characteristic, so essential in the estimating the current velocity components, at the greater number of the mareographic stations of the Baltic Sea.

The charts of the flow characteristics, presented in the work, indicate that for each months in the vicinity of the baltic Deeps the clusters of closed cyclonic (anticyclonic) gyres in the horizontal current fields can be seen. These spatial patterns are easily correlated with the distributions of upwelling (downwelling) regions in the fields of the vertical current velocity component. In these gyre - like structures conditions are created in which chemical, biological or geological substances can accumulate more readily, by comparison with adjacent water regions. This may, in following, intensify activity of biological processes or form zones with imperceptible concentration of oxygen or with occurance of hydrogen sulphide). Location of the spatial distributions of clusters (patterns) of so - called "dead - zones" (low concentration of oxygen or zones with occurance of hydrogen sulphide) in the deepest areas of the Baltic Sea (Melvasalo et al. 1981; Andersin and Sandler, 1988; Trzosinska, 1994) are nearly identical with the areas of the "permanent" upwelling (downwelling) observed at the charts of the isolines of the vertical current velocity component *w*.

Results of field investigations on the coastal upwellings, frequently observed in different parts of the Baltic Sea (tab. 12, fig. 5.25) may provide useful information to confirm qualitatively validation of the diagnostic model. The location of the zones of upwellings are similar to the location of the regions with clusters of the extremal values of vertical velocity in the coastal zones of the model Baltic Sea basin (fig. 5.17 - 5.24).

Thus it seems reasonable to conclude, that the presented in the paper "atlas" collection of typical mean "states" of the water dynamics for selected months may be useful for elucidating the hydrological background necessary to diagnose the state of the Baltic Sea marine environment on seasonal time scale, especially in stagnation periods.