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Water upwelling due to differential coastal heating

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Day heating / night cooling in coastal zone of large water bodies causes a specific water-exchange between coastal and off-shore regions. Experiments in 5m-long laboratory tank with inclined 2m-portion of the bottom (A=0.1, water depth in deep part D=15-20 cm) are reported, demonstrating a structure of fields of temperature and water currents under conditions of heating from the surface. In shallow regions at the top of incline, water temperature rises faster, so that horizontal temperature gradient between top and deep parts of the tank is established in some tens of minutes. The shape of the horizontal temperature profile at the surface is self-similar, with nearly constant temperature difference between top and deep parts (for fixed heat flux and bottom slope). Off-shore transport of warmer coastal waters is established in near-surface layer, with maximum of the current not at the surface, but obviously (1-3 cm) below it. The return (on-shore) flow is formed immediately below the off-shore flow, with its thickness twice larger and the speed twice smaller than that of the on-shore flow. Maximum speed of the return flow is observed at the depth of about 0.4 D. Further down, no significant currents were registered. This two-layered basin-wide exchange causes water upwelling along the inclined portion of the bottom.

Simple analytical model is developed in order to explain the observed results. Using several analytic expressions for the dependency of water temperature from depth, time and horizontal co-ordinate, we analyze the field of the horizontal pressure gradient. For logarithmic and linear vertical temperature profiles, the horizontal pressure gradient in the basin has its maximum at the depth of about 0.4 D, what is in full agreement with the laboratory experiments. Thus, an upwelling along the inclined part of the bottom is caused by the basin-wide exchange of convective nature, where the driving element is the on-shore flow, arising due to thermally-induced horizontal pressure gradient within water body.

Field data, obtained in summer of 2006 the Baltic sea coastal zone, as well as numerical modelling results (3D-non-hydrostatic model MIKE3-FlowModel, DHI Water & Environment) corroborate the discussed features. It is argued that the considered mechanism (along with the Eckman transport) significantly contributes to the formation of the coastal upwelling in summer time.

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