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Development of differential coastal cooling above sloping bottom: laboratory and numerical modelling

Natilya Stepanova
Shirshov Institute of Oceanology of Russian Academy of Sciences (SIO RAS), Marine Currents, Russian Federation (nata_chu@mail.ru)

The process of formation of differential coastal cooling above sloping bottom, often observed in autumn in coastal regions of seas and large lakes, is investigated by means of laboratory experiments and numerical modelling. During this period, an integral heat flux is directed from water to atmosphere. When water temperature is above that of maximum density (what is typically the case in autumn), it results in a negative buoyancy flux through the surface and the appearance of vertical convection. Water temperature decreases, and in shallow parts the process goes faster than in deeper ones, so that significant horizontal temperature gradients above sloping bottom are formed along with vertical thermal homogeneity of every particular water column. The corresponding density and pressure gradients cause large-scale exchange flows between shallow and deep parts of a basin. The goal of this work is an investigation of the process of establishment of the surface water temperature profile from the coast to the deep part and comparison of the characteristics of this profile with the observed flow rate of the horizontal exchange flows.

A series of laboratory experiments was conducted in a rectangular plexiglas laboratory channel with internal dimensions 33 cm [U+F0B4] 33 cm [U+F0B4] 750 cm; a 5m-long part of the bottom had a slope of A$\sim$0.03; walls and bottom were thermally insulated. Heat exchange through the surface with cooler air in laboratory provided natural cooling; initial water temperature varied between 25 and 31 ° C, air temperature – from 19 to 25 ° C. Maximum water layer depth (10, 12, 13, 16, 20, 22.5, 24, 24.5, 27 cm) and the initial air-water temperature difference ($\Delta\sim$4, 5, 6, 8, 9, 11 °C) were changing parameters in the experiments. Registration of water temperature time series in 8 points (1 cm below the water surface in the sloping region with time step 30 s) and vertical profilings in these locations were carried out by electronic thermistors. Flow-rate of horizontal exchange was calculated using deformation of tracks of tracers (potassium permanganate crystals) at appropriate time intervals, recorded by video- and photo-cameras. Total duration of every experimental run was about 1-2 hours, of which the process of the establishment of the horizontal temperature profile in the region above the slope took about 20-30 min. Equality of time rates of change of surface water temperature in deep and in shallow parts was taken as an indicator that the development of the exchange flow has reached its (quasi)steady state. Thus, the shape of the shallow-deep surface temperature profile in (quasi)steady exchange regime becomes also stable. It turned out from the experiments, that, in (quasi)steady state, the shape of any individual section of the profile is completely similar to the shape of the full profile, whereas during the process of the establishment this profile has fractures, sections with high temperature gradients or parts with almost linear temperature increase with the distance from the shore. This way, in natural basins for example, an information on the SST field in coastal zone during autumnal cooling can, with some level of confidence, tell whether the steady-state regime of horizontal exchange between open and coastal zone has developed in the given area.

Numerical simulations using 3-dimensional non-hydrostatic MIKE3-FlowModel (www.dhi.dk) were carried out in order to reproduce both (i) the described laboratory experiments and (ii) the process of autumnal cooling in channel-shaped basin with all sizes and depths, reproducing that of the coastal area off the Curonian Spit (South-Eastern Baltic Sea). Results of simulation of the laboratory experiment are in a good agreement with the observed process; however, change to “natural” basin scale has brought many complications to the process of the development of the horizontal surface temperature profile even in much simplified (channel-like) basin. It seems that (quasi)steady exchange flows above sloping bottom at natural scale manifest themselves through almost linear dependency of water-surface temperature between shallow and deep parts of a basin. This feature is also found at remote sensing SST images, but has no explanation up to now.

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