INTERNAL SEICHES OF LARGE AMPLITUDE IN THE ELONGATED LAKES AND PHENOMENON OF "LOCH NESS MONSTER"

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Summary Degeneration of the strongly nonlinear internal seiches in elongated lakes is investigated. Three-dimensional non-hydrostatic free-surface numerical models are used to study formation of the internal bore and it interaction with the lake slope. Two configurations of lakes are considered: (i) idealized elliptic-shape lake and (ii) Loch Ness Lake. In both cases it was revealed that due to "spoon-like" shape of the lake ends, three-dimensional focusing of internal waves was occurred and supercritical jet along the lake axis was appeared. The supercritical flow causes an internal wave wake, which is observed at the surface of the lake as distortions of the elevations. We hypothesize that this complicate flow pattern and it surface signs sometimes can be interpreted as manifestation of phenomenon, known as "Loch Ness Monster".

Introduction. In the freshwater lakes in moderate latitudes stratification occurs as a result of seasonal warming of the upper water layer. Than the intense wind surges (usually in autumn) tilt the surfase and generate long basin-scale low-frequency standing internal waves (seiches). Depending on the initial interface tilt and stratification occurs wide spectrum of possible flow regimes from linear to strongly nonlinear [1]-[2]. Nonlinearity leads to an asymmetry of waves, the appearance of the surge and further disintegration of it on a sequence of solitary waves. For finite values of the tilted interface two kinds of nonlinear effects can be essential: (1) nonlinear steepening of the long waves and (2) formation of internal bores when flows in layers achieve a supercritical state.

Degeneration of basin-scale internal waves in idealized elongated lake. Firstly the degeneration of large-scale waves in the small elongated elliptic-shape lake with relatively deep proper and shallow shelf is studied. Simulation was carried out using free-surface nonhydrostatic model [3]. Model is based on the fully nonlinear Navier-Stokes equations in the Boussinesq approximation with using SGS model of turbulence. Grid resolution is $500\times100\times60$ nodes, and the σ -system is used to describe the bottom topography smoothly. The considered lake has the length 5 km, width 1 km and maximal depth 30 m (see fig. 1a). It is filled with two layers of different temperature with the density difference between the layers $\Delta\rho = 2$ kg m^{-3}. The thickness of the interface layer is about 5 m. The ratio between upper layer to the maximal depth is $h_1/H_{\max} = 0.15$. Initially thermocline was inclined along the lake with initial tilt $\eta_{i0}/h_1 = 1.7$, where η_{i0} is maximal deviation from undisturbed value of the depth of isosurface of maximal vertical gradient of temperature (see fig. 1b). Such values of η_{i0}/h_1 and $h_1/H_{\max}$ correspond to an initial distribution of the density when the interface crosses the upper boundary of the basin and the flows form gravitational currents [2]. According to the classification of regimes [1]-[2] in the rectangular basin with the two-layer stratification in this case the internal bore is formed, when flows in layers achieve a supercritical state.

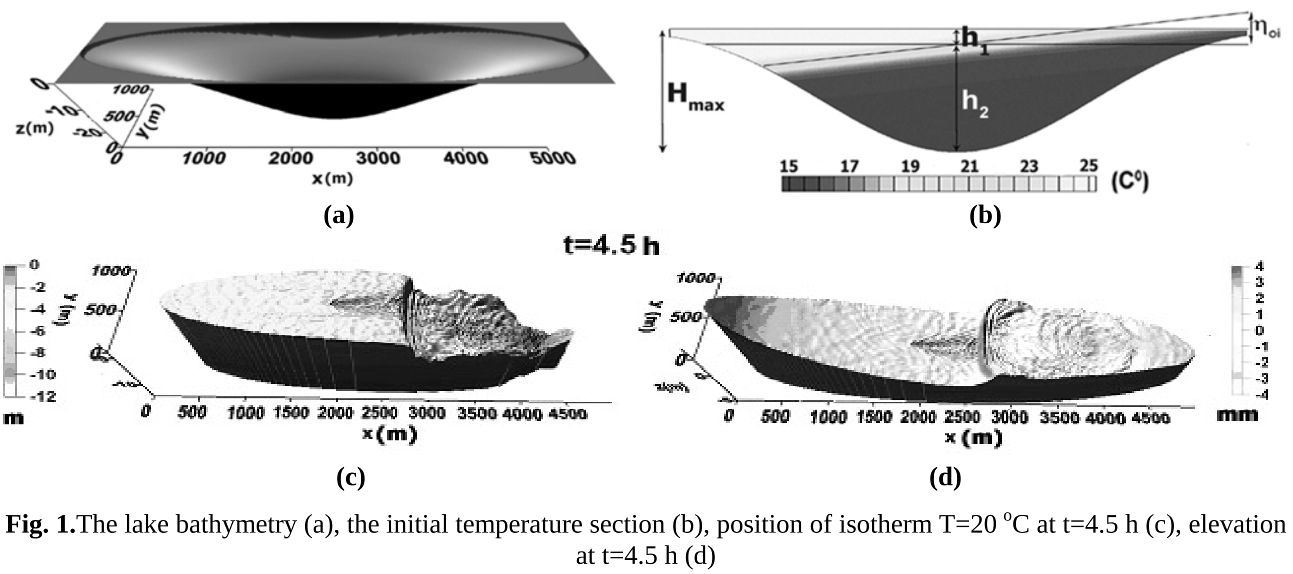

Fig. 1. The lake bathymetry (a), the initial temperature section (b), position of isotherm T=20 ^{o}C at t=4.5 h (c), elevation at t=4.5 h (d)

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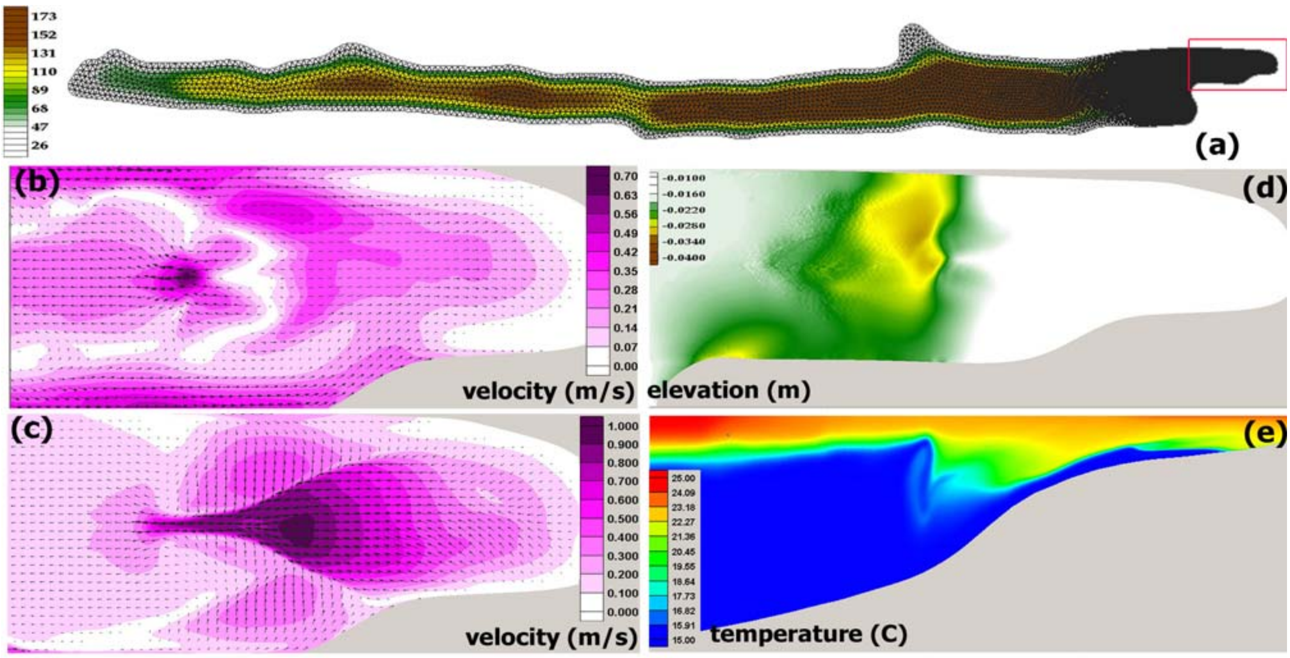

Fig. 2. The Loch Ness bathymetry and unstructured grid (a); velocity field at the 10 m depth at t=4 h (b); bottom velocity field at t=4 h (c); surface elevation at t=4 h. (d); vertical section of temperature at t=4 h (e).

Results of simulation of interaction of basin-scale motions with the spoon-like topography of the ends of lake are shown at fig. 1 (c-d). A formation of large amplitude internal bore on the surface of interface is seen in fig. 1c. The bore evolves into the solibore with a sequence of solitary waves. Unlike rectangular basin three-dimensional shape of the lake brings new peculiar properties of flow. It was revealed that bottom topography at the ends of the lake lead to the concentration of the flow and formation of jet along the lake axis. This supercritical jet is visible as supercritical flow causing the internal wave wake. This wake is visible at the surface of lake as distortions of the elevations. The jet-like flow propagates with velocity around 1 m/s in front of the solibore that have larger amplitude (Fig. 1d). These unexpected results sent us in search of similar effects in the real lake.

Degeneration of basin-scale internal waves in Loch Ness Lake. The Loch Ness Lake (Scotland) is long (about 37 km), deep (its deepest point is 227 m) and narrow (average width is 1.6 km) lake. The bathymetry map of the Loch Ness (fig 2a) shows that lake ends have also the spoon-like shapes. The internal surges in the Loch Ness were observed by [4]. Here we present first numerical study of the formation of the internal surge in the Loch Ness Lake and its interaction with lake topography. Simulations were carried out using SELFE model [5]. The unstructured grid contains about 70000 triangular elements with a refinements at the north-eastern part of lake and sparse grid at the rest area (see fig 2a), whereas 70 sigma layers are used. The stratification parameters are $h_1/H_{\max} = 0.15$, $\eta_{i0}/h_1 = 1.7$ and $\Delta\rho = 2$ kg m^{-3}. During the transformation of basin-scale internal wave in the northern end of the Loch Ness (highlighted in fig. 2a) a complicate flow was also revealed. Figure 2c shows formation of the intensive jet at the bottom with maximal velocity around 1 m/s. The velocity field at the depth 10 m (fig. 2b) illustrates that the fluid is pushed forward through the bore with a velocity about 70 cm/s, while surface velocities are around 0.5 m/s and directed conversely. The vertical section of temperature (fig. 2e) shows that strong jet is appeared entraining fluid from the upper layer that subsequently leads to the intensive mixing. This flow causes the complicate surface elevation field shown in fig. 2d that is similar to fig. 1d. However, the surface pattern is not clear as in fig. 1d because of resolution of 10 m in the north-eastern part of lake is not enough to resolve formation of the wave wake. We hypothesize that complicate flow pattern and it surface signs resulted form interaction of internal surge with lake topography sometimes can be interpreted as manifestation of phenomenon, known as "Loch Ness Monster".

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