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Baikal ice rings: a new hydrodynamic approach

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ABSTRACT. The phenomenon of ice rings in Baikal is discussed. It is shown that the thawing of ice from below in the shape of a ring is due to the formation of a vertical circular Stewartson layer on the lateral surface of the geostrophic eddy and, as a result, the appearance of a divergent vortex in the intersection area of the vertical cylindrical Stewartson layer and the horizontal under-ice Ekman layer.

Keywords: ice rings, Baikal, eddy, under-ice Ekman layer, Stewartson layer

1. Introduction

For the first time, giant rings on the ice of Lake Baikal were discovered by scientists of the Limnological Institute of the Siberian branch of the Russian Academy of Sciences (LIN SB RAS) with the help of satellite images in spring 2003 in Middle Baikal near cape Krestovsky (Granin, 2009). Similar rings were later captured by images in different years, starting from 1975, on Lake Hovsgol in Mongolia (Kouraev et al., 2016).

During further research, it was found that similar ice structures with a diameter of 4–5 km or even more, sometimes reaching 10 km, often appear on the ice of Lake Baikal in spring before the destruction of the ice cover. Of course, such giant rings could only be seen by satellites. The rings have an almost round shape in diameter with the width of a ring of darker and thinner ice being about 1 km. The thickness of darker ice may be about 20–30 cm, while out of the ring the ice thickness reaches 1 m. Dark circles in space images are precisely these areas of thin ice.

Under-ice measurements of currents and the thermal structure of water under the rings shows, that there is an anticyclonic eddy in the geostrophic area of the lake under the ice, which is transporting warmer deep water to the lower surface of the ice, and that leads to the ice thawing from underneath. But the question why the ice is being melted from the bottom side of the ice cover in the shape of a ring remains open. This paper is devoted to the theory of this phenomenon.

2. Problem statement

Melting of the ice in the form of a ring occurs in the Ekman layer adjoining the lower surface of the ice. Let us have a look at the geostrophic anticyclonic eddy and the under-ice Ekman layer. Let us consider a homogeneous fluid and set the structure of the anticyclonic geostrophic eddy as the topographic eddy (McCartney, 1975; Zyryanov, 1985). In fact, observation shows, that the rings normally occur in the corners of the canyons of Lake Baikal. According to the hydrodynamic approach proposed, the geostrophic eddy caused by bottom topography is formed in the area under a ring – under-ice canyon eddies. Taking as a basis the topographical nature of the geostrophic eddy, we focus on the dynamics of flows in the Ekman layer. We assume that the kinematic of the geostrophic vortices in Lake Baikal is similar to topographic eddies. Note that both are anticyclonic.

3. Results and discussions

It is shown that a divergent circular vortex appears under the ice in the form of a horizontal vortex torus in the circular intersection area of the vertical cylindrical Stewartson layer, formed on the lateral surface of the canyon geostrophic eddy, and the horizontal under-ice Ekman layer.

As seen from the figure, warmer deep waters rise within the anticyclonic geostrophic eddy into the Ekman layer. The most intensive horizontal and vertical water movements occur in the Ekman layer on the periphery of the geostrophic eddy (Fig. 1).

Horizontal velocity field in the under-ice vortex in the Ekman layer is strongly divergent (Fig. 2). The velocity vector deviation angle from the tangent to the ring averages between 30° to 45° to the left of the ring based on the observation (Fig. 2 , on the left) (Kouraev et al., 2016). According to the theory, the velocity vector deviates by an angle of ~ 38° to the left of the ring (Fig. 2, on the right). It is caused by the formation

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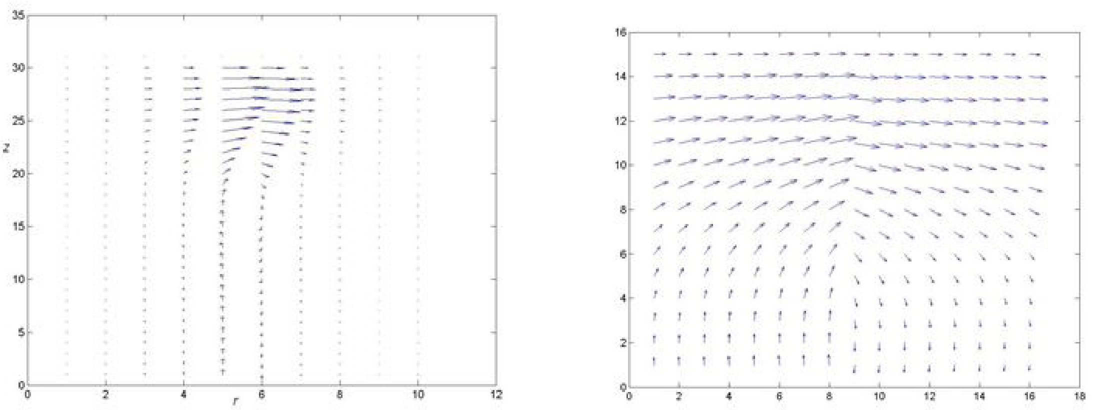

Fig.1. Non-dimensional velocity field ($v_r(r,z)$, $w(r,z)$) in the vertical plane ($r = 5$ – the lateral boundary of the geostrophic eddy), (on the left); more detailed picture of the current velocity ($v_r(r,z)$, $w(r,z)$) in the vertical plane in the intersection area of Stewartson layer and Ekman layers ($r = 8$ – the lateral boundary of the geostrophic eddy), (on the right).

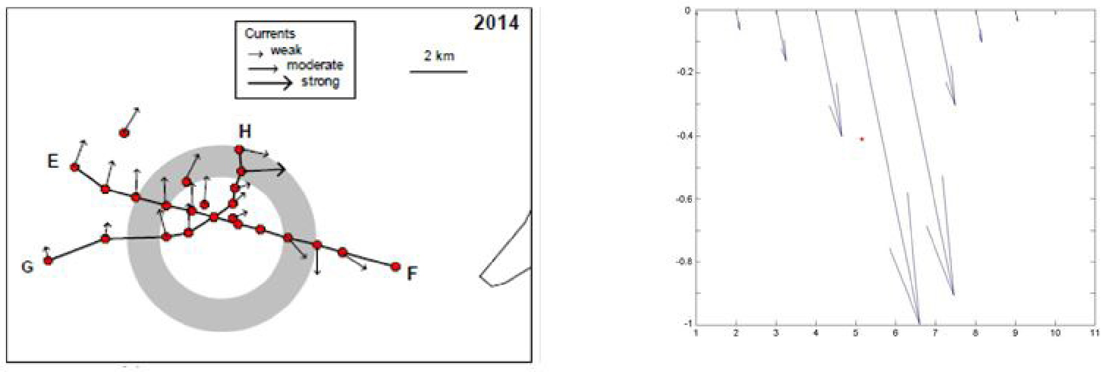

Fig.2. Measured current velocity under ice across the ice ring near cape Nizhnee Izgolov'e (Lake Baikal, 2014, April 3), (Kouraev et al., 2016), (on the left); calculated current velocity in the Ekman layer under ice (on the right).

of the viscous Stewartson's layer (Fig. 2) on the lateral surface of the geostrophic eddy.

So, we can make the main conclusion: the thawing of ice from below in the shape of a ring is due to the formation of a vertical circular Stewartson layer on the lateral surface of the geostrophic eddy and, as a result, the appearance of a divergent vortex in the intersection area of the vertical cylindrical Stewartson layer and the horizontal under-ice Ekman layer.

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