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Processing of in-situ Measurements of Surface Velocity and Temperature in Lake Shira

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Abstract. Long-term field measurements of current velocity, wind velocity and temperature have been conducted in Lake Shira during 2013-2018. The first studies of surface currents were carried out using the Lagrangian drifter in 2018. In this work, the principal component analysis was used to identify the main components of the near-surface current and surface temperature. The data obtained using the drifter was analyzed with the connection of the wind pattern.

Keywords: in-situ measurements, drifter, principal component analysis.

1 Introduction

At present, we have a large amount of information about the hydrophysical characteristics of Lake Shira. The temperature data by using thermal braids, velocity data by using acoustic doppler current profiler (ADCP), surface current by using a drifter were obtained. The structure of the data obtained is extremely complex and special methods must be used to highlight the main processes. The analysis of surface temperature and surface velocity was carried out using the principal components analysis (empirical orthogonal functions). After identifying the main components for the surface temperature data (2014, 2015, 2018), the correlation between the first modal coefficient and air temperature was calculated. For the velocity in the surface layer, the first mode was compared with the distribution of the velocity of the stationary flow of a homogeneous fluid, and on this basis the form of the coefficient of vertical turbulent exchange was determined.

2 Analysis of surface velocity using a drifter

In contrast to point measurements of velocity the studies using drifters can reveal the vortex structure of the flow. As is known, vortices are a mechanism of both horizontal mixing, leading to a uniform horizontal distribution of phyto- and zooplankton, and vertical, which leads to the transfer of nutrients from deep-sea zones in the coastal. Lagrangian drifters are widely used to study currents in the ocean and in large lakes. For example, studies have been conducted of coastal currents in North Carolina [1], wind currents in the North Pacific [2], surface circulations in the North Seas [3], surface circulations in the North Atlantic [4] and the Bay of Biscay [5], Studies are known for the Great American Lakes [6,7], Lake Kinneret [8] and Lake Stechlin [9].

In the summer of 2018, the Institute of Biophysics of the SB RAS measured current velocities using a satellite quasi-Lagrangian drifter in Lake Shira (Republic of Khakassia, Russia).

In Fig. 1, the solid line indicates the trajectory of the drifter during the experiment and the points on the line indicate the times when the wind changed direction. The experiment was started on 12/12/18 at 7:22 and lasted for 23 hours. The average drift speed is 9 cm/s.

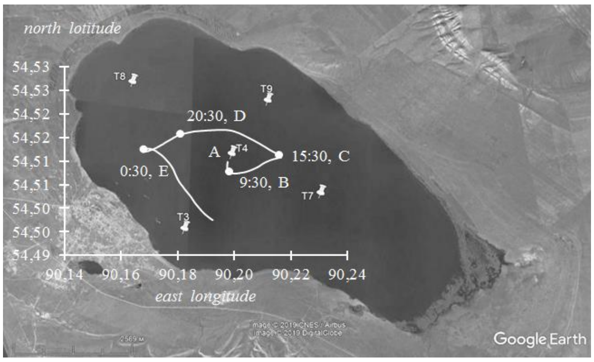


Figure 1. Drifter experiment July 12-13, 2018. The trajectory of the drifter.

To explain the structure of the current obtained using the drifter we analyzed the wind pattern in the area of the location of Lake Shira. The wind speed and direction data were obtained from several weather stations located around Lake Shira (Fig. 2).

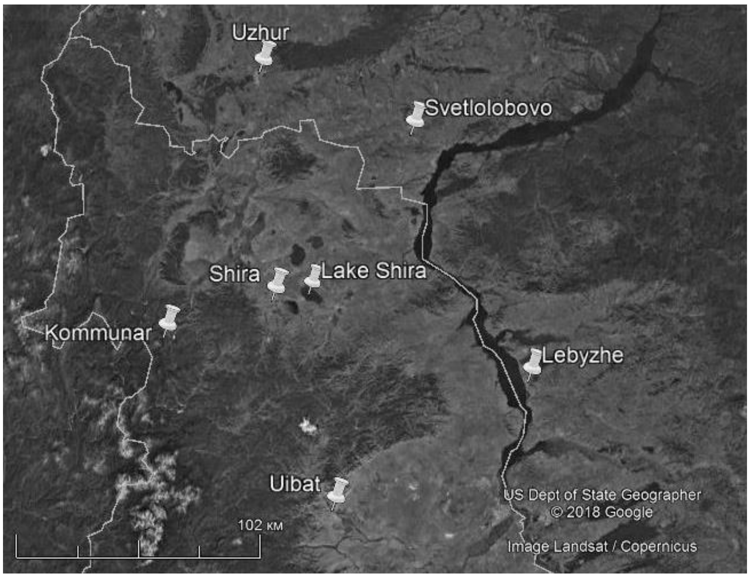
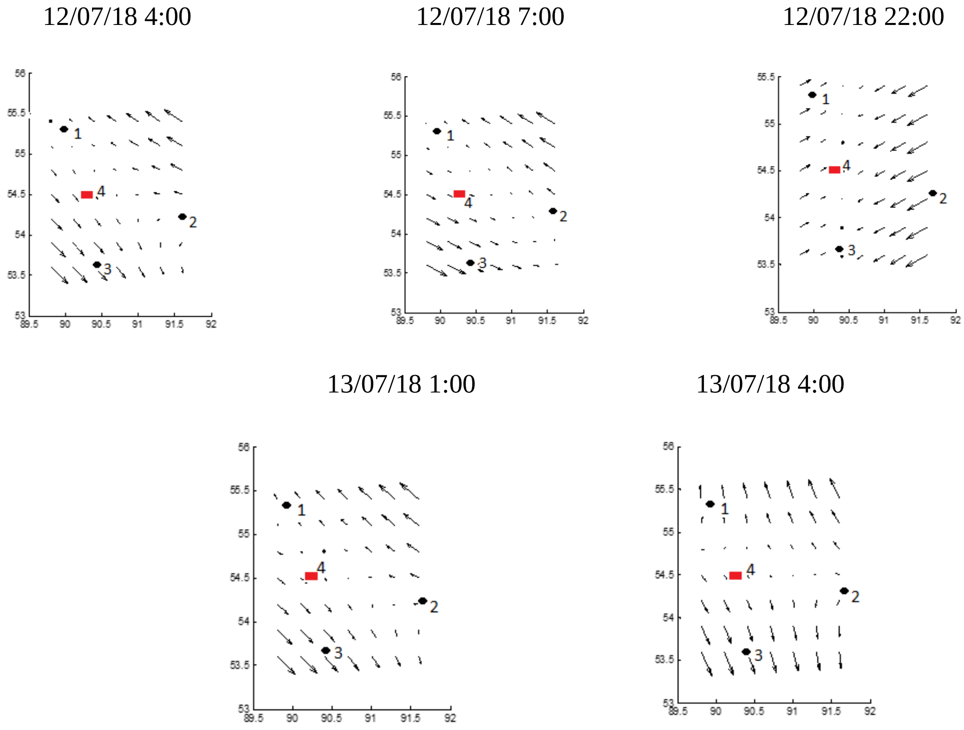


Figure 2. Weather stations located around Lake Shira.

For analysis, three stations located at the vertices of a triangle that covers the lake were selected. The "triangle" was considered: Uzhur - Lebyazhye - Uybat and linear interpolation was carried out inside this triangle.

Figure 3 shows the wind velocity field constructed according to the data of three weather stations (1 – Uzhur, 2 – Lebyazhye, 3 – Uybat) at different points in time that correspond to the time of the drifting experiment. The number 4 and the rectangle mark the location of Lake Shira.


12/07/18 4:00

12/07/18 7:00

12/07/18 22:00

13/07/18 1:00

13/07/18 4:00

Figure 3. Wind speed in the area of Lake Shira.

The calculation results show that the wind has a cyclonic vorticity at all points in time, except 12/07/2018 22:00 which corresponds to the drift trajectory.

Almost during the entire measurement period, the wind induced a cyclonic vortex, which corresponds to Fig. 1. The change in the direction of the vortex motion on the night of June 13 is consistent with the change in the direction of the wind (Fig. 1 and the upper right graph in Fig. 3).

3 Surface velocity analysis

In summer of 2014-2015 in Lake Shira long-term velocity measurements were carried out. These data were analyzed using the method of empirical orthogonal functions, which is one of the kind of statistical data processing. The field observations are recorded in the form of a finite sum of terms of different scales, representing the function that depends on spatial variables (modes) and time-dependent modal coefficients.

The measurements in the summer of 2014 were analyzed using the method of empirical orthogonal functions. We obtain the first mode - a complex-valued vector which does not depend on time and its dimension is equal to the number of measurement points in space.

It is known that in summer the lake is stratified by temperature and salinity.

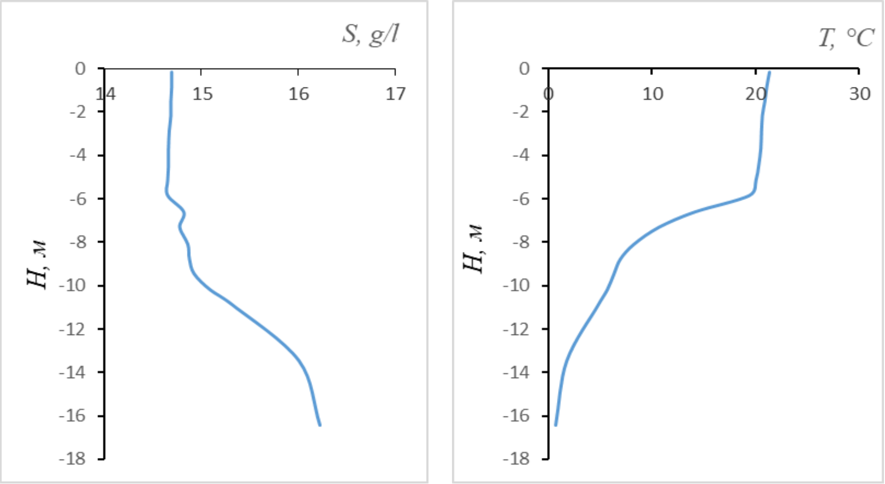


Figure. 4. Salinity and temperature in Lake Shira in summer period of 2013-2014.

The upper mixed layer can be considered as a layer where the liquid is homogeneous. This gives reason to compare the first mode obtained using the method of empirical orthogonal functions with known solutions for the stationary flow of a homogeneous liquid in the layer of the depth of 9 m.

For comparison, an analytical solution with considered the drift component of the Ekman model was used [10, 11].

The solution for a constant coefficient of vertical turbulent exchange has the form

$$w = u + iv = \frac{\tau^w}{\rho_0} \cdot \frac{\mathrm{ch}(\alpha(z+H)) + \dfrac{k_b}{K_z \alpha}\mathrm{sh}(\alpha(z+H))}{K_z \alpha \,\mathrm{sh}(\alpha H) + k_b \mathrm{ch}(\alpha H)}.$$

Here $w = u + iv$ is complex horizontal velocity, H is depth of basin, k_b is bottom friction coefficient, ρ_0 is average density, $\tau^w = \tau_x^w + i\tau_y^w$, τ_x^w, τ_y^w are wind stresses along the axes Ox, Oy respectively, $\alpha = \sqrt{il/K_z}$, where l is Coriolis parameter.

In the case when the coefficient of vertical turbulent exchange is determined by the formula $K_z = \delta e^{\lambda z}$, the solution is found with using modified Bessel functions $I_1(\xi)$, $K_1(\xi)$

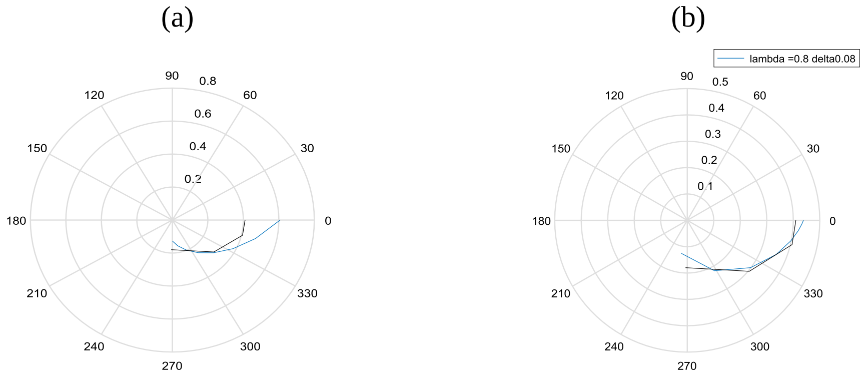
$$w = C_1 \xi I_1\left(\frac{2}{\lambda}\sqrt{\frac{\alpha}{\delta}}\xi\right) + C_2 \xi K_1\left(\frac{2}{\lambda}\sqrt{\frac{\alpha}{\delta}}\xi\right).$$

An arbitrary constants C_1, C_2 are found from the boundary conditions at the bottom and on the surface.

The eastern and northern components of the velocity in the analytical solution were selected and were compared with the corresponding velocities of the first mode for the first nine measurement points, counting from the surface to a depth of 9.58 m.

For this purpose, the standard deviation of the values for the first mode from the analytical solution was determined. As a result, it was found that in the near-surface layer the best value is achieved for the coefficient of vertical turbulent exchange exponentially decreasing in depth.

The best approximation in terms of standard deviation was obtained for a constant $K_z = 0{,}0011\ m^2/s$ with standard deviation $M = 0{,}174$ (a), for $K_z = \lambda e^{-\delta z}$, where $\lambda = 0.8,\ \delta = 0.08$ and standard deviation $M = 0{,}07$ (b). On Fig 5 is shown graphs with these coefficients.


(a)

(b)

Figure. 5. Hodograph obtained using the method of empirical orthogonal function is a black line; velocity hodograph for Ekman model is a blue line

a) K_z = 0,0011 m^2/s, b) $K_z = \delta e^{\lambda z}$; δ = 0,08; λ = 0,8.

4 The continuous temperature measurements

In 2013, 2015 and 2018 years the measurements of temperature were carried out. The surface temperature was analyzed using the method of empirical orthogonal functions. The Fig. 6 shows the correlation of surface temperature with the air temperature.

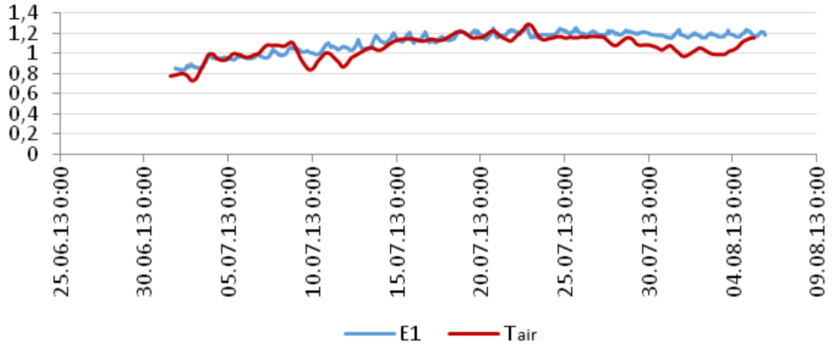


Figure 6. 2013, r = 0.74, r = 0.744 (with a delay of 1.5 hours), r = 0.746 (with a delay of 3 hours).

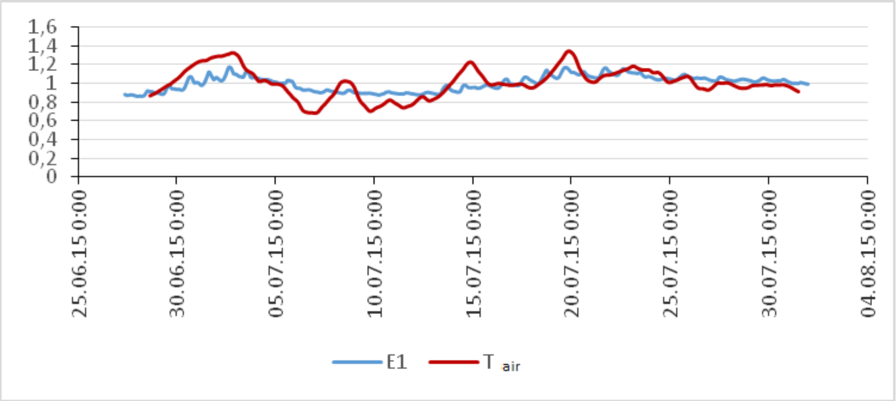


Figure 7. 2015, r = 0.7. r = 0.73 (delay of 3 hours).

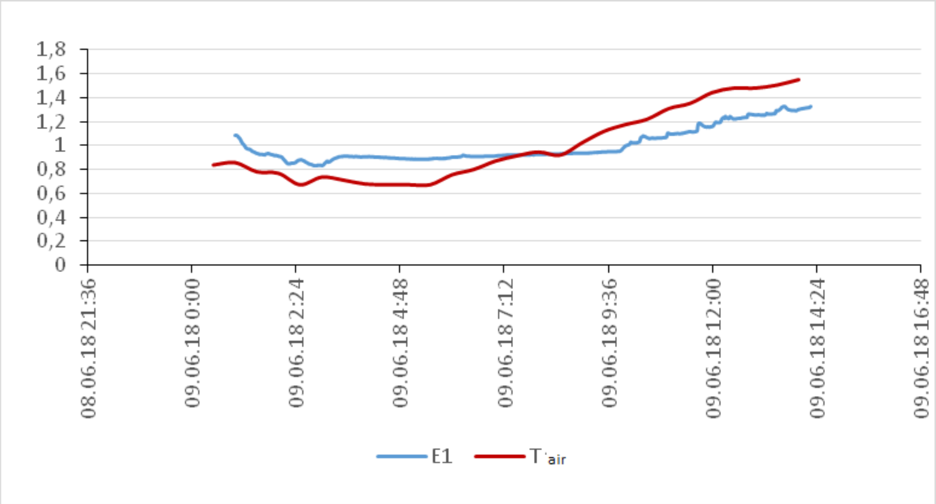


Figure 8. 2018, r = 0.91, r = 0.96 (with a delay of 1.5 hours), r = 0.92 (with a delay of 3 hours).

5 Conclusion

The application of the empirical orthogonal functions in the analysis of long-term measurements of the current velocity and temperature in Lake Shira made it possible to identify the peculiarities of the current in the lake in summer.

The correlation between the first modal coefficient and the surface air temperature is maximum, if it’s calculated with a shift of 1.5-2 hours.

In the upper mixed layer, the analysis of the first mode of the velocity and its comparison with the analytical solution for a stationary flow of a homogeneous fluid showed the advantage of using an exponentially decreasing coefficient of vertical turbulent exchange compared to the case of constant coefficient of vertical turbulent exchange

The analysis of the direction of the flow using a drifter showed that the direction of the wind circulation in the region of Lake Shira and the surface current are generally consistent.

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