AIR/SURFACE INTERACTION OVER SMALL LAKE IN WINTER

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INTRODUCTION

Adequate estimation of gas emission from the northern territories requires calculation of balances of heat, moisture, and gases at the surface of water bodies on the sub-grid scale of climate models. Lakes are an important ”liquid land” surface type. Having a lower albedo and larger heat capacity than solid land, lakes absorb more solar radiation and store more heat, and often have different surface temperature than the surrounding landscape. Lake surfaces are aerodynamically much smoother than vegetated land surfaces, thus enhancing variations of fluxes of momentum, heat, moisture and gases between the land and the atmosphere. Existent estimations of lake-atmosphere fluxes are often based on experimental studies in the ocean and lakes where the wind sheltering and mesoscale turbulence effects are not significant.

Quantification the momentum, heat, and mass exchange between the atmosphere and the underlying surface is a central problem of the atmospheric boundary-layer (ABL) research. Parameterization of air-sea/land fluxes is of obvious relevance for the modelling of coupled atmosphere-ocean/land system, including climate modelling, weather forecasting, environmental impact studies, and many other applications. Traditionally, the flux-gradient and flux-variance relationships in the surface layer are described by Monin-Obukhov similarity theory (Monin and Obukhov 1954), which assumes horizontal homogeneity of the underlying surface, including surface fluxes, aerodynamic and thermal roughness (Garratt 1994; Kaimal and Finnigan 1994; Wyngaard 2010). This assumption is reasonable in many instances, and allows focusing on 1-D processes, but it is nominally violated in the inhomogeneous forest zone where horizontal gradients are steep (Panin, Bernhofer 2008). Statistical properties of turbulence in the atmospheric surface layer have been extensively studied over homogeneous surfaces. However, detailed description of disturbances in the flow, generated over transition zones between surfaces with different roughness remains an important subject of theoretical and experimental studies (Garratt 1990, 1994, Coceal and Belcher 2005, Detto et al, 2008). This task is complicated by the absence of energy balance closure formulation -is a fundamental and pervasive problem in micrometeorology (e.g., Foken, 2008; Panin and Bernhofer 2008; Leuning et al. 2012 and references therein).

This paper presents the results of experimental studies of the turbulent structure of the surface layer in winter. Experiments were conducted over a small lake (close to White Sea Biological Station (WSBS) of Moscow State University) surrounded by forest.. The purpose of this study is evaluation of turbulent transport in the system “lake water– near-surface air – surrounding forest”. In order to distinguish the influence of the inhomogeneous landscape on the turbulent exchange in the atmosphere-surface system, excluding the effects of the thermal regime of the lake, the experiment was carried out in winter time over an ice-covered lake surface. In the first case (2015) we used an array of acoustic anemometers mounted at different distances from the lake. Measurements were taken at two heights in the center of the lake. In the second case (2017) 6-meter mast with instruments was installed in the center of the lake. There were 3 levels of ultrasonic three-component anemometers (2m, 4m and 6m) and two levels of standard meteorological measurement (3m and 5m). Temperature profile in the atmosphere was recorded with 50m step by microwave profiler MTP-5. Turbulent fluxes were calculated with Eddy-Covariance and gradient methods.

RESULTS

In the cold period under stable conditions more intensive vortex formation is observed. Maximum magnitude of vortices is comparable to the size of the lake. Over substantially inhomogeneous surface (such as the smooth surface of the lake, surrounded by forest) mesoscale structures with a discrete set of sizes, depending on the lake size were observed. Sensible heat flux (H) from the northern part and from the southern part were comparable; however, the friction velocity (u*) was 40% smaller in the north when compared to that in the south. Hence, in the first order analysis the flow into the forest edge experiences a significant ‘‘jump’’ in the mean momentum flux but no concomitant change in the sensible heat flux (Fig. 1).

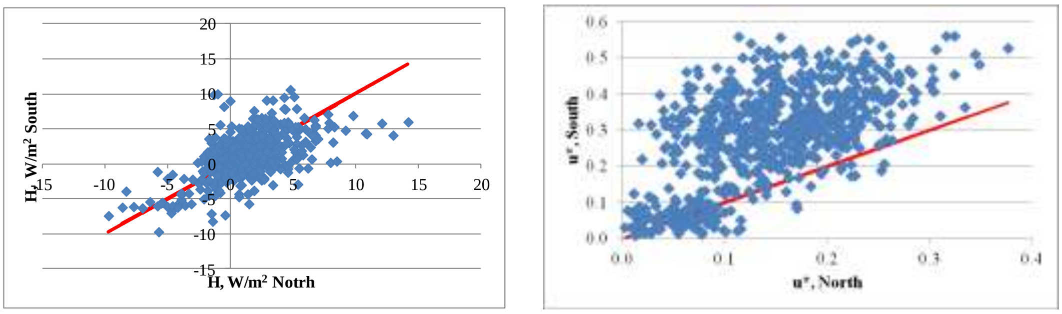

Figure 1. Comparisons between (a) friction velocity (u*), (b) sensible heat flux (H) measured in the northern and southern parts of the lake.

It was revealed that the intensity of the turbulent transfer essentially depends on the height and location of sensors, and the wind direction. Stratification in the near-to-surface air does not play significant role. Besides, there is no constant-flux layer. When the turbulence of the atmosphere is significant, strong vertical mixing leads to strong heat flux directed from the atmosphere to the surface (negative flow). Because of the non-uniform mixing, the layer of constant flow is absent in this case, which makes it difficult to use the similarity theory to calculate fluxes (Fig. 2).

a) b)

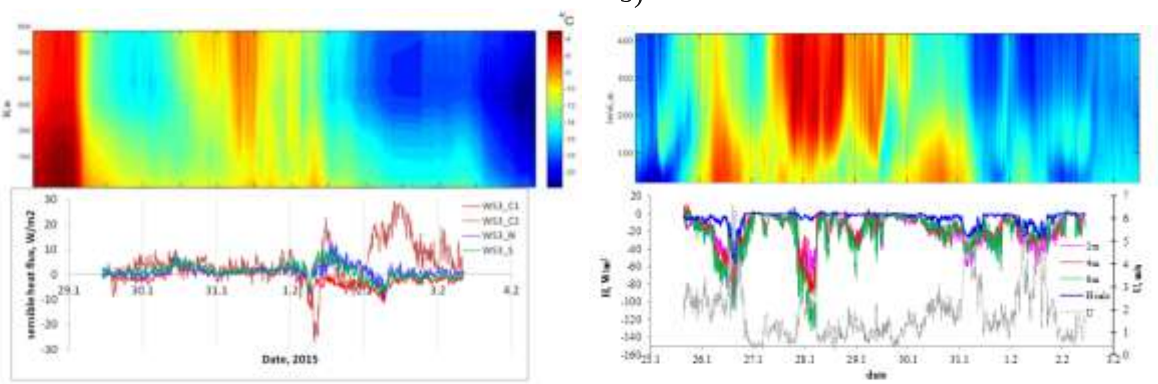

Figure 2. Temperature profile in atmospheric boundary layer and (a) turbulent heat fluxes from measurements, spatial and vertical location of sensors; (b) turbulent heat fluxes from measurements and gradient calculations.

Apparently, the heterogeneity of the landscape (the surrounding forest) also plays a role, leading to the formation of mesoscale circulation. As a result, the values of the measured heat fluxes (about 50-120 W/m^2) and calculations by means of the gradient method (about 5 W/m^2) are significantly divergent.

CONCLUTION

The results show that the calculation of the energy transfer characteristics over inhomogeneous surface by traditional methods, including the similarity theory, is difficult. Due to the discrepancy between the low wind speed and the degree of turbulence, calculations based on the Monin-Obukhov theory underestimate fluxes. Conducted experiments show that the structure of surface boundary layer above small lakes is very complex and that the standard approach in framework of the similarity theory is not applicable. It is necessary to develop new parameterizations including those from LES modeling.
This inhomogeneity generate meso-scale and even sub-meso-scale flows and waves. It is argued here that these (sub) meso-scale motions may significantly contribute to the vertical structure of the boundary layer and hence, to the vertical exchange of heat and mass between the surface and the atmosphere.
Precise estimation of transfer coefficients of air-water momentum, heat, moisture and trace gases is still difficult, resulting in concomitant errors in flux estimates.

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