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Numerical modelling of greenhouse gases in boreal lakes

Lakes occupy a significant part of land in many northern regions, e.g. in Northern Siberia, Karelia, Finland and Canada. The thermodynamic interaction between lakes and the atmosphere results in a spectrum of atmospheric phenomena ranging from internal boundary layer dynamics over lakes to severe snowfalls above unfrozen large lakes in the late autumn. This led to inclusion of lake parameterizations into climate models and numerical weather prediction systems. However, these lake parameterizations are still confined to heat and momentum exchange at the lake-atmosphere interface, whereas observational evidence is growing on the importance of greenhouse gases emissions from lakes. In order to extend our current knowledge on the dynamics of these emissions and gain a capability of making future projections of climate taking into account lake carbon fluxes, suitable modelling framework is to be developed. However, the modelling task faces two kinds of problems here. First, a lake model involving explicit treatment of both key biotic and abiotic controls of methane and carbon dioxide emissions is to be developed. And second, air surface layer parameterizations are needed that are adequate to lake-adjacent typical landscapes met in high latitudes. From this point a special attention must be paid to a case of a lake, surrounded by bluff topography (a forest), that violates the hypotheses underlying Monin-Oboukhov similarity theory. Large Eddy Simulation (LES) occurs to be an only feasible tool to explicitly reproduce turbulent flow and fluxes over such a landscape. In this abstract we present a short overview of the above-mentioned issues with examples from the authors' recent research.

The major methane source in lakes is thought to be an anaerobic organics decomposition, occuring mostly in sediments. This organics originates from different sources: net primary production (NPP) of a lake ecosystem, the organic soil mass collapsing onto the lake bottom as a result of coastal abrasion, groundwater discharge, and an "old" organics at the front of talik below the thermokarst lakes. Once generated, methane is being transported to the atmosphere by three major mechanisms: diffusion of dissolved gas (either in molecular or turbulent mode), bubbling and the transport through aerenchyma of vegetation. The bubbling is the most effective transport mechanism, while diffusion often vanishes in surface waters of deep lakes, where the methane concentration is depleted by an aerobic oxidation. This is one of reasons why shallow lakes usually emit much more methane than the deep ones.

We adopted the one-dimensional model LAKE (Stepanenko et al., 2011) containing a module of methane production, transport and sink processes in bottom sediments and in a water column to three thermokarst lakes in Seida place, Komi Republic, Russia (the meteorological variables and methane fluxes were measured *in situ* by the University of Eastern Finland (Marushchak et al., 2013; Repo et al ., 2009)), and a thermokarst lake Shuchi in Kolyma river basin, Russia (measurements by K.M.Walter Anthony, University of Alaska, Fairbanks). In both cases the model was able to realistically reproduce seasonal methane fluxes, whereas short-scale temporal variability of these fluxes was captured less successfully. The calibration of the model was performed only in the rate of methane production in the bottom sediments.

A modelling study by LES technique (Glazunov et al., 2010), has been performed for an idealized case of an elliptic lake surrounded by forest. The “forest” is represented by a regularly spaced set of vertically elongated blocks. The background boundary layer stratification, wind speed and direction were varied. It is shown, that the statistics of the flow (including fluxes of scalars, e.g. greenhouse gases) are almost insensitive to stratification resulting from turbulent kinetic energy predominantly produced by shear generation at heights around the tree canopy. This strongly questions the applicability the Monin-Oboukhov similarity to this case. Another important conclusion derived is that the constant-flux layer does not exist in the first meters above the lake surface, i.e. the flux at 1.5 m height may differ from that at the surface by 1.6-1.7 times. This has a direct implication for eddy covariance measurements above lakes, that are typically performed at this height.

References

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