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Interactive comment on "Turbulent mixing and heat fluxes under lake ice: the role of seiche oscillations" *by* Georgiy Kirillin et al.

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We thank the reviewer for positive evaluation of our study and for the valuable comments aimed at improvement of the paper readability. We agree to the major remarks of the Reviewer and will incorporate the suggested amendments in the manuscript, unless they appear superfluous and a compromise between detailing and conciseness should be preferred.

The content-related comments/questions are discussed below:

Q: How were the temperature effects on the ice-water heat transport accounted for? What is the effect of the ice structure on the heat transport across the ice cover?

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Discussion paper

A: This fully legitimate comment points at an apparent (and intentional) gap in our study, regarding the heat budget closure of the entire air-ice-water system. Temperature conditions at the two boundaries—the air-ice and the ice-water interface—are indeed crucial for the heat budget of the ice cover. We, however, intentionally limited the scope of the present paper to the heat transport in the water column and its influence on the ice-water heat exchange. By this, we carefully considered the processes governing formation of temperature gradients at the ice base, including convective heating of the ice-covered water column (Section 3.2) and dynamics of the temperature profile in the stratified interfacial layer under ice driven by diurnal variations in convection and by wind-driven ice oscillations (Section 3.4). In turn, the heat budget at the ice surface and within the ice cover are left to be a subject of a parallel study by Leppäranta et al. (2018). There are certain physically justified reasons for this separation. First, the newly discovered mechanism of oscillatory produced turbulence and its effect on the ice-water heat flux required a dedicated analysis. Second, the physics of ice melt allows intuitive differentiation of processes above and beneath the ice base in a straightforward way, as described below.

The heat exchange at the upper ice boundary is dominated by the air temperatures, which varied during the observations period in the narrow range from -1 °C to $+2$ °C (see Section 3.1). Hence, for the period under investigation, the ice surface temperature remained close to the freezing point of 0 °C, which also implies that *the entire ice cover had nearly constant temperature of* 0 °C. Slightly positive air temperatures also imply stable conditions in the ice-atmosphere boundary layer, which additionally restrict the surface heat exchange between the atmosphere and the ice cover. The heat budget of the ice cover is driven in this case by the heat exchange at the ice bottom and by the absorption of solar radiation within the ice cover, *whereas the conductive heat transport accross the ice cover is small*. The situation is characteristic of the early stage of the ice cover melt and was considered in detail by Aslamov et al. (2014). A distinctive feature of small polar lakes, also mentioned by the Reviewer, is the inhomogeneous vertical structure of the ice cover. While, as mentioned above, the conductive heat flux during the melting phase is weakly affected by the ice structure due to homogeneous temperature distribution within the ice cover, the crystal orientation, impurities, and air bubbles can play a critical role in absorption of the solar radiation by ice. This fact provides a tentative explanation for the relatively high ice melting rates during the observation period, and is considered in detail by Leppäranta et al. (2018). The structure of the ice has a major impact to the melting via the optical properties, albedo and transmittance. In 2014 half of the ice sheet was snow-ice (white ice), and its low transmittance limited the transfer of sunlight to water and also the ice experienced internal deterioration from absorption of solar radiation. At the upper boundary the heat balance was positive and caused surface melting. The surface heat balance was dominated by the solar + longwave radiation balance, turbulent fluxes being small. Upper surface melting and internal melting accounted for 1–2 cm per day.

To provide the reader with an appropriate context, a modified version of the above paragraph will be added to the revised paper.

Q: What is the influence of the under-ice water flow on the ice-water heat exchange?

A: We directly measured the flow rates in the under-ice boundary layer and did not observe any mean flow except the oscillatory water motions due to barotropic seiches (Section 3.4, Figs. 6 and 8). As we demonstrated in a previous study based on data from the same lake (Kirillin et al., 2015), the lake-wide under-ice circulation can indeed be strong under ice at the concluding stage of the ice-covered period, when lateral density gradients form by partial opening of an ice-covered lake. River inflows can also potentially contribute to the under-ice flow, but their effect is often localized along the flow path (Kirillin et al., 2012). The oscillating flows, as discussed in this study, dominate the turbulence production throughout the ice-covered period in small (in terms of the Rossby radius) lakes, whereas density currents are the major turbulence producers in large lakes (Aslamov et al., 2014).

Comments on the minor remarks:

- For the sake of conciseness, we respectfully decline the suggestion on adding of a list of symbols. The paper is not heavily loaded with mathematical derivations, and all symbols are defined at their first appearance. Adding an extra list would be repetitive and would require additional printing costs.
- To suggestion on adding a hydrogeological map: While we agree that the river inflow may potentially affect the ice cover growth/decay, the groundwater generally appears to have a minor influence on the ice cover regime of polar lakes. To avoid overloading of Figure 1 with auxiliary information, we will add the direction of in- and outflow in Kilpisjärvi to the figure.
- The rest of suggestions referred to the figure legends will be thankfully incorporated into the revised version of the paper.

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