Direct measurements of turbulent fluxes in the ice-ocean boundary layer of the central Arctic Ocean: Application of the eddy-covariance method

Yusuke Kawaguchi[1], Benjamin Rabe[2], Mario Hoppman[2], Ivan Kzunetov[2], Alejandra Quintanilla Zurita[2], Jacob Allerholt[2] and Daniel Scholz[2]

[1]*Atmosphere and Ocean Research Institute, The University of Tokyo, Japan*

[2]*Alfred Wegener Institution, Germany*

The long-term prediction of sea ice extent and volume in the Arctic Ocean is a challenging issue even today amid the progressing global warming. It is partially responsible for the uncertainties in the estimate of heat budget around the sea ice, which requires the occasional manned observations. Based on our measurements at different sites in the central Arctic, this study aims to quantify the exchange of heat and momentum between ice and ocean as well as the update of sea ice parameterizations in numerical models. With these aims in mind, we participated in the German-led Arctic expedition 'ArcWatch 1' with RV Polarstern during late summer, 2023. There, we carried out detailed surveys of the heat balance at the ice-ocean boundary layer on sea-ice floes thicker than 1 m, including the direct measurement of turbulent heat flux, $HF = \langle w'T' \rangle$, turbulent kinetic energy, $TKE = (\langle u' \rangle^2 + \langle v' \rangle^2 + \langle w' \rangle^2)/2$, and the interfacial friction velocity, $|\boldsymbol{u}_0^*|^2 = \sqrt{\langle u'w' \rangle^2 + \langle v'w' \rangle^2}$, based on the eddy-

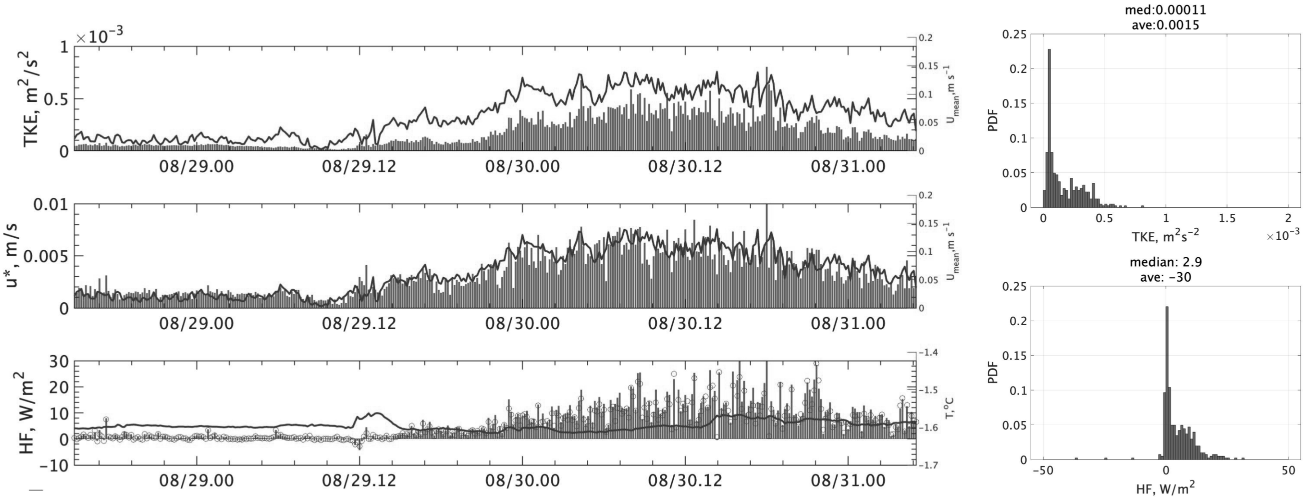

Figure: left) Timeseries of turbulent kinetic energy (TKE), friction velocity (u^*_0), and heat flux (HF) for ice floe #1. Note that HF is positive if directed downward from ice to water. Right) Histograms of TKE (top) and HF (bottom).

covariance method. We also performed a measurement of the conductive heat ($\dot{q}$) through the ice column with a series of temperature sensors on an autonomous drifting buoy (ice buoy). For the eddy covariance flux (ECF) measurements, a three-dimensional velocimeter was situated at a depth of 0.5–0.7 m underneath the bottom surface of a targeted ice floe. The velocimeter was coupled with a temperature sensor, both situated in the same sampling volume for simultaneous data acquisition. The ECF system collected 2048 samples of w and T at frequency of 8 Hz, for a duration of 4 min 16 sec, at a burst interval of 10 min. After the procedure of mean-value subtraction, the deviations of distinct variables are used for the co-spectral calculation. We perform an integral over the frequency domain to obtain the vertical fluxes. From the ice buoy, $\dot{q}$ was calculated from the vertical gradient of ice temperatures over depths of 0.1–0.7 m from the ice surface.

According to our observations in August, we find that the HF was mostly directed upward at the depth of the ECF in the ice-ocean boundary layer. The magnitudes of turbulent variables obtained by the ECF varied depending on the drift speed of the ice floe. Regarding the heat budget, the ECF revealed that HF's variability in a day is highly coherent with the drift speed, whose daily average falls within 5–15 W m^{-2}. The in-situ temperature surveys clarified that the sea-ice column was -1.0 to -0.4°C and apparently warmer than the underlying seawater in the ice-ocean boundary layer, being -1.6 to -1.4°C. From the vertical gradient of ice temperatures, $\dot{q}$ was downward relative to the interface and estimated to be 2–5 W m^{-2}. By tracking the iso-thermal lines near the freezing point, from the ice buoy, the ice floe became thinner by 35 cm over the month. To melt that much ice requires 10 W m^{-2} or more, generally consistent with summation of the two kinds of heat fluxes converging near the interface.

References

Kawaguchi, Y. et al., Turbulent mixing during late summer in the ice-ocean boundary layer in the central Arctic Ocean, J. Geophys. Res. Oceans, 127(8), e2021JC017975, 2022.