EGU21-5304
https://doi.org/10.5194/egusphere-egu21-5304
EGU General Assembly 2021

Deriving the full turbulent stress tensor from paired ADCP measurements: application to under-ice convection

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The Reynolds stress tensor (RST) is the key characteristic of turbulence describing the paths of turbulent kinetic energy transfer and its anisotropy. Despite recent technical advances in application of multi-beam acoustic Doppler current profilers (ADCPs) to in situ acquiring of the RST components, derivation of the full Reynolds tensor from raw flow measurements remains a challenging problem. We present a method for derivation of the full set of turbulent stresses, based on combined use of two ADCPs with two beams from adjacent devices crossing at some point. In the proposed framework, two 3-beam ADCPs with vertically aligned axes constitute the minimum configuration sufficient to derive 6 equations for all 6 RST components.
The method was applied to studying turbulence in a convectively mixed layer in ice-covered Lake Kilpisjärvi. The calculated dynamics of all six stress components revealed diurnal periodicity along with the variations with the periods of a few hours. The pulsations intensities (diagonal components of RST) remained positive except short outliers; less than 5% of cases did not meet the so-called realizability requirements (positive definiteness of the stress matrix). The off-diagonal stresses demonstrated sign-changing dynamics, mirroring the inter-component energy transfer.
The ratio of pulsation intensities along vertical and horizontal axes varied in the range from 0.02 to 0.25. The r.m.s. values of horizontal and vertical pulsations reached diurnal maximums of 4 and 1 mm/s correspondingly, the latter being close to 1/3 of the convective velocity w*, in accordance with the previous studies on free convection.
The new approach provides an immediate insight into the internal structure of the turbulent boundary mixing, especially relevant to anisotropic non-stationary flows, like buoyancy-driven convection. The preliminary results on under-ice convection elucidate strong anisotropy of the convective flow — a key to understanding the heat and mass transport in ice-covered waters.