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The role of snow-surface coupling, radiation and turbulent mixing in modeling a stable boundary layer over Arctic sea-ice

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Observations indicate that the Arctic regions are very sensitive to climate change and warm more rapidly than the global average in the last few decades, a feature known as 'Arctic Amplification'. Global climate models reproduce a similar signal for the Arctic warming, though their magnitude varies substantially both in temporal and spatial patterns. Especially in wintertime, large biases are found, indicating the need for a better understanding of the stable boundary layer (SBL) coupled to the surface. The uncertainty may partly be caused by differences in model formulations for the most relevant snow/ice physics, atmospheric mixing and radiation used in the various models. This multiplicity of processes inspires us to investigate which process has the relatively largest impact in determining the model behavior.

This study focusses on the role of snow-surface coupling, radiation and turbulent mixing in a polar boundary layer. The goal is to gain insight in the relative role of these small scale processes and how these processes can compensate each other. As such, we extend the GABLS1 model intercomparison for turbulent mixing (Cuxart et al., 2006) with the other relevant physical processes in the SBL over sea-ice. We use the Single Column Model (SCM) version of the Weather Research and Forecasting (WRF) mesoscale meteorological model and run different combinations of boundary-layer and radiation schemes (using one state of the art surface scheme). As such, an intercomparison of schemes within a single model is obtained. We confirm a wide variety in the state of the atmosphere and the surface variables for the selected parameterization schemes.

Subsequently, a sensitivity analysis for one particular combination of parameterization schemes is performed for the governing processes of surface coupling, radiation and turbulent mixing. Using a novel analysis method based on time-integrated SBL development, the variation between the sensitivity runs indicates the relative orientation of model sensitivities to variations in governing processes. Furthermore, this sensitivity can explain the variety of model results obtained in the intercomparison of different parameterization schemes.

We apply the same analysis for several geostrophic wind speeds to represent a wide range of synoptic conditions. Our results indicate a shift in process significance for different wind regimes. For low wind regimes, the model sensitivity is larger for coupling and radiation, while for high wind speeds, not surprisingly, the largest sensitivity is found for the turbulent mixing process. Additionally, we find that for the studied variables, the orientations of the processes can overlap. This implies that compensating errors in the different parameterization schemes can remain hidden and this may explain the relatively slow progress in model development. Furthermore, an interesting non-linear feature was found for turbulent mixing for frequently occurring and low wind speed cases, where the 2m temperature increases for decreased amounts of mixing.