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A sensitivity study on wintertime low-level mixed-phase Arctic clouds using LES simulations

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Arctic air mass transformation is linked to the evolution of low-level mixed-phase clouds. These clouds can alter the structure of the boundary layer and modify the surface energy budget due to their greenhouse warming effect. In this study, we used a large-eddy simulation model (MIMICA) coupled to a bulk sea ice model to study in detail wintertime advection of moist and warm air over sea ice from a Lagrangian perspective. We examined the stages of cloud formation, evolution and decay and thus the transition from a stable to a well-mixed boundary layer and vice versa. Furthermore, we conducted sensitivity tests in order to examine how different dynamical and cloud microphysical parameters affect the liquid water path (LWP), ice water path (IWP), net surface longwave radiative flux and lifetime of the cloud. All simulations were carried out assuming prescribed constant cloud condensation nuclei (CCN) and ice crystal number concentrations (ICNC). The results show that radiative cooling at the surface give rise to fog formation which is elevated and transformed into a mixed-phase cloud. Due to top-down convection, the boundary layer becomes well-mixed as a coupling between the surface and cloud turbulent regimes is achieved. In our baseline simulation, the cloud persists for about 5 days altering the surface energy balance by increasing the downward longwave radiative flux. The net surface longwave radiative flux is balanced mainly by the conductive heat flux from the ocean beneath the sea ice to the atmosphere. After approximately 5 days of simulation, the cloud glaciates due to the Wegeron-Bergeron-Findeisen (WBF) process leading to a sharp decrease of the surface temperature. The sensitivity tests show that the LWP is mostly affected by the CCN concentration and ICNC but also by the drizzle formation. The IWP is most sensitive to horizontal convergence and divergence and thereafter to the ICNC . During the time period before the cloud reaches its maximum LWP, the net surface longwave radiative flux is mostly sensitive to the LWP. After the maximum is reached, the IWP becomes more important in determining the surface energy budget. Horizontal convergence and divergence strongly affect cloud lifetime. A change in these values modified the cloud lifetime in our simulations to between 2 to more than 6 days. Changes in the ICNC and CCN concentration also modified the cloud lifetime, but to a lesser extent (about half a day). However, if drizzle was suppressed completely, the cloud glaciated much faster than in the baseline case so that the lifetime decreased to approximately 4 days.