Fingerprints of Arctic aerosol-cloud-turbulence interactions in conserved variable space

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Abstract

Late springtime Arctic mixed-phase convective clouds over open water in the Fram Strait as observed during the recent ACLOUD field campaign are simulated at turbulence-resolving resolutions. The main research objective is to gain more insight into the coupling of these cloud layers to the surface, and into the role played by interactions between aerosol, hydrometeors and turbulence in this process. A composite case is constructed based on data collected by two research aircraft on 18 June 2017. The boundary conditions and large-scale forcings are based on analysis data, while the case is designed to freely equilibrate towards the observed thermodynamic state. The results are evaluated against a variety of independent aircraft measurements. The observed cloud macro- and microphysical structure is well reproduced, consisting of a stratiform cloud layer in mixed-phase fed by surface-driven convective transport in predominantly liquid phase. A 3D volume rendering of the simulated liquid clouds is shown in the Figure. Comparison to noseboom turbulence measurements suggests that the simulated cloud-surface coupling is realistic. A joint-pdf analysis of relevant conserved state variables is then conducted, suggesting that locations where the mixed-phase cloud layer is strongly coupled to the surface by convective updrafts act as “hot-spots” for invigorated turbulence, cloud and aerosol interactions. A mixing-line analysis reveals that the turbulent mixing is similar to warm convective cloud regimes, but is accompanied by hydrometeor transitions that are unique for mixed-phase cloud systems. Distinct fingerprints in the joint-pdf diagrams also explain i) the typical ring-like shape of ice mass in the outflow cloud deck, ii) its slightly elevated buoyancy, and iii) an associated local minimum in CCN. The obtained modeling results advocate the application of this analysis method also to observational datasets.

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Fingerprints of Arctic aerosol-cloud-turbulence interactions in conserved variable space

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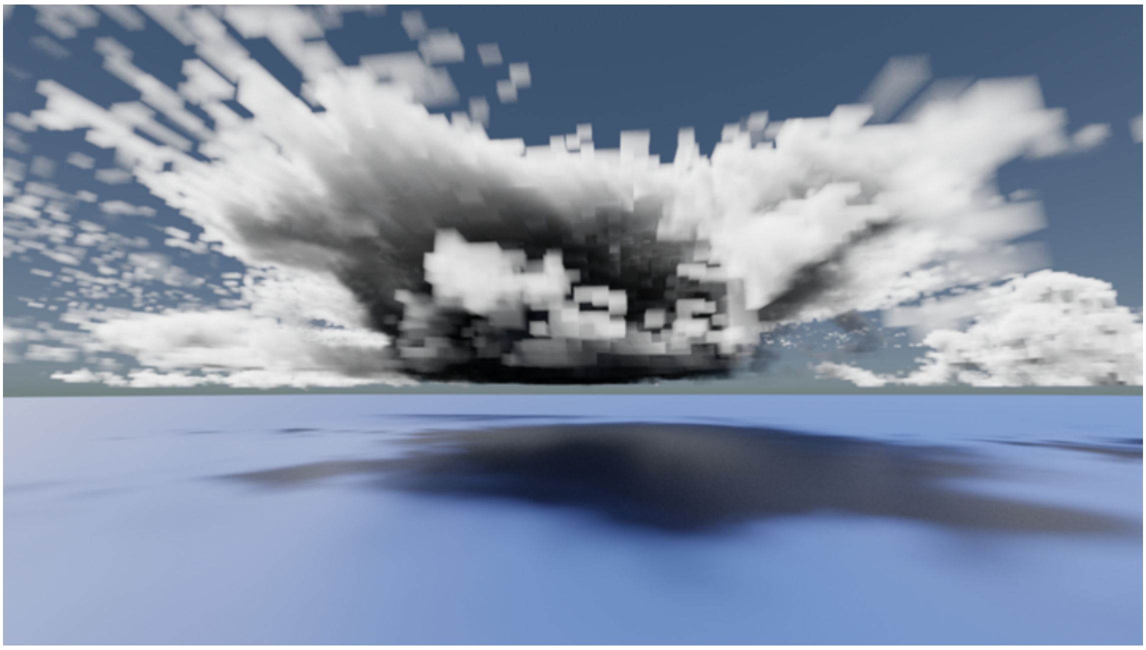
Abstract Text:

Late springtime Arctic mixed-phase convective clouds over open water in the Fram Strait as observed during the recent ACLOUD field campaign are simulated at turbulence-resolving resolutions. The main research objective is to gain more insight into the coupling of these cloud layers to the surface, and into the role played by interactions between aerosol, hydrometeors and turbulence in this process. A composite case is constructed based on data collected by two research aircraft on 18 June 2017. The boundary conditions and large-scale forcings are based on analysis data, while the case is designed to freely equilibrate towards the observed thermodynamic state. The results are evaluated against a variety of independent aircraft measurements. The observed cloud macro- and microphysical structure is well reproduced, consisting of a stratiform cloud layer in mixed-phase fed by surface-driven convective transport in predominantly liquid phase. A 3D volume rendering of the simulated liquid clouds is shown in the Figure. Comparison to noseboom turbulence measurements suggests that the simulated cloud-surface coupling is realistic. A joint-pdf analysis of relevant conserved state variables is then conducted, suggesting that locations where the mixed-phase cloud layer is strongly coupled to the surface by convective updrafts act as "hot-spots" for invigorated turbulence, cloud and aerosol interactions. A mixing-line analysis reveals that the turbulent mixing is similar to warm convective cloud regimes, but is accompanied by hydrometeor transitions that are unique for mixed-phase cloud systems. Distinct fingerprints in the joint-pdf diagrams also explain i) the typical ring-like shape of ice mass in the outflow cloud deck, ii) its slightly elevated buoyancy, and iii) an associated local minimum in CCN. The obtained modeling results advocate the application of this analysis method also to observational datasets.



Plain-Language Summary:
Marine clouds over open water close to the sea ice edge play an important role in the rapidly shifting Arctic climate system. These clouds typically contain both liquid droplets and ice chrystals. They are also often convective in nature, driven by the large temperature difference between air and ocean. How exactly these clouds work is not fully understood yet, in particular the role played by interactions between turbulence, cloud processes and atmospheric aerosol. This study aims to increase our understanding of such marine mixed-phase convective cloud systems, by combining measurements from the recent ACLOUD campaign in 2017 the Fram Strait with high-resolution simulations on supercomputers. First the realism of the simulated clouds is investigated, making use of a variety of aircraft measurements. A 3D volume rendering of these simulated convective clouds is shown in the Figure. The nature of the cloud system is then further investigated by considering data clustering in scatterplots of selected atmospheric variables as sampled from the simulations. We find that aerosol-cloud-turbulence interactions leave distinct fingerprints in such diagrams. While this provides new insights into the inner workings of such cloud systems, the results also advocate the application of this technique to observational datasets.

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