Arctic Mixed-phase Clouds Persist with Little Help from the Local Surface

Research Highlight

The persistence of Arctic low-level stratiform, mixed-phase clouds has been an important emerging topic over the past decade. Significant radiative effects from these clouds modulate the surface energy budget, which plays a critical role in ongoing dramatic decreases in sea-ice extent and other major changes in the Arctic climate system. These clouds are thought to persist through a combination of in-cloud feedbacks and large-scale forcing. The large-scale environment appears to provide the background in terms of atmospheric moisture, while in-cloud radiative-dynamical-microphysical processes act upon the background state to sustain supercooled liquid water. Many details of this system are lacking, in particular the relative partitioning of moisture, energy, and aerosol sources that maintain these clouds. Little is known about these clouds in the central Arctic due to a dearth of cloud observations over sea ice.

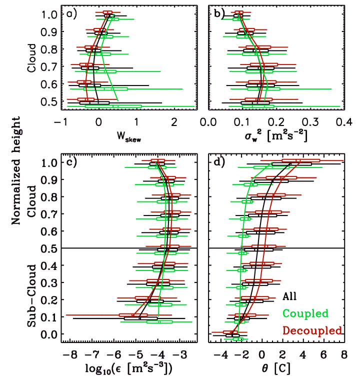

Figure 1. Normalized profiles of (a) vertical velocity skewness and (b) variance, (c) turbulent dissipation rate, and (d) potential temperature. Black curves are all data, while red and green are for decoupled and coupled cases, respectively. Normalization is relative to the cloud top (1.0), base (0.5), and surface (0.0). Box-and-whiskers show the 5, 25, 50, 75, and 95th percentiles while the continuous vertical curves are the mean values.

The Arctic Summer Cloud Ocean Study (ASCOS) took place from an icebreaker stationed near the North Pole in late summer 2008. Aboard the ship was a comprehensive suite of cloud, aerosol, and atmosphere observing instruments, including cloud radar, microwave and infrared radiometers, ceilometer, radiosondes, particle counters, and aerosol profiles measured from a helicopter. Measurements from these instruments were used collectively to characterize cloud dynamical and microphysical properties, aerosol concentrations, and atmospheric structure associated with a week-long period of near-continuous low-level stratiform clouds.

Radiative cooling near the top of these clouds drives upside-down shallow convection over a depth that extends from cloud top, down to below the cloud base. The depth and other properties of this cloud-driven mixed-layer were characterized during ASCOS using a combination of turbulent dissipation rate profiles derived from cloud radar and equivalent potential temperate profiles derived from radiosondes and a scanning microwave radiometer. Layers of high-dissipation rate corresponded nicely with layers identified to be well-mixed from the potential temperature perspective. During the week of observations analyzed here, the cloud-driven mixed-layer base was elevated above the surface, i.e., the cloud was decoupled from the surface 75% of the time. The rest of the time the mixed-layer extended down to the surface, acting to couple the cloud and surface.

Characteristic profiles through the cloud-driven mixed-layer provide insight into the history of air masses supporting these clouds (see Figure 1). Surface-coupled clouds had a mixed-layer equivalent potential temperature near -2°C. This temperature was approximately the same as the surface value, which was constrained by the mixture of sea-ice in open ocean water at the time, and indicated that the cloud-driven mixed-layer was well-mixed with, or equilibrated with, the surface. On the other hand, for clouds that were decoupled from the surface the mixed-layer equivalent potential temperature was, on average, 4°C warmer than the near surface values. This suggests that these mixed-layers had not interacted significantly with the colder local surface. Back trajectory modeling also indicated that air masses associated with surface-coupled cloud scenes had advected into the region at low-levels (near the surface), while those that were decoupled from the surface typically descended as they approached the observation site, originating from locations south of the sea-ice edge.

Helicopter profiles of aerosol number concentration (particles >300 nm that commonly activate to form cloud water droplets) showed a consistent relationship with the cloud and atmosphere structure. For decoupled cloud cases, there was always a minimum in aerosol concentration at some height between the cloud-driven mixed-layer base and the surface. On the other hand, surface coupled cases generally showed a constant aerosol concentration from the surface up to cloud base (i.e., particle number was well-mixed). Lastly, for the few cases with helicopter measurements above cloud top, aerosol concentrations were generally larger.

Together, these findings suggest a few important points about the low-level clouds observed during ASCOS. First, decoupled clouds occurred ~75% of the time during the continuous “stratocumulus” time period. This suggests that decoupled clouds are frequent and persistent. Second, potential temperature signatures and model back trajectories suggest that the cloud-level airmasses had origins to the south of the sea-ice edge. Aerosol profiles indicated that the primary source of aerosols for these low-level clouds was not from the local surface, rather they appear to have advected at, or above, cloud height along with the moisture for cloud maintenance. Lastly, these details together suggest that particle and moisture entrainment near cloud top may be critically important for these clouds.

Reference(s)

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Cloud Life Cycle, Cloud-Aerosol-Precipitation Interactions