An Arctic Springtime Mixed-Phase Cloudy Boundary Layer Observed during SHEBA

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ABSTRACT

The microphysical characteristics, radiative impact, and life cycle of a long-lived, surface-based mixed-layer, mixed-phase cloud with an average temperature of approximately −20°C are presented and discussed. The cloud was observed during the Surface Heat Budget of the Arctic experiment (SHEBA) from 1 to 10 May 1998. Vertically resolved properties of the liquid and ice phases are retrieved using surface-based remote sensors, utilize the adiabatic assumption for the liquid component, and are aided by and validated with aircraft measurements from 4 and 7 May. The cloud radar ice microphysical retrievals, originally developed for all-ice clouds, compare well with aircraft measurements despite the presence of much greater liquid water contents than ice water contents. The retrieved time-mean liquid cloud optical depth of 10.1 ± 7.8 far surpasses the mean ice cloud optical depth of 0.2, so that the liquid phase is primarily responsible for the cloud's radiative (flux) impact. The ice phase, in turn, regulates the overall cloud optical depth through two mechanisms: sedimentation from a thin upper ice cloud, and a local ice production mechanism with a time scale of a few hours, thought to reflect a preferred freezing of the larger liquid drops. The liquid water paths replenish within half a day or less after their uptake by ice, attesting to strong water vapor fluxes. Deeper boundary layer depths and higher cloud optical depths coincide with large-scale rising motion at 850 hPa, but the synoptic activity is also associated with upper-level ice clouds. Interestingly, the local ice formation mechanism appears to be more active when the large-scale subsidence rate implies increased cloud-top entrainment. Strong cloud-top radiative cooling rates promote cloud longevity when the cloud is optically thick. The radiative impact of the cloud upon the surface is significant: a time-mean positive net cloud forcing of 41 W m^{-2} with a diurnal amplitude of ~20 W m^{-2}. This is primarily because a high surface reflectance (0.86) reduces the solar cooling influence. The net cloud forcing is primarily sensitive to cloud optical depth for the low-optical-depth cloudy columns and to the surface reflectance for the high-optical-depth cloudy columns. Any projected increase in the springtime cloud optical depth at this location (76°N, 165°W) is not expected to significantly alter the surface radiation budget, because clouds were almost always present, and almost 60% of the cloudy columns had optical depths >6.

1. Introduction

Recent decades have witnessed a resurgence of interest in the Arctic climate, initially driven by general circulation model simulations that indicate a strong Arctic response to increasing greenhouse gases (e.g., Houghton et al. 1995). Observations show some support for annual-mean model predictions; these include a rapid warming of the Arctic surface (Chen et al. 2002; Serreze et al. 2000; Stone 1997), decreasing sea ice extent and thickness (Chapman and Walsh 1993; Parkinson et al. 1999), changes in water vapor advection (Groves and Francis 2002), and vegetation changes (Sturm et al. 2001).

An increase in spring and summer cloudiness and decrease in winter cloudiness from 1982 to 1999 has also been noted in satellite data (Wang and Key 2003). Surface observations at Barrow, Alaska, similarly report an increasing spring cloudiness over time (Stone et al. 2002), and increases in springtime cloud optical

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