J2.11 PROPERTIES OF WATER-ONLY, MIXED-PHASE, AND ICE-ONLY CLOUDS OVER THE SOUTH POLE: PRELIMINARY RESULTS

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1. INTRODUCTION

The South Pole Atmospheric Radiation and Cloud Lidar Experiment (SPARCLE) was conducted at South Pole Station in the austral summer of 1999/2000 and throughout the full year of 2001 (Walden et al, 2001). As part of SPARCLE, we have studied climate processes over the Antarctic Plateau, including humidity, temperature, and pressure measurements in the near-surface inversion layer (Hudson et al., 2004), the water vapor continuum at low temperatures (Rowe et al., 2006), spectral downwelling longwave radiation and cloud fraction (Town et al., 2005), and long-term changes in cloud cover (Town et al., 2006).

We are also studying the microphysical properties of clouds. Walden et al (2005) have shown that water-only clouds exist at low temperatures (below –30 C) at South Pole. Therefore, it is important to fully understand the occurrence of different cloud types over the annual cycle, because of their large effect on the radiation budget. Lubin et al. (1998) have shown that the general circulation over Antarctica is sensitive to the phase of the cloud particles. It is, therefore, important to distinguish the microphysical properties of water, mixed-phase (water and ice), and ice clouds over Antarctica. This paper describes some preliminary results of microphysical properties of clouds observed over South Pole Station in February and May of 2001.

2. INSTRUMENTATION

During SPARCLE, the Polar Atmospheric Emitted Radiance Interferometer (P-AERI) was operated nearly continuously from January through October 2001. The P-AERI measures downwelling spectral infrared radiance at a resolution of 1 cm^{-1} between about 420 and 3000 cm^{-1} (3 – 24 micrometers). The infrared spectra are used here to retrieve microphysical properties of clouds over South Pole Station. The uncertainty in the P-AERI measurements are discussed by Town and Walden (2005); the AERI instrument, in general, is described by Knuteson et al. (2004a,b). In addition, a micropulse lidar (MPL) was operated during the year [Campbell et al., 2002; Welton and Campbell, 2002]. Since clouds are thin over South Pole [Mahesh et al. (2001); Mahesh et al. (2005)], the MPL routinely measures both cloud-base and cloud-top heights. On occasion, In-situ measurements of cloud particles were made using a hydrometeor videosonde (HYVIS) (Murakami and Matsuo, 1990; Orikasa and Murakami, 1997). Walden et al. (2005) have reported preliminary results of the size distribution of super-cooled water clouds over South Pole from HYVIS measurements.

During 2001, the South Pole Meteorological Office launched radiosondes to measure the temperature, humidity, wind speed, and wind direction as a function of pressure. Over the course of this year, the SPMO transitioned from using Atmospheric Instrumentation Research (AIR) model 5A sondes to Vaisala RS-80 sondes, so the quality of the sonde profiles varies throughout the year. Hudson et al. (2004) have shown that the humidity profiles measured by AIR 5A sondes are biased quite low in relative humidity and have very long response times to changes in atmospheric humidity as compared to the Vaisala RS-80 sondes. The effect of the humidity profiles on the retrievals described below are currenlty being investigated.

3. METHODS

Retrievals of cloud microphysical properties were derived using the method of Turner et al. (2003) and Turner (2005). This method uses as input, a cloud mask derived from the MPL, the infrared spectra from the P-AERI, and clear-sky radiative transfer calculations using radiosonde profiles as input. The radiative transfer calculations were performed with the line-by-line

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radiative transfer model (LBLRTM) (Clough et al., 1992). Turner's model then retrieves the effective particle radius and optical depth, as well as the particle phase. The determination of cloud particle phase has shown good agreement with depolarization lidar measurements in the Arctic even in mixed-phase clouds (D. Turner, pers. comm., 2006).

In this study, we use retrievals that have been determined from zenith-looking P-AERI measurements to derive cloud optical depth and effective radius. However when determining the relative occurrence of different cloud types, we use all current sky viewing angles in the P-AERI dataset. We also use 2 February 2001 as a test case, because we have in-situ measurements of cloud particles from the HYVIS on that day from 0245 to 0400 UTC.

4. RESULTS

Some preliminary retrieval results are shown in Figures 1 and 2 for 2 February 2001 and 1 May 2001. Part (a) in each figure shows an image of the MPL data for that day; the x-axis is in Fractional Day and represents a 24-hour period. Part (b) shows the microphysical-property retrievals for the same 24-hour period; the upper panel shows the particle phase, the middle panel shows the infrared optical depth, and the lower panel shows the effective particle size.

On 2 February, the MPL detected a fairly uniform low-lying cloud. The retrievals show that the clouds are almost entirely mixed-phase. The retrievals of optical depth indicate that most of the cloud is composed of water droplets [black bars (from water) compared with white bars (from ice)]. The effective particle sizes throughout the day are between about 5 and 10 micrometers. The particle sizes for water droplets and ice crystals are comparable.

There is good agreement with the in-situ results from the HYVIS between 0245 and 0400 UTC. Walden et al. (2005) report that the HYVIS measured only super-cooled water droplets during this time period. They also reported a size distribution with a mode of about 7 to 8 micrometers. The mean effective radius from the retrievals is about 7 micrometers over this time period.

The situation is quite different on 1 May 2001 (Figure 2). The MPL shows high clouds about 5 to 7 kilometers above the surface, which are sometimes multi-layered. The retrievals show that the clouds are ice-only. The optical depth is much lower than the Feb case, by about a factor of 10. (Notice the different scale in optical depth on the y axes of Figures 1 and 2.) The sizes of the ice crystals are between about 5 and 10 micrometers. These sizes are smaller than those reported by Walden et al. (2003) for *precipitated particles* (primarily blowing snow and diamond dust), which have typical sizes 10 to 15 micrometers.

We have also investigated the fraction of cloud types (water-only, mixed-phase, and ice-only) over South Pole for the months of February and May 2001. The seasonal cycle at South Pole is usually defined as: summer (December, January), autumn (February, March), winter (April, May, June, July, August, September), and spring (October, November). Because of this, February represents a transition period from summer to winter, while May represents the deep winter. We are interested in determining how often do mixed-phase clouds exist at South Pole throughout the year? To answer this question, we use the retrievals to calculate the relative occurrence of water-only, mixed-phase, and ice-only clouds for February and May. First, the MPL data are used to determine clear versus cloudy skies. Then the retrievals are used to determine the type of cloud for all cloudy cases.

The results for February 2001 are shown in Figure 3. For the first couple of weeks, the clouds are primarily of water-only and mixed-phase. However toward the end of the month, ice-only clouds become more prevalent. On 26 February, almost all the clouds are composed of ice. On this day, the surface temperature was below –40 C, but there were days earlier in the month when this was also the case, especially on days with clear-sky conditions. However, this was the first day of the year when the temperature at the top of the near-surface inversion layer (at about 600 meters above the surface) dipped below –30 C. This may indicate that the entire lower troposphere must cool off sufficiently before ice-only clouds become the dominant cloud type. Data from March 2001 will hopefully confirm the conditions under which ice-only clouds become prevalent. Note that preliminary results for May 2001 show that virtually all clouds are ice-only in winter.

5. CONCLUSIONS

Retrievals of cloud microphysical properties over South Pole Station in 2001 indicate that mixed-phase and water-only clouds exist well into autumn. The retrieved particle sizes agree well with validation data from in-situ measurements made on 2 February 2001. Ice-only clouds appear to predominate when the lower troposphere over the Antarctic Plateau cools below about –30 C.

6. ACKNOWLEDGMENTS

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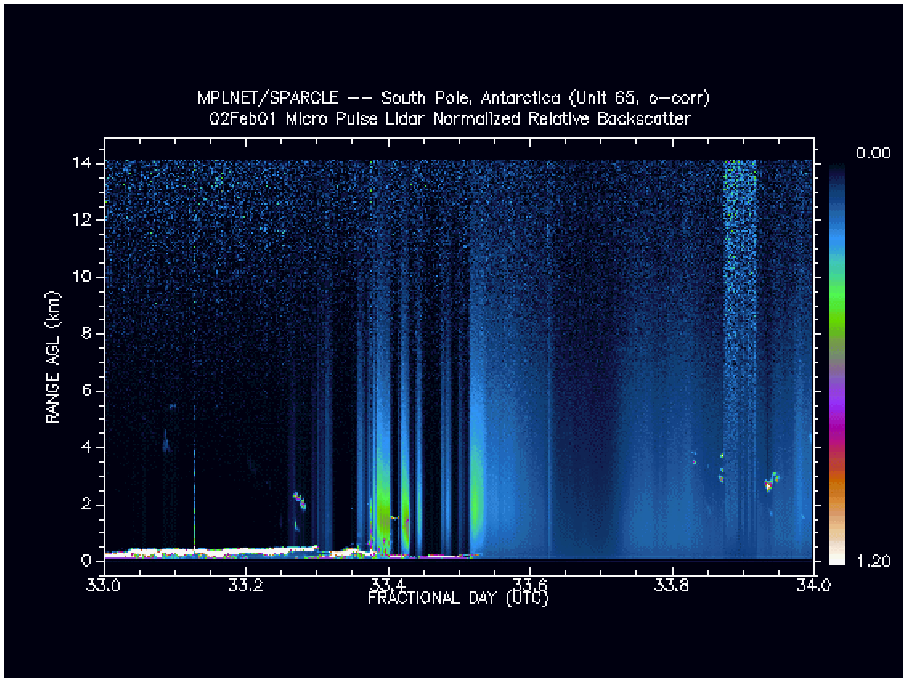
a)



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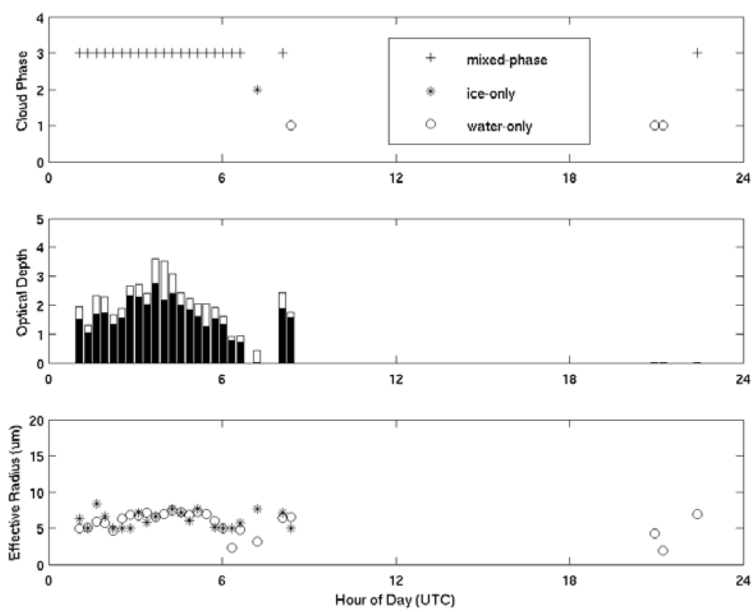
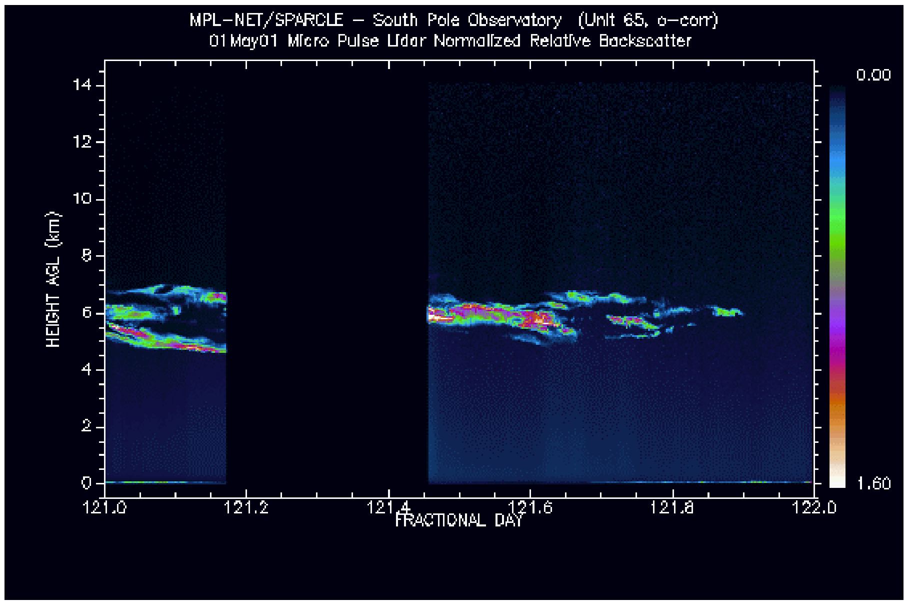


Figure 1. a) Normalized relative backscatter from the micropulse lidar (MPL) measured at South Pole Station on 2 February 2001. The abscissa is Fractional Day. The ordinate is the height above the surface; the surface elevation at South Pole is 2835 meters above sea level. **b)** Retrievals of cloud microphysical properties derived using the method of Turner (2005). The upper panel shows the cloud particle phase (1 = water-only, 2 = ice-only, and 3 = mixed-phase). The middle panel shows the infrared optical depth, and the bottom panel shows the effective radius of cloud particles for both ice crystals (asterisk) and water droplets (open circles).

a)



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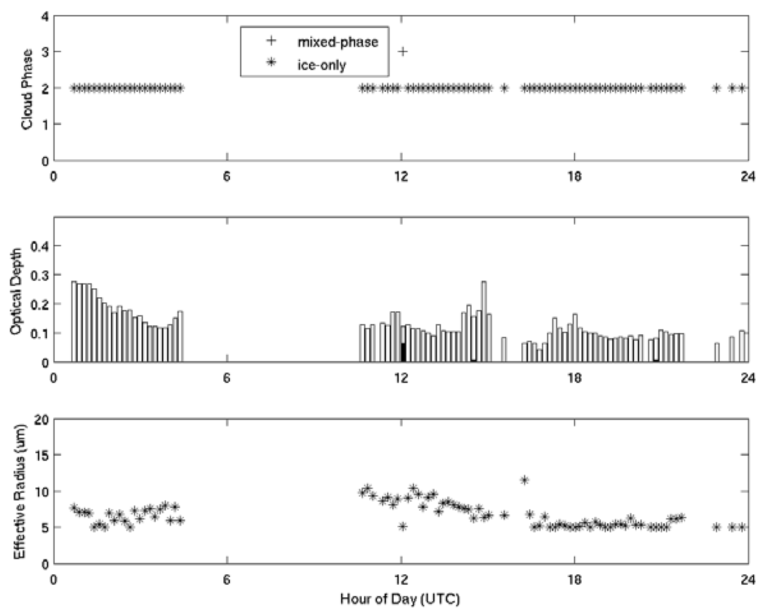

Figure 2. **a)** Normalized relative backscatter from the micropulse lidar (MPL) measured at South Pole Station on 1 May 2001. The abscissa is Fractional Day; data are missing between 121.2 and 121.45 days. The ordinate is the height above the surface; the surface elevation at South Pole is 2835 meters above sea level. **b)** Retrievals of cloud microphysical properties derived using the method of Turner (2005). The upper panel shows the cloud particle phase (1 = water-only, 2 = ice-only, and 3 = mixed-phase). The middle panel shows the infrared optical depth; this scale differs by a factor of 10 from Figure 1. The bottom panel shows the effective radius of cloud particles for both ice crystals (asterisk) and water droplets (open circles).

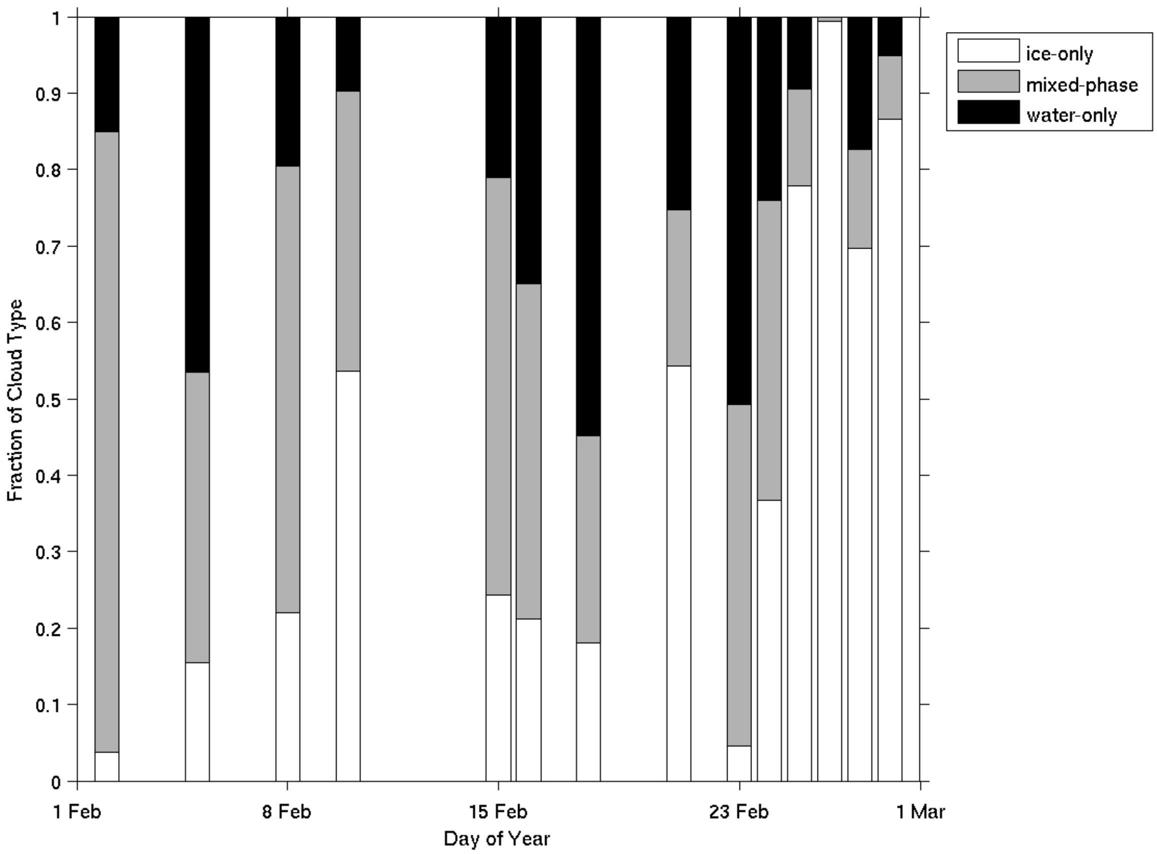

Figure 3. Relative occurrence of different cloud types (ice-only, mixed-phase and water-only) for the month of February 2001 at South Pole Station. Only days that have sufficient data for averaging (between 41 and 196 P-AERI measurements) are shown. Clear-sky conditions occurred on 6, 11, 12, 13, and 14 February 2001.