Cirrus Cloud Bimodal Size Distributions from ARM Remote Sensing Data

Research Highlight

Aircraft data collected in cirrus clouds suggest that significant bimodality of the particle size distribution (PSD) is a common occurrence and that total ice crystal concentrations exceed 1 per cubic cm. While there are good reasons to suspect that bimodal PSDs occur in cirrus, the extreme bimodality in aircraft data and the very high concentrations of crystals were difficult to explain theoretically. The ARM remote sensing data are well suited for exploring this problem because the millimeter-wavelength cloud radar (MMCR) effectively measures the largest particles in a PSD while the Raman lidar is able to provide information on the smaller population of ice crystals—all this without touching the crystals and potentially changing their character. Therefore, an optimal estimation algorithm that uses millimeter wavelength Doppler radar moments and Raman lidar extinction was developed to retrieve cirrus PSDs that consist of two independent modified gamma functions. These distribution functions, when combined, have the capacity to describe the strongly bimodal PSDs reported by aircraft in situ probes.

In situ measurements from the 2000 cloud IOP at the ARM Southern Great Plains (SGP) site are used to compare with the retrieval results. The PSD in situ data from the 2DC for large particles agree well with data from retrievals. For smaller particles, the number concentrations observed by the FSSP are much higher (by approximately a factor of 10) than what is derived from the remote sensing data and are well outside the retrieval uncertainties. To bring the small particle concentration retrieved from the remote sensing data into agreement with the FSSP, the Raman lidar extinction would need to be increased by a factor of five. Since the Raman lidar-derived optical depth agrees reasonably with optical depths derived from the multifilter rotating shadowband radiometer, we conclude that the FSSP data are erroneous.

The statistics of cirrus microphysical properties are derived by applying the retrieval algorithm to 313 h of 10-min averages collected over the ARM SGP site during 2000. The PDFs of the IWC, the effective radius, and the number concentration for different temperature ranges are shown in Figure 1. Among other characteristics, this graphic shows that concentrations of small particles in excess of 1 per cubic cm in cirrus are exceedingly rare, with average concentrations near 100 per liter.

However, PSD bimodality does seem to be an important feature of many cirrus clouds. In Figure 2, we plot the frequency of occurrence of PSD bimodality for the temperature ranges shown in Figure 1. We find that bimodality in the PSD is rare at cold (T. 223 K) temperatures but is a significant feature of many cirrus layers, with 40% frequencies of occurrence in warmer (T. 243 K) cirrus layers.

While high concentrations of small particles in excess of 1 per cubic cm appear to be a rare feature in most middle latitude cirrus clouds, there are likely regions of nucleation where such high concentrations exist. However, the ubiquity with which aircraft suggested these high concentrations is not consistent with ARM remote sensing data. We do find that bimodal PSDs are a common feature in many warm cirrus layers, and accounting for small and large modes in many retrieval algorithms will be necessary. Further research is needed to understand why these bimodal PSDs are present in these clouds.

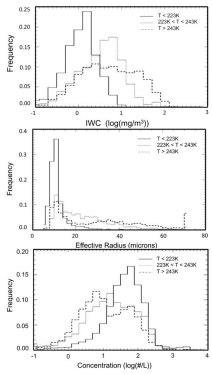

Figure 1. Frequency distribution of ice water content (top), effective radius (middle), and crystal concentration (bottom) derived from 313 h of cloud property retrievals using the bimodal algorithm. The distributions are shown as a function of the layer-mean temperature shown in the legend.

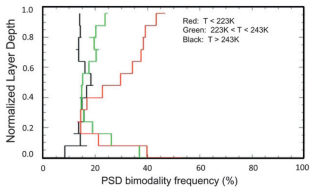

Figure 2. Vertical profiles of the frequency of occurrence of significant bimodality as a function of layer-mean temperature derived from 313 h of cirrus over the SGP site.

Reference(s)

Zhao Y, GG Mace, and JM Comstock. 2011. "The occurrence of particle size distribution bimodality in midlatitude cirrus as inferred from ground-based remote sensing data." Journal of the Atmospheric Sciences, 68(6), doi:10.1175/2010JAS3354.1.

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