Mixed-Phase Cloud Vertical Velocities and Dynamical-Microphysical Interactions

Contributors
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Research Highlight

Vertical air motions play a key role in determining the microphysical composition of clouds. In order to examine this dynamical-microphysical interaction in more detail, a method has been developed to derive vertical air motions in liquid-containing clouds from cloud radar Doppler spectra. The fundamental assumption of the method is that small cloud particles, in this case liquid water droplets, have a negligible terminal fall speed and therefore act as tracers of vertical air motions. For all cloud parcels identified to contain liquid water droplets, the edge of the measured Doppler spectrum associated with these small particles can be used to estimate the vertical velocity. Corrections to this estimate must be made to account for various spectral broadening effects. Examples of this retrieval are shown in the layer-averaged and vertically resolved vertical velocities in Figures 1a and 1b.

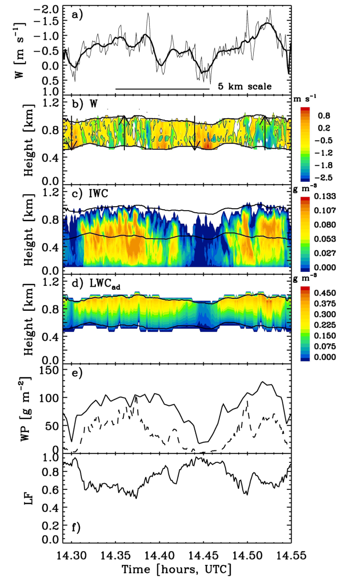

Figure 1. Cloud dynamical and microphysical properties during 28 October 2004 at M-PACE, including (a) layer-averaged vertical velocity, (b) vertically resolved vertical velocity, (c) ice water content (IWC), (d) liquid water content (LWC), (e) liquid (solid) and ice (dashed) water paths, and (f) the liquid fraction, or LWP/(LWP +IWP). Liquid cloud boundaries are included in panels (b), (c), and (d). In panel (a), both the full resolution and a 45-sec running averaged are plotted as well as a bar representing a 5-km length scale.

Radar-derived vertical velocities were evaluated against aircraft measurements made as part of the Mixed-Phase Arctic Cloud Experiment (M-PACE) which took place in the fall 2004 near Barrow, Alaska. While one-to-one comparisons were not possible due to flight patterns, statistical comparisons suggest that the retrieval performs well. A small bias is seen whereby the radar-retrievals indicate upward vertical velocities of 0.1 – 0.2 m/s larger than the aircraft observations. Many profile comparisons show good agreement in terms of both magnitude and vertical structure, while others appear to suffer from differences caused by sampling distinct air masses.

In coordination with these vertical velocity retrievals during M-PACE, single-layer mixed-phase cloud microphysical properties were also derived from ground-based cloud radar, lidar, radiosonde, and microwave radiometer measurements using existing approaches. Example retrievals of both cloud ice and liquid water properties are given in Figures 1c-1f. The associations between vertical velocity and cloud microphysical properties for this time period are quite clear; both liquid and ice mass tend to increase during an updraft and decrease during a downdraft. In general during M-PACE, low-level, single-layer, mixed-phase stratiform clouds were topped by a 400- to 700-m deep liquid water layer from which ice crystals precipitated. These clouds were strongly dominated (85% by mass) by liquid water. Cloud-scale circulations were observed with a temporal variability of up to ±2 m s-1 from the mean state, while dominant scales-of-variability in both vertical air motions and cloud microphysical properties occurred at 0.5 – 10 km wavelengths.

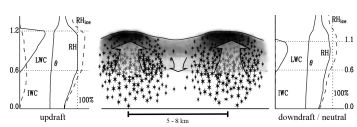

Figure 2. A conceptual model illustrating the interdependence of cloud microphysics, thermodynamic profiles, and vertical motions in autumn Arctic mixed-phase stratiform clouds observed near the coast of Alaska. The bounding plots contain generalized profiles of liquid and ice water content, potential temperature, and relative humidity with respect to both liquid and ice. Horizontal dashed lines are the top and bottom of the cloud liquid (shown at typical heights in km), while the vertical dashed line is RH = 100%. The left plot details the conditions that occur in a broad updraft, while the right plot represents conditions under neutral or downward motion. In the central diagram, the level of shading represents the amount of liquid water mass, the density of stars indicates the amount of ice mass, arrows indicate general air motions, and a horizontal length scale is provided.

Retrievals such as those shown in Figure 1 have been generalized in the context of a conceptual model relating cloud-scale dynamics and microphysics in Arctic autumn stratocumulus (Figure 2). In updrafts, both cloud liquid and ice mass grow, although the net liquid mass growth is usually largest. The liquid water profile becomes nearly adiabatic, while the ice water profile shows a maximum near the base of the cloud liquid water. Between updrafts, nearly all ice falls out and/or sublimates and there appears to be no new ice particle initiation, while the cloud liquid diminishes but does not completely evaporate. The persistence of liquid water throughout these cloud cycles suggests that ice forming nuclei, and thus ice crystal, concentrations must be limited; that ice crystal fallout is significant; and that water vapor is plentiful.

Reference(s)

Shupe, MD, P Kollias, M Poellot, and E Eloranta. 2008. "On deriving vertical air motions from cloud radar Doppler spectra." Journal of Atmospheric and Oceanic Technology 25: 547-557.

Shupe, MD, P Kollias, POG Persson, and GM McFarquhar. 2008. "Vertical motions in Arctic mixed-phase stratiform clouds." Journal of Atmospheric Sciences 65: 1304-1322.

Working Group(s)

Cloud Properties