The Evolution and Distribution of Water Vapor and Microphysical Properties in Cirrus Clouds

Contributors
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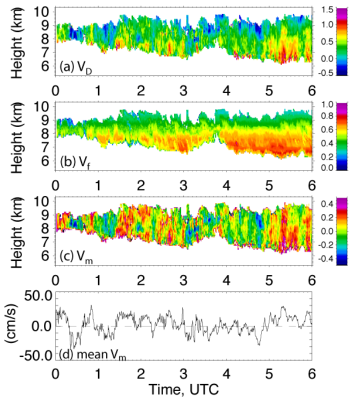
Research Highlight

Clouds come in a variety of shapes and sizes, and each type contributes differently to the climate system. While low-level water clouds tend to have a cooling effect on the atmosphere, high-level cirrus clouds that are composed of ice can have the opposite effect. Located in the upper layer of Earth's atmosphere--the troposphere--these icy clouds help regulate humidity and likely play a role in the transport of water vapor into the stratosphere. Because cirrus clouds can have either a warming or cooling effect on the atmosphere, understanding these interactions is critical to improving their representation in large-scale models. In this study, ARM researchers explore the mechanisms that influence the evolution and distribution of water vapor and cloud properties in upper tropospheric cirrus clouds.

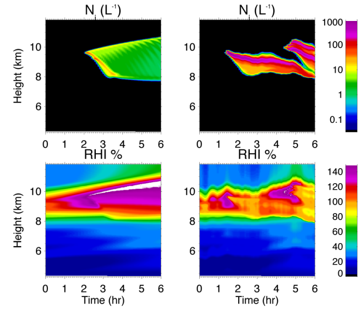
To study the effects of vertical velocity, ice formation mechanisms, and ice crystal growth rate in cirrus clouds, the research team used a detailed microphysical model to simulate cirrus clouds observed over the U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Climate Research Facility located near Lamont, Oklahoma. Measurements from ARM Raman lidar and Doppler radar instruments were used to both initialize and evaluate the model. A unique aspect of the approach was the use of vertical velocity derived from ARM Doppler velocity measurements to drive the cloud-scale vertical motions in the model.

The team's key findings suggested cloud-scale dynamic variability as the primary mechanism needed to reproduce observed quantities, while nucleation mechanism is secondary. Nevertheless, the simulated distribution of water vapor and cloud properties compared better with observations when ice formation mechanisms were aided by the presence of solid aerosol particles (i.e., ice nuclei). Sensitivity tests also showed that slow ice crystal growth tended to overestimate the number of small ice crystals without significant influence on bulk cloud properties such as ice water path and cloud thickness.

Compared to observations, the most realistic simulations were forced using cloud-scale vertical motions, and included rapid growth of ice crystals that formed via frozen drops or ice nuclei. By constraining the large and small modes of the particle size distribution using lidar extinction and radar reflectivity, ice crystal number concentrations for this case were on the order of 10-100 L-1. This is much smaller than the concentrations measured by aircraft probes—possibly due to bias by shattering of large particles on probe inlets. This study demonstrates the potential use of radar Doppler velocity measurements to characterize the cloud-scale vertical motion in cirrus clouds, and can help guide the direction of future modeling efforts related to cirrus clouds.



Vertical velocity (Vm) derived from millimeter cloud radar (MMCR) Doppler velocity measurements in cirrus clouds observed over the ACRF SGP site.



Cloud model simulations of cirrus clouds using large-scale forcing (left panel) and cloud-scale forcing (right panel).

Reference(s)

Comstock JM, R Lin, DO Starr, and P Yang. 2008. "Understanding ice supersaturation, particle growth, and number concentration in cirrus clouds." Journal of Geophysical Research – Atmospheres, 113, doi:10.1029/2008JD010332.

Working Group(s)
Cloud Modeling, Cloud Properties