Earth-satellite observations reveal cloud-droplet evolution

Takashi Y. Nakajima

Synergy of remote observations, model predictions, and radiative transfer leads to better understanding of cloud formation.

Clouds in Earth’s atmosphere (see Figure 1) play important roles in the planet’s climate by, for example, reflecting radiation back into space efficiently and transferring energy from one place to another. The International Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) pointed out that clouds account for much of the uncertainty in estimating Earth’s energy balance. Therefore, a better understanding of cloud distribution and cloud lifecycles would contribute to climate-change studies by improving Earth-simulation models, such as the General Circulation Model (GCM). As a result, for the past 30 years, satellite-based remote-sensing techniques have been used to measure many geophysical parameters to support GCM development.

In recent studies, a new method for visualizing cloud radar reflectivity from satellites has been proposed: contoured frequency by optical-depth diagram (CFODD). This method plots the frequency of radar reflectivity, Ze, against in-cloud optical depth as the vertical coordinate. CFODD produces a more useful profile of in-cloud events than the conventional method, the contoured-frequency-by-altitude diagram, which compares reflectivity with the geometrical height from the ground. For instance, in Figure 2, note how the CFODD grouping by near-cloud-top cloud droplet radius (CDR) reveals the droplet-growth processes occurring within the cloud layer from the cloud mode (CDR ~10µm), through drizzle (~100µm), and eventually to rain (~1mm).

The CDRs themselves are retrieved from shortwave IR-wavelength data collected by passive-imaging sensors, such as the moderate-resolution imaging spectroradiometer (MODIS) onboard the Aqua satellite. This is one of the constellation of earth-monitoring satellites known as the ‘A-Train’ currently flying in formation in the same polar orbit.

Despite all this, cloud-evolution processes spanning from 10 minutes to several hours still cannot be measured from space because of the coarse temporal resolution of the polar-orbiting satellites. However, another tool for interpreting satellite data, the spectral-bin microphysics cloud model (Bin model), can be used instead. In the Bin model, the size-distribution function of cloud particles is explicitly predicted, taking into account various microphysical processes such as nucleation from aerosols, condensational growth, and collision-coagulation (see Figure 3). The features of the resultant simulated cloud, showing the timeline of cloud growth with high temporal resolution of just seconds, will partly assist in understanding the satellite measurements.

For a system that works in a wide range of conditions, a bridge is clearly needed between the simulated-cloud droplet sizes resulting from the Bin model and the satellite-obtained CFODD. This can be achieved via satellite-sensor simulators based on accurate radiative transfer calculations. Previously, we developed the global-imager signal simulator for the Advanced Earth Observing Satellite-II (Midori-II) global-imager science mission by the Japan Aerospace Exploration Agency (JAXA). This was

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Figure 2. Contoured frequency by optical depth diagram (CFODD). R21 denotes cloud droplet radii (CDR) obtained from the moderate-resolution imaging spectroradiometer (MODIS) 2.1μm band.

based on the R-system for transfer of atmospheric radiation-5b (RSTAR5b) calculation program. Another satellite signal simulator, the multipackage Satellite Data Simulator Unit (SDSU), enables simulation of sensor signals from visible-to-IR imagers, microwave scanners, and precipitation radars onboard the Tropical Rainfall Measuring Mission and the Global Precipitation Measurement satellites.

The EarthCARE science team at JAXA has begun to develop a comprehensive signal simulator for satellite sensors, called the Joint (J-)Simulator, based on SDSU. J-Simulator consists of a visible-to-IR simulator (multispectral imager), a light detection and ranging (LIDAR) simulator (atmospheric LIDAR, ATLID), a cloud-profiling radar simulator, and a broadband radiometer simulator. The J-Simulator can take cloud parameters calculated using the Bin model and cloud-resolving model (CRM) as inputs and output the expected measured sensor signals from the satellite. Here, the signals are radiance, brightness, temperature, and LIDAR backscatter or radar reflectivity. Thus, actual data obtained from satellite remote sensing can be used to validate models, such as the Bin model and CRM. In turn, these models aid in the understanding of the physical processes that are hidden in the remote-sensing data.

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During the writing of this article, clouds have grown and decayed several times, not randomly, but rather following the physical rules of nature. Using observations and modeling, which contribute to climate-change studies, a consistent understanding of the rules governing cloud-growing processes is being realized. For more information about our research strategy, please see our latest article.7

Author Information

Takashi Y. Nakajima
Tokai University
Tokyo, Japan

Takashi Y. Nakajima received a doctor of science degree from the University of Tokyo in 2002. He began work at JAXA in 1994 and moved to Tokai University in 2005. He is an associate professor. His research fields include light-scattering theory and remote sensing of clouds and aerosols.

References