Effects of Storms on Microwave Brightness Temperatures and its Application to Estimate Cloud Parameters from AMSU-B

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Abstract

Clouds play a major role in our climate by affecting the earth's heat, moisture, and radiation balance. Those that are associated with storms, and can reach or penetrate into the tropical tropopause layer (TTL, about 14–18 km), contribute to the exchange of air between the troposphere and the stratosphere, and hereby influence the physical and chemical processes occurring in the TTL and the stratosphere. However, in climate models clouds still remain a biggest source of uncertainty. Since the launch of the Special Sensor Microwave Temperature 2 (SSM/T2) onboard the Defense Meteorological Satellite Program (DMSP), the Advance Microwave Sounding Unit (AMSU)-B onboard NOAA-15, 16, and 17, and the AMSU/HSB (Humidity Sounder for Brazil) on board Aqua satellite, the radiometric signatures of clouds at frequencies of 90–190 GHz are explored extensively. These frequencies are more sensitive to scattering by frozen hydrometeors. Consequently, the effects of clouds and precipitation provide possibilities to estimate cloud parameters. The goal of this thesis is to understand the effects of storms on microwave brightness temperatures (mainly in the frequency range of 90–190 GHz) and to explore the retrieval of cloud parameters from them.

Four observation cases (two over ocean and two over land), analyzed using aircraft passive microwave measurements in the frequency range of 10 to 220 GHz in conjunction with aircraft radar measurements, show that the high frequencies are sensitive to ice scattering in the upper layers of storms, especially the three water vapor channels around 183.3 GHz (183.3 ± 7, 183.3 ± 3, and 183.3 ± 1 GHz). Cloud model data and cloud microphysical parameters, derived from aircraft radar observations have been used as input for a microwave radiative transfer model to investigate the effects of cloud microphysical parameters. The observations at AMSU-B frequencies are found to depend crucially on the variations in particle size distribution, ice water path, phase transition temperature, and cloud structure. The three water vapor channels have less influence from liquid water than the window channels of 89 and 150 GHz of AMSU-B, but more influence from the frozen hydrometeors in high altitudes.

The brightness temperature sensitivities at the frequencies between 89 and 183 GHz are investigated by simulations using the Goddard Cumulus Ensemble (GCE) model data of a simulated oceanic tropical squall line. Only the window channel at 89 GHz has an apparent dependence on the surface emissivity. The sensitivity to variations in liquid water content at all channels is generally apparent in the high altitude levels above 5 km, with higher sensitivities at 89, 150, and 183.3 ± 7 GHz. The sensitivity to variations in frozen hydrometeor contents at all channels is generally apparent in the altitude levels above 7 km, which suggests a possibility to estimate the frozen hydrometeors in these altitude levels in tropical deep convective clouds.

The different sensitivities to altitude and amount of hydrometeors suggest a method to estimate the canting angle and tilt direction of tilted convective cloud using brightness temperatures at 183.3 ± 1 and 183.3 ± 7 GHz. The method provides a possibility to estimate the vertical displacement of cloud structure and thereby to estimate the accurate location of surface rainfall. This is important when validating precipitation retrieval based on observations of the ice scattering above surface rainfall against surface rain observations.

Methods to detect deep convective clouds and convective overshooting from measurements at the three water vapor channels of AMSU-B are developed. Thresholds for the brightness temperature differences between the three channels are used to detect deep convective clouds, and an order relation is used to detect convective overshooting. The distributions of deep convective clouds and convective overshooting in the tropics (30° S to 30° N) from March 2002 to February 2003 show a seasonal variability between the winter and the summer hemisphere. The deep convective clouds over land penetrate more frequently into the tropical tropopause layer than those over ocean. The averaged deep convective cloud fraction is about 0.3 % in the tropics and convective overshooting contributes about 22 % to this.

Algorithms to estimate the ice water paths in the upper layers of tropical deep convective clouds are developed using the three water vapor channels around 183 GHz of AMSU-B. The distributions of ice water path and ice water content and their seasonal variabilities agree quite well with TRMM products. Their monthly zonal means agree with the surface rainfall from TRMM. Although the average amount of deep convective cloud fraction in the tropics is only about 0.3 %, it contributes about 34 % to the total ice water path.