Microwave Radiative Transfer in the Mixed-Phase Regions of Tropical Rainfall

T. T. WILHEIT
Department of Atmospheric Science, Texas A&M University, College Station, Texas

P. V. HOBBS*
Atmospheric Sciences Department, University of Washington, Seattle, Washington

K. JIN+
Department of Atmospheric Science, Texas A&M University, College Station, Texas

A. L. RANGNO
Atmospheric Sciences Department, University of Washington, Seattle, Washington

M. E. TRIESKY AND J. R. WANG
NASA Goddard Space Flight Center, Greenbelt, Maryland

(Manuscript received 29 November 2005, in final form 10 April 2006)

ABSTRACT

Here airborne observations of the mixed-phase regions of tropical oceanic rainfall are reported as part of the Kwajalein Experiment. The University of Washington Convair-580 aircraft carrying upward-viewing 21- and 37-GHz microwave radiometers spiraled down through stratiform rain. It was observed that the microwave absorption coefficient in the bright band (melting layer) in the stratiform rainfall was roughly twice or thrice that of the rain below. Radiative transfer models of the melting layer have a similar range of uncertainties. In addition to the potential bias from modeling uncertainties, comparison with previous observations suggests that there is a natural variability of about the same magnitude.

The aircraft also made penetrations of a convective line at altitudes of 2.6, 3.4, and 4.5 km. From the microwave observations, it can be concluded that the effect of supercooled water above the freezing level was extremely small, on the order of 2% or less of the total rain signal for this case.

1. Introduction

It would be difficult to overstate the importance of tropical rainfall. The latent heat that it releases drives the largest scales of atmospheric circulation, and the freshwater input it provides is a major factor in the thermohaline circulation of the oceans. Thus, quantitative understanding of the weather and climate system of the earth requires similarly quantitative understanding of tropical rainfall. The measurement of tropical oceanic rainfall, with which this paper is concerned, is difficult. Most of the Tropics are ocean covered with the attendant logistical difficulties in making conventional rainfall measurements. Land areas have their own set of difficulties. The only practical approach to measure rainfall throughout the Tropics is to use satellite-based measurements. Passive microwave measurements have many advantages for this measurement and are applied on the Tropical Rainfall Measuring Mission (TRMM) satellite via the TRMM Microwave Imager (TMI) and on the *Aqua* satellite via the Advanced Microwave Scanning Radiometer (AMSR-E; Kummerow et al. 1998; Kawanishi et al. 2003; Wilheit et al. 2003)

---

* Deceased.

+ Current affiliation: NASA JPL, California Institute of Technology, Pasadena, California.

Corresponding author address: Dr. T. T. Wilheit, Department of Atmospheric Science (3150), Texas A&M University, College Station, TX 77843-3150.
E-mail: wilheit@tamu.edu

The original TRMM Level-2 (Kummerow et al. 2001) and Level-3 (Chang et al. 1999) algorithms treated the hydrometeors as being all liquid below the freezing level (0°C isotherm). The Level-3 algorithm treats the hydrometeors as all frozen above the freezing level and assumes that their impact is negligible at the frequencies being used (19.35 and 21.3 GHz). Clearly, this is too simple. In stratiform rain, the falling snow melts over some distance after it passes the freezing level causing the familiar radar bright band, and some supercooled water is advected above the freezing level in updrafts, especially in convective precipitation.

There has been considerable effort in recent years (Bauer et al. 1999, 2000; Bauer 2001; Olson et al. 2001a,b) to model the radiometric impact of the melting layer of stratiform rain. These models use 1D and 2D nonhydrostatic cloud models, thermodynamic models of the melting process, and various electromagnetic models of the mixed-phase particles to compute the absorption and scattering within the melting layer. Also, Liang and Meneghini (2005) have performed detailed electromagnetic calculations of the radar reflectivity of the melting layer. Each model includes a mixture of first principles modeling and parameterization. Since there is a range of choices for the parameterizations, the results vary. Generally, the results suggest an increase in the absorption and extinction coefficients within the melting layer. At 37 GHz over the typical 0.5-km thickness of the melting layer, these coefficients are 2–3 times their values within the fully melted rain layer below, reflecting the range of mixed media parameterizations used to calculate the bulk dielectric properties of the droplets. At lower frequencies, the ratio of the absorption in the melting layer to that of the rain below is larger with a great deal of variability depending on the mixed media parameterization.

Although the nominal measurement of the precipitation radar (PR) on TRMM is backscatter strength (Z), proper interpretation requires an attenuation correction because of moderately strong attenuation at 13.8 GHz. This process is described by Iguchi et al. (2000). They assume a relationship between the attenuation coefficient (k) and Z of the form $k = \alpha Z^{\beta}$, where β is in the range of 0.77–0.8 depending on the assumed drop size distribution (DSD). This inherently results in an increase in attenuation in the bright band. For typical bright bands, the excess attenuation is of the order of a factor of 2 or 3 above the attenuation of the fully melted rain below, essentially the same as one would infer for the 37-GHz attenuation based on the models mentioned above rather than the even greater increased attenuation one would infer from the frequency dependence of the modeling studies discussed above.

In an effort to verify the effect of the bright band on microwave radiances, Bauer (2001) located 48 events in TRMM PR data that contained identifiable bright bands. He ran simulations appropriate to these cases using three cloud-resolving models, the Goddard Cumulus Ensemble Model-1 (GCE-1), the Goddard Cumulus Ensemble Model-3 (GCE-3), and the Meteo-France Large Eddy Model CETP (Meso-NH). Each model was run both with and without his melting layer model included and radiative transfer calculations were performed for the TRMM Microwave Imager viewing parameters. He used the radar data to partition the TMI observations into stratiform rain with a bright band and stratiform rain without a bright band. He then compared the probability distribution functions for the brightness temperatures from the simulations and the observations both with and without a bright band. The GCE-1 results are typical. At 10.7 GHz, many more high brightness temperatures (>200 K) were observed than simulated, but the presence of the bright band seemed to increase the brightness temperature in both the simulations and the observations by similar amounts. At 19.35 GHz, the observed range of brightness temperatures is greater than simulated. The observed bright band effect is negative for brightness temperatures less than about 200 K and much greater than simulated above 200 K. At 37 GHz, the simulated brightband effect is small and the observed brightband effect is negative. The ranges of the brightness temperatures are reasonably consistent between the simulations and the observations. At 85.5 GHz, the simulated brightband effect is very small and the observed effect is large in magnitude but negative. There were essentially no observations below 200 K, but about 10% of the simulated brightness temperatures were below this value. As is often observed, the simulations give much more scattering by ice than is observed over the oceans, but this is a separate issue. Since spaceborne radiometers measure an integrated effect of the entire rain column and the surface, quantitative interpretation of these observations is a challenge.

More direct observations are difficult and infrequent. Two measurements were reported by Chang et al. (1993) in stratiform rain. As with this paper, there were no radar observations to support the presence or absence of a bright band. This paper adds to the very sparse observational database of the radiometric effects of the melting layer.

Radiometric observations of the effects of supercooled water in updrafts likewise are scarce. Aircraft safety considerations make an already difficult observation even more so. A token amount of emission, presumably from supercooled water, was reported by Chang et al. (1993); the authors are not aware of any other observations. This paper reports an upper limit to the supercooled water that could have been present in a convective rainfall event.