Optical Depths and Microphysics of Tropical Clouds—Results from the MCTEX

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Introduction

The Maritime Continent Thunderstorm Experiment (MCTEX) was conducted in November and December 1995 on Melville and Bathurst Islands, north of Darwin off the north coast of Australia. Analysis of lidar, radiometer, and radar measurements of synoptic cirrus and cirrus outflows from island thunderstorms [from instruments based at Pularumpi, Melville Island (11º 24' S, 130º 25' E)] is now largely complete. Optical properties derived from lidar-radiometer sensing of 22 cloud cases are presented here. We also describe current work in combined lidar-radar sensing of cirrus particle size parameters. Participation in MCTEX was supported by the Atmospheric Radiation Measurement (ARM) Program and is further described in Platt et al. (1997).

LIRAD Method

The principal analysis technique employed was the lidar-radiometer (LIRAD) method, described by Platt et al. (1987). The analysis is based on the relation between lidar cloud integrated attenuated backscatter $\gamma'(\pi)$ and the cloud infrared (IR) absorption emittance ε_a:

$$\gamma'(\pi) = \frac{k}{2\eta}\left[1 - \exp\left(-2\alpha\eta \log\frac{1}{1-\varepsilon_a}\right)\right],$$

where k is the cloud isotropic backscatter-to-extinction ratio, η is a multiple scattering factor, and α is the ratio between the lidar visible extinction coefficient and the infrared absorption coefficient.

Cloud boundaries were determined using a version of the boundary detection method described by Young (1995). The calibration of the raw lidar profiles to produce profiles of $\gamma'(\pi)$ also followed methods in this paper. IR emission due to water vapor (particularly significant in the tropics) was calculated from microwave measurements of water vapor path using a technique similar to that used in Platt et al. (1998).

Variety of MCTEX Cirrus

Figure 1 shows a sample of the cirrus clouds measured during MCTEX, along with radiosonde profiles of air temperature. The backscatter coefficient values have been corrected for attenuation. There was an abundance of thin layers of cirrus near the tropopause or in the tropopause folds. (These thin layers were often invisible to the millimeter-wave radar.) Several cases of medium-density cirrus and deep anvil cirrus were also observed.

Optical Properties

Graphs of the various cloud statistics (Figure 2) show cirrus infrared optical depths that are similar to those found at Kavieng in the Pilot Radiation Observation Experiment (PROBE) (January 1993). The tropical values of emittance are generally higher than the midlatitude values for a given cloud temperature, but are still well correlated with

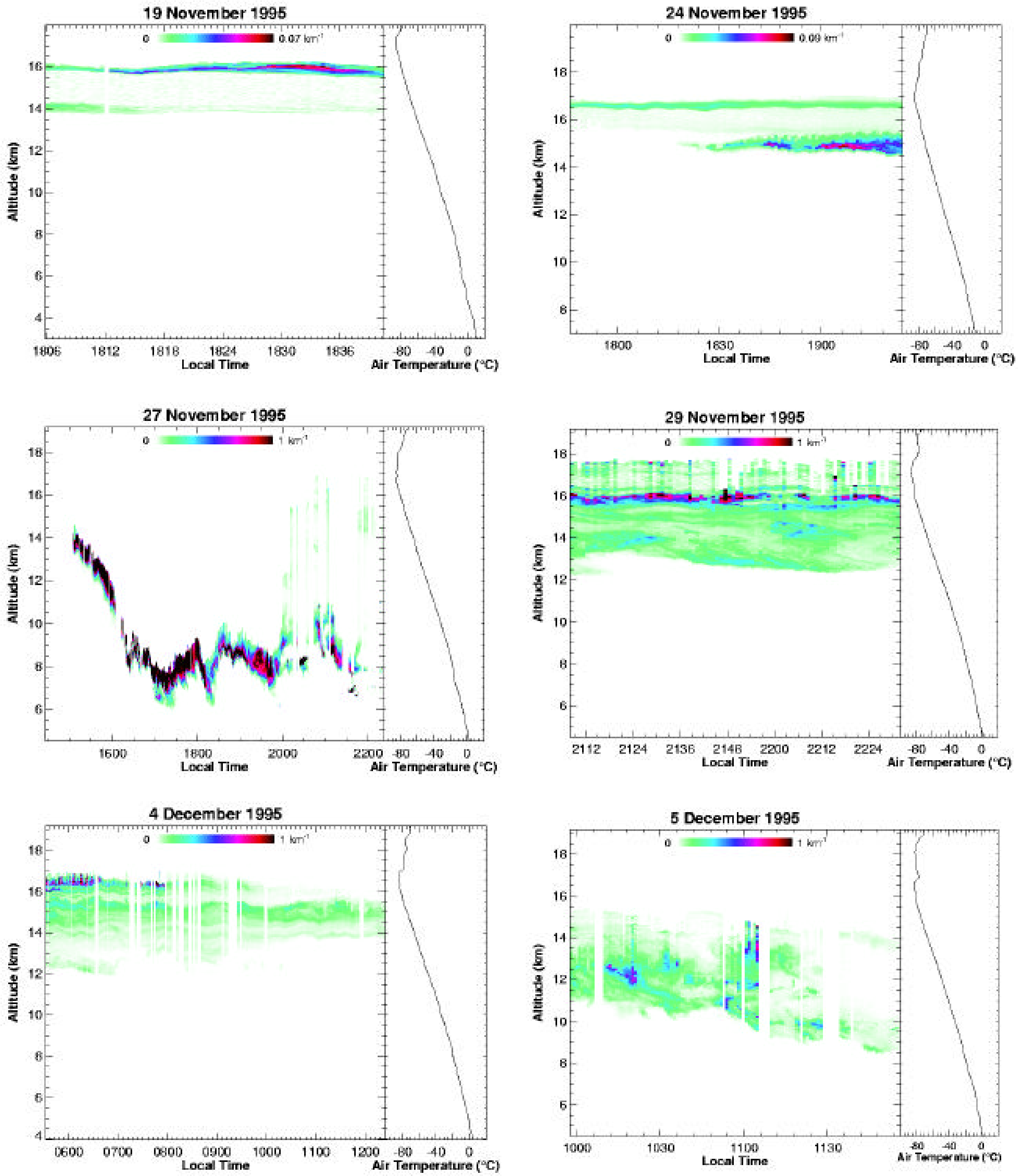

Figure 1. Time-height diagrams of lidar backscatter coefficient and sonde temperature profiles for 6 of the 22 cases included in the LIRAD analysis. The 27 November case is optically thick deep anvil cirrus; the lidar pulses were completely attenuated in the lowest 1 km to 2 km of the cloud. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/austin-98.pdf*.)

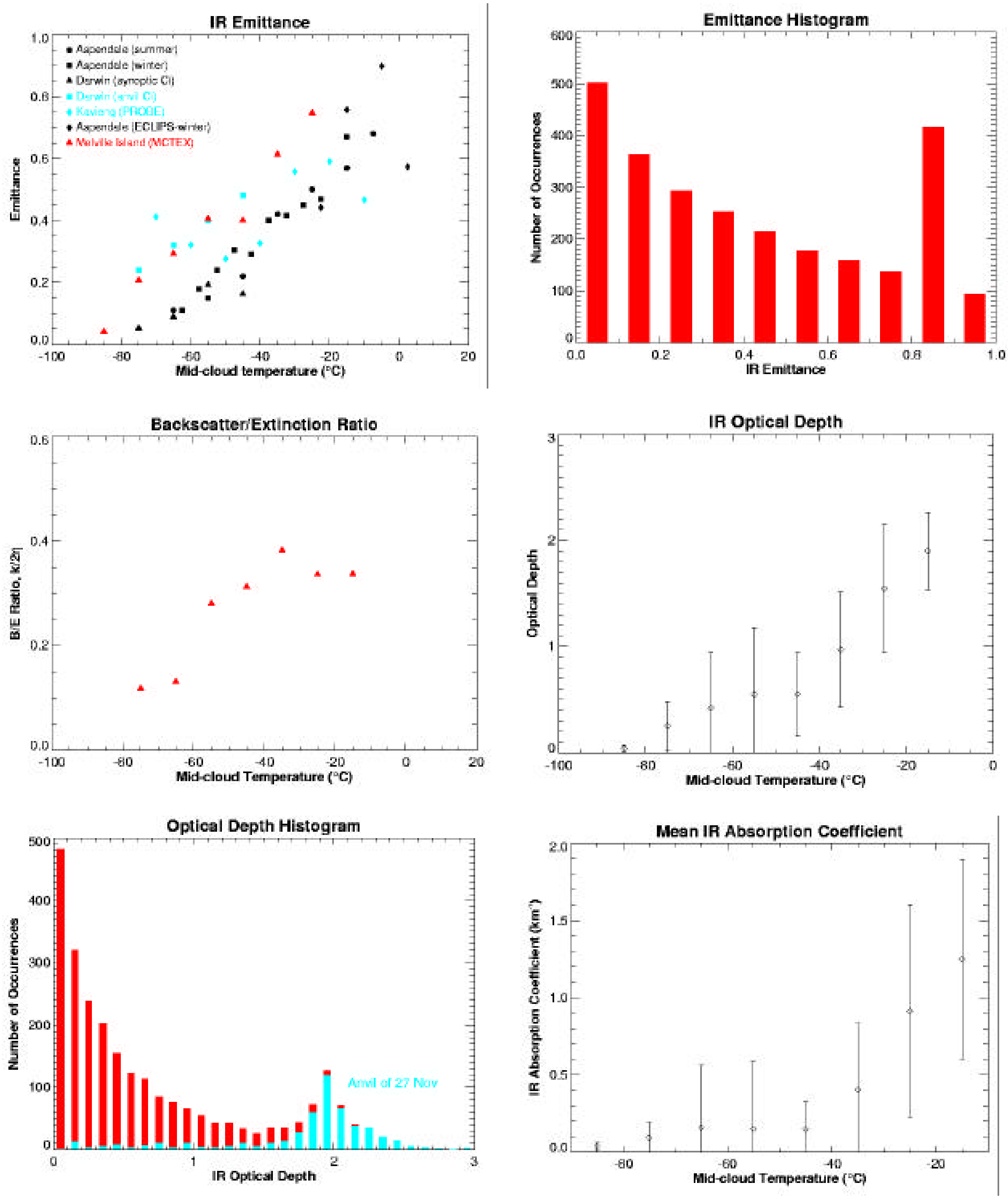

Figure 2. These graphs show various optical properties obtained from LIRAD analysis of the 22 MCTEX cases. The first graph compares IR emittances measured in MCTEX with those from other cloud experiments. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/austin-98.pdf*.)

cloud temperature. The histogram of emittance shows a peak at 0.8 because the cloud base in the 27 November deep anvil case was cooling on descent, causing retrieved emittance values to be depressed from unity. Values of the backscatter-to-extinction ratio k at temperatures in the -80°C to –60°C range are quite small, being about 0.08 to 0.1 for reasonable values of η. This implies large visible solar optical depths for quite small values of backscatter. A comparison of lidar and millimeter-wave radar backscatter indicates that the high cold cirrus layers were below the threshold of detection of the radar, as mentioned previously. The significance to climate of these high tropical layers, composed of small particles, cannot be overemphasized. If they indeed have quite high visible optical depths, then they will reflect out considerable solar radiation, but have low emittances. These layers appear to be quite prevalent in the Tropical Western Pacific (TWP) region.

Particle Size Retrieval

Work is continuing on the refinement of methods for retrieving cirrus particle size and number density from combined lidar and millimeter-wave radar backscatter data. Various particle size distributions have been compared, including a modified gamma (similar to Intrieri et al. 1993), power-law, Marshall-Palmer, and a hybrid distribution with power-law and exponential regions (Platt 1997), shown in Figure 3. Retrievals have been computed based on ice spheres, solid hexagonal cylinders, and hexagonal plates. Figure 4 shows examples of retrieved effective radius from MCTEX data.

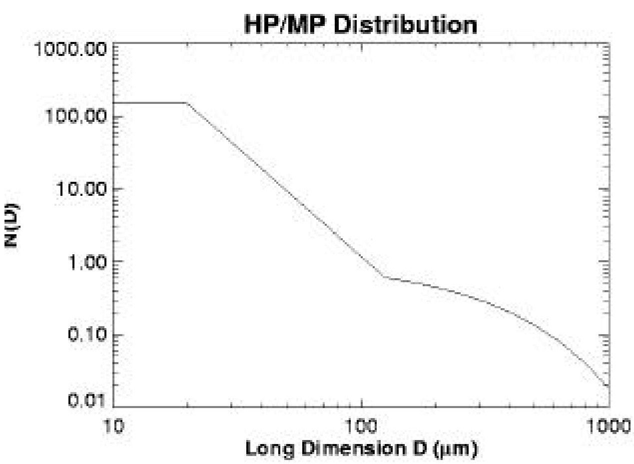

Figure 3. A hybrid particle size distribution with Heymsfield-Platt power-law and Marshall-Palmer exponential regions was compared with other distribution functions.

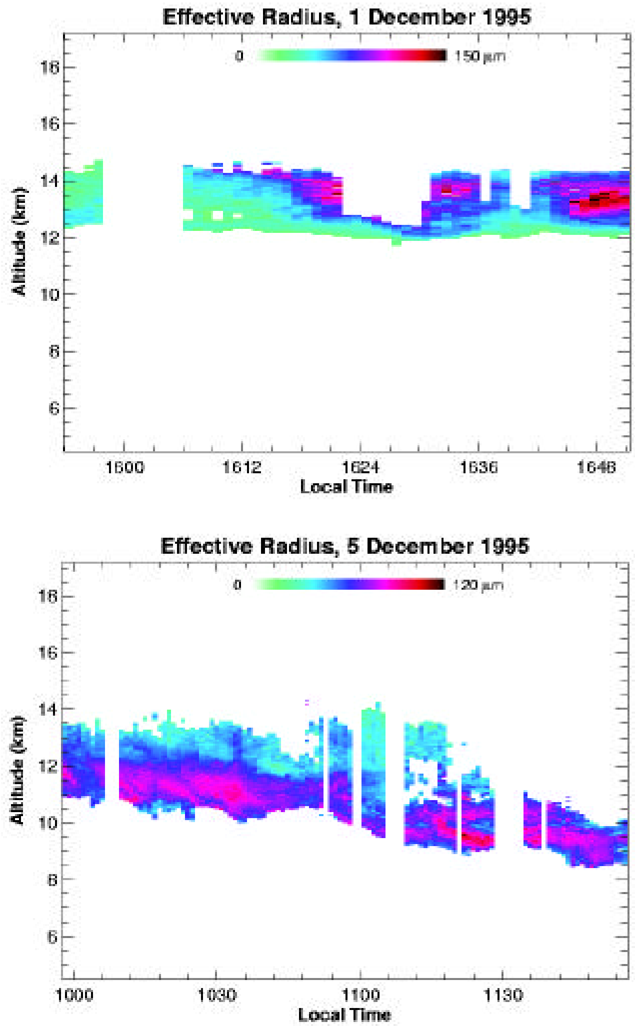

Figure 4. Two examples of retrieved particle effective radius. These estimates were based on ice spheres with a modified gamma size distribution. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/austin-98.pdf*.)

Conclusions

The LIRAD method is again demonstrated to provide accurate values of IR and visible optical depth, as well as information on cloud particle size and habit. The key to the method is use of a precise, fast, narrow-beam spectral radiometer, such as has been built for the ARM Program. This enables precise information on the small radiancesfrom high, cold tropical cirrus clouds. The LIRAD method also has excellent synergy with the lidar-radar method of obtaining profiles of particle size in cirrus. [A micropulse lidar (MPL) such as the ARM MPL may be sufficient.]

Together, they form a powerful basis for ground-based sounding of detailed cloud properties—a mainstream ARM application.

Lidar and millimeter-wave radar are clearly complementary in their ability to sense thin cirrus layers and penetrate optically thick clouds. LIRAD/millimeter-wave radar data on clouds can be used to calculate heating rates and radiation divergence in the atmosphere (Huffman et al. 1998).

Installation of fast radiometers at ARM sites is highly recommended. At the same time, numerous in situ studies of cirrus cloud particle types at every height, location, and temperature are needed urgently.

Acknowledgments

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