LIRAD Analysis of TWP Cirrus at Nauru

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Introduction

The purpose of this work is to implement algorithms for retrieval of high-cloud emittance and optical depth using lidar-radiometer (LIRAD) analysis based on available continuous data streams from the Atmospheric Radiation Measurement (ARM) Program's Cloud and Radiation Testbed (CART) sites. Routine, continuous operation of the micropulse lidar (MPL), infrared thermometer (IRT), microwave radiometer (MWR), and frequent sonde soundings should allow for near-continuous retrieval of LIRAD products, subject to time and accuracy limitations described later in this paper. Initial development of these techniques has focused on the Tropical Western Pacific (TWP) sites, where cirrus clouds are common and temperatures remain inside the range of the IRT. We present preliminary results based on measurements at Nauru over a three-month period in 1999. These results utilize a recently released higher-level MPL data stream. Algorithms used in this analysis are being refined for use in a LIRAD Value-Added Procedure (VAP) for automated retrieval of cirrus optical properties.

Lidar Calibration and Cloud Boundary Detection

The lidar signal must be calibrated and cloud boundaries determined before the LIRAD algorithms may be applied. Calibration is accomplished by fitting the measured lidar signal to a sonde-based theoretical molecular backscatter signal in a clear region of each lidar profile. The default calibration region is the portion of the profile between 4.5 km and 9 km, but the bounds of the region are adjusted to avoid cloud layers. Cloud boundaries are detected using a threshold algorithm that was developed to compensate for the lower resolution and higher noise level of the MPL. The calibration and cloud boundary detection procedures are described in Mitrescu et al. (1999).

A seven-day sample of calibrated attenuated lidar backscatter and detected cloud boundaries from Nauru is shown in Figure 1. The Nauru MPL data are shown at 90 m vertical resolution; each row represents a single day. Clouds with bases below 9 km have been ignored in order to simplify the analysis of cirrus cases. Two types of noise are immediately evident in the lidar data. Solar noise is evident during daylight periods (before 0700 Universal Coordinates Time [UTC] and after 1800 UTC). This noise is particularly significant at equatorial sites like Nauru where the sun appears near zenith. While clouds are occasionally discernable during daytime measurements, these periods have been omitted from the present analysis. The second type of noise-like feature is seen where the atmospheric return is anomalously high at the top of the vertical profiles; this is due to clouds that are present in or below the calibration region. Again, many of the affected profiles should be salvageable in more refined versions of the algorithm, if the cloud base is sufficiently high, but these profiles are rejected for now.

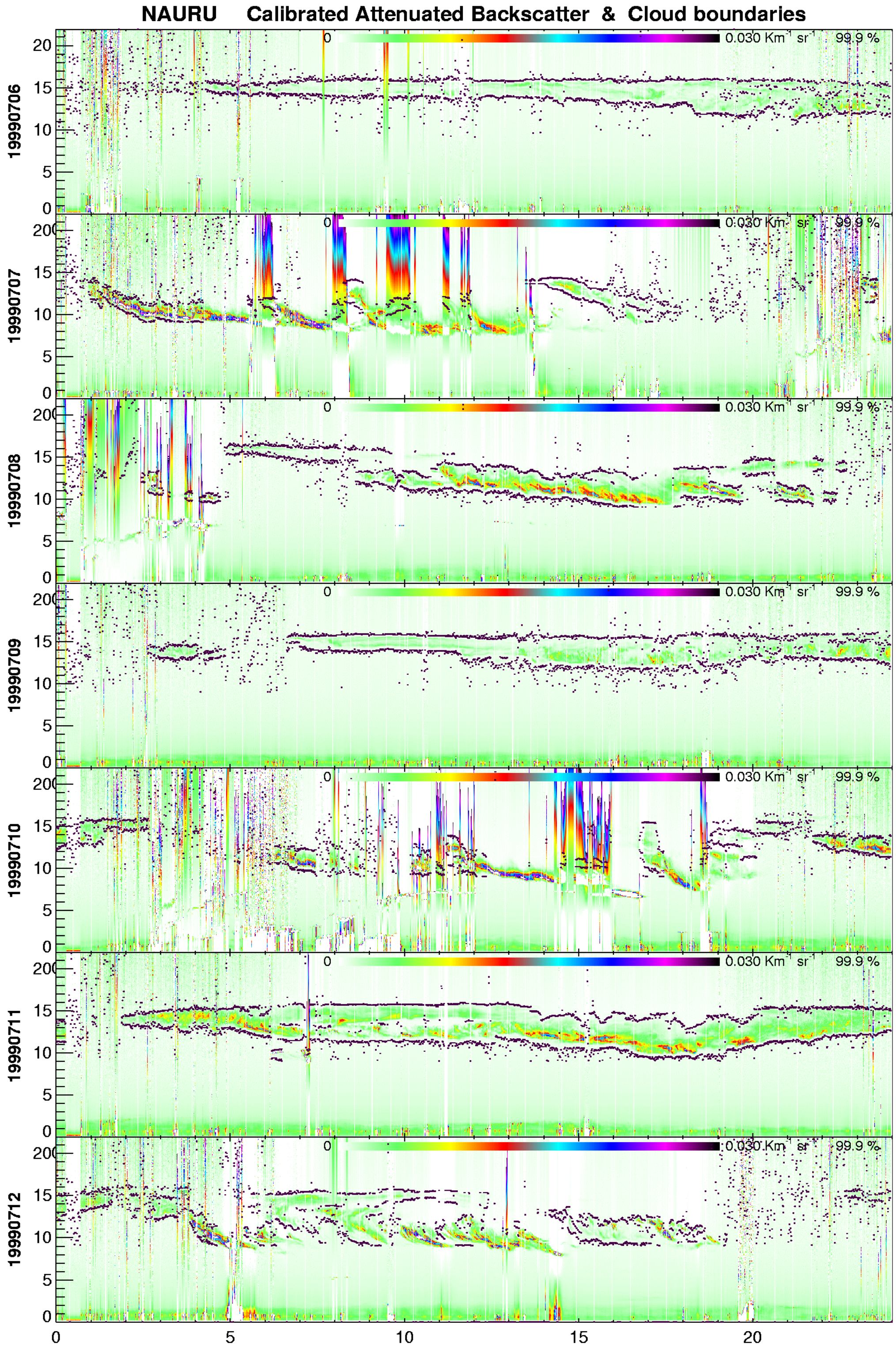

Figure 1. Seven days of calibrated MPL backscatter at Nauru from July 1999, together with retrieved cloud boundaries.

LIRAD Analysis and Results

The LIRAD method was developed by Platt (1973, 1979) with some extensions due to Young (1995) and has been used in studies of tropical cirrus (Platt et al. 2000) and equatorial cirrus (Platt et al. 1998). The method requires data from a visible lidar and an infrared radiometer, ideally observing the same cloud column, as well as sonde profiles and water vapor path from a microwave radiometer. The results shown here use four ARM data streams that correspond to these instruments; these are listed in Table 1. The twpmplnor1campC2.c1 data stream was only recently made available.

Table 1. ARM data streams used in this analysis.

ARM Data Stream	Contents
twpmplnor1campC2.c1	MPL normalized relative backscatter
twpskyrad60sC2.b2	IRT 10-micrometer radiance
twpsondewnpnC2.a1	Profiles of temperature, pressure, moisture
twpmwrlosC2.b2	Microwave radiometer water vapor path

The LIRAD analysis performed here was most similar to that done in Platt et al. (2000), which examined data from northern Australia. A detailed description of modifications for the MPL case will be the subject of a forthcoming paper.

Figure 2 shows various LIRAD quantities and results from a single day at Nauru (July 11, 1999). The top panel is a time-height diagram of calibrated, attenuated lidar backscatter. Subsequent rows show integrated attenuated backscatter, retrieved infrared emittance, retrieved infrared (IR) optical depth, IRT measured radiance and MWR measured water vapor path, derived IR cloud radiance, and sonde-based mid-cloud temperature. In addition to the cloud base and time-of-day restrictions described earlier, shots with high IRT radiance (indicating low cloud) were discarded as well, even if no low cloud base was detected. This low cloud rejection algorithm is rather crude and will be refined later.

LIRAD processing similar to that shown in Figure 2 was performed on 47 days of measurements from the three-month period of May to July 1999 at Nauru. Analysis was limited to those days having all four data streams available, having cirrus clouds present, and having sufficient periods free of low cloud that would obstruct lidar observations of cirrus. Results of these analyses are shown in Figures 3 and 4, which show histograms of IR emittance and IR optical depth for the three months considered. We see that a large fraction of cirrus cases have optical depths less than 0.5. In fact, the emittances and optical depths shown here may be biased slightly high due to low-level clouds that are not completely removed by the current screening method.

Optical properties retrieved from the Nauru analysis are compared with results from other field experiments as a function of mid-cloud temperature in Figures 5, 6, and 7. Backscatter/extinction ratio values are smaller for the Nauru results due in part to the larger multiple scattering factor η (i.e., η closer to unity, implying *less* multiple scattering) that is associated with the smaller aperture of the MPL.

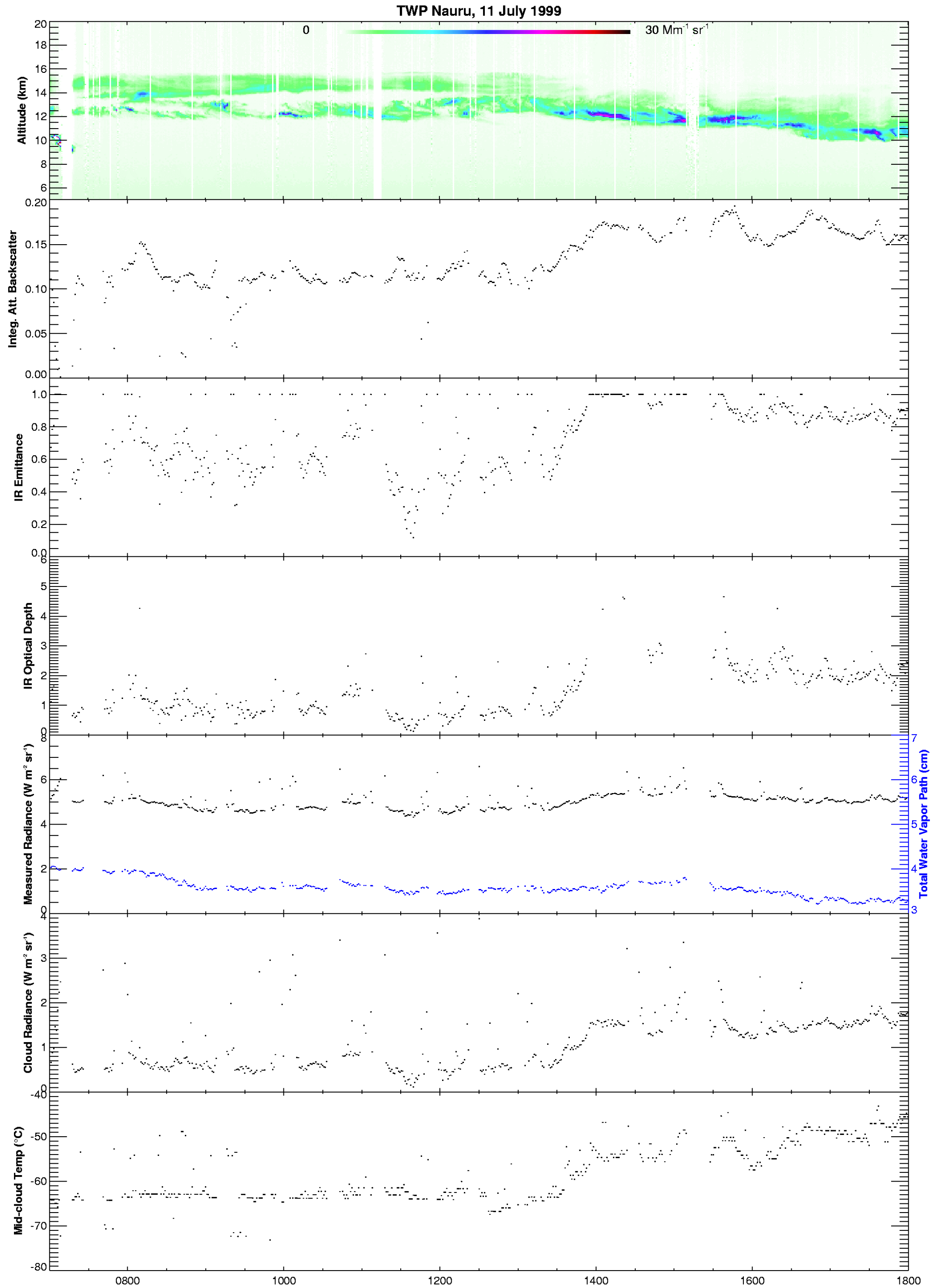

Figure 2. LIRAD quantities for July 11, 1999, at Nauru: (a) lidar calibrated attenuated backscatter, (b) integrated attenuated backscatter, (c) retrieved infrared emittance, (d) retrieved IR optical depth, (e) IRT measured radiance and MWR measured water vapor path, (f) derived IR cloud radiance, and (g) sonde-based mid-cloud temperature.

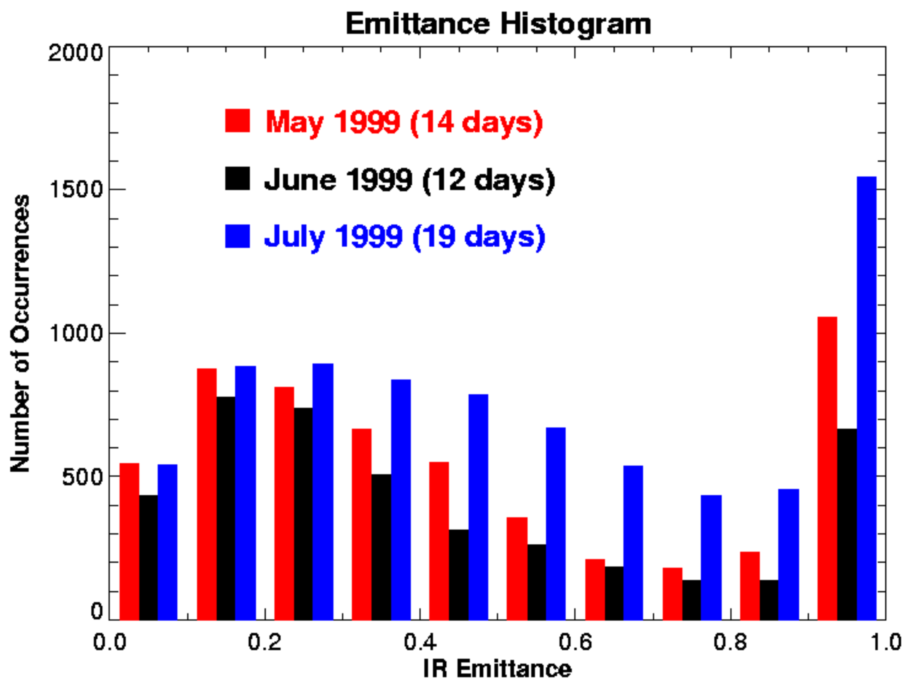

Figure 3. Histogram of retrieved IR emittance for cirrus above 9 km on observable days in May, June, and July 1999 at Nauru. Analysis is restricted to nighttime periods (0700 UTC to 1800 UTC).

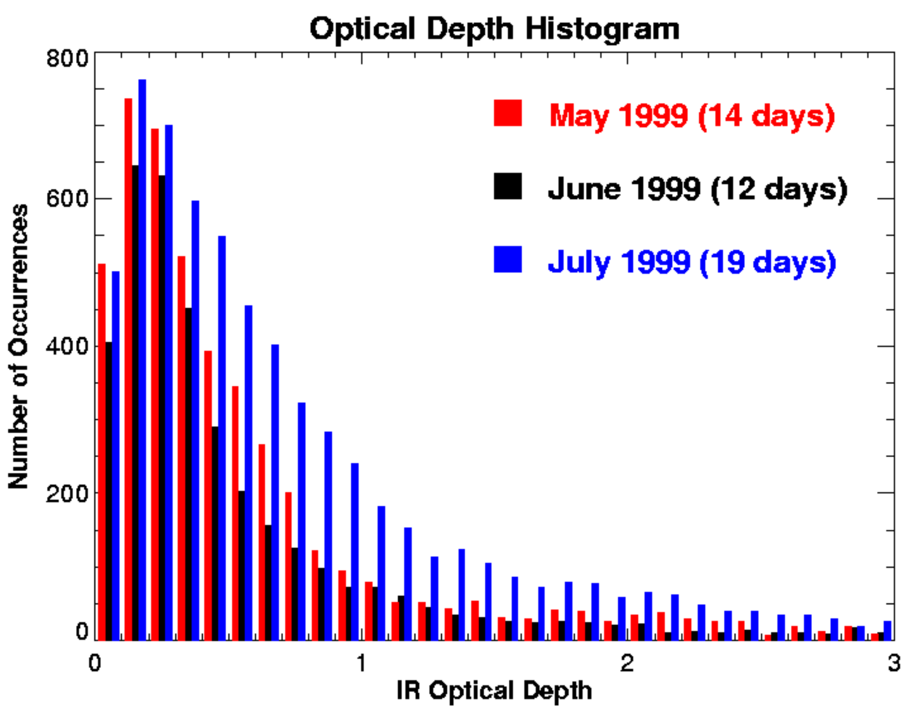

Figure 4. Histogram of retrieved IR optical depth for cirrus above 9 km on observable days in May, June, and July 1999 at Nauru.

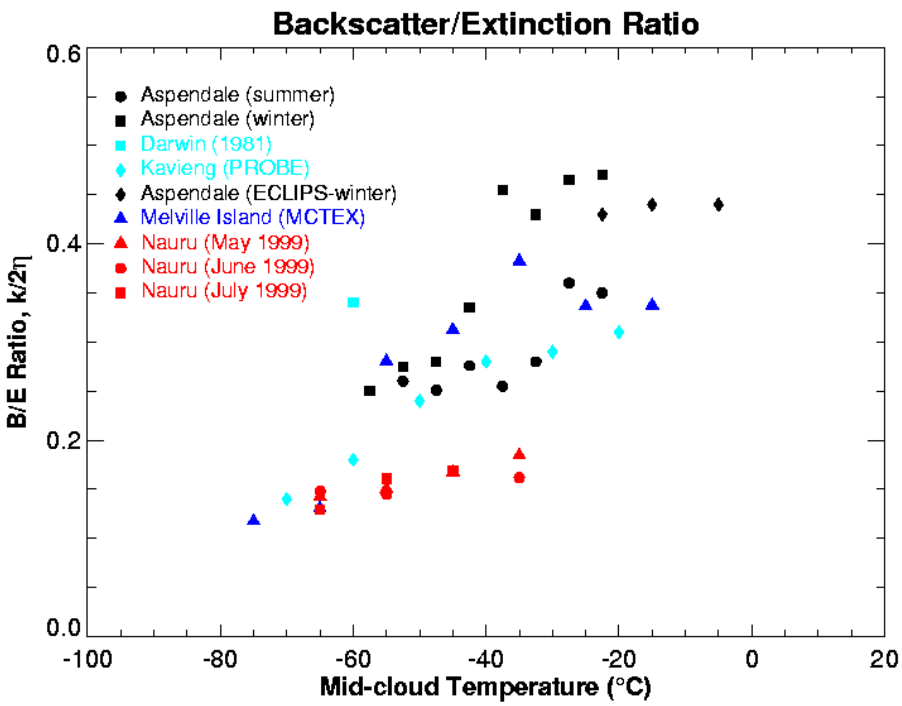

Figure 5. Retrieved values of visible backscatter/extinction ratio k/2η from Nauru data, compared with results from previous field campaigns.

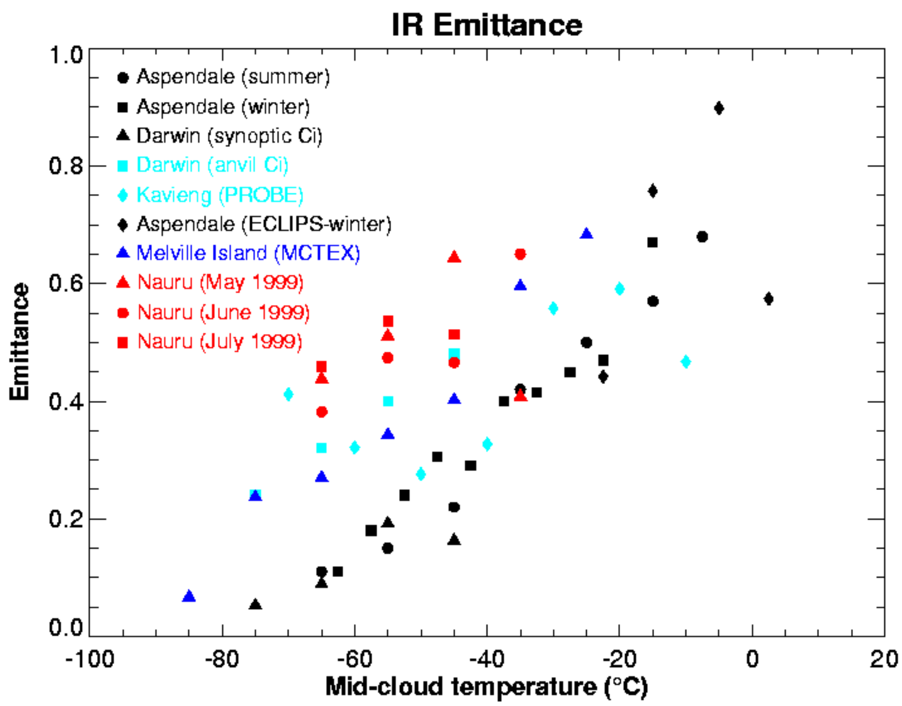

Figure 6. Retrieved values of IR emittance from Nauru data, compared with results from previous field campaigns.

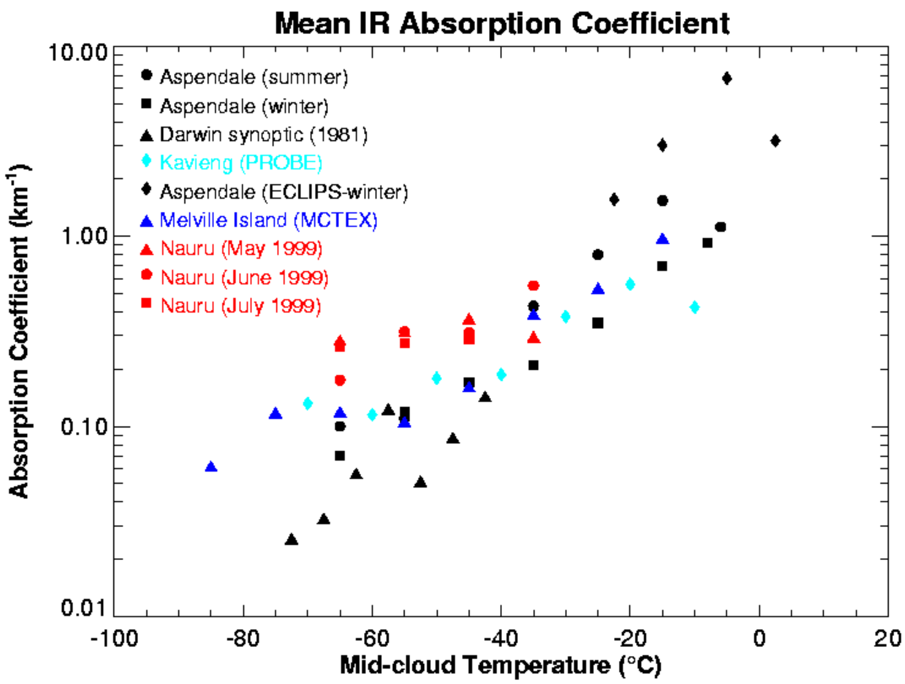

Figure 7. Retrieved values of mean IR absorption coefficient from Nauru data, compared with results from previous field campaigns.

(The MPL aperture is 0.1 mrad, compared to 2 mrad to 5 mrad in the other experiments shown.) The IR emittance and absorption coefficient values may be biased slightly high as mentioned above. Future refinements of this work should eliminate these biases.

Conclusions

Current results from the application of LIRAD algorithms to TWP data using recently available data streams are encouraging for nighttime periods; daytime periods will be more challenging, but may be possible, at least in part. The wide field of view of the IRT (2.6° or 45 mrad) is one probable source of bias; a sensitive IR radiometer with an aperture closer to that of the MPL (0.1 mrad) should increase accuracy.

Acknowledgments

This research was supported under the U.S. Department of Energy, Office of Energy Research, Grant DE-FG03-98ER62569.

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