LIRAD Analysis of Equatorial Cirrus at the TWP (Manus Island and Nauru) CART Sites

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Introduction

The purpose of this work is to obtain high-cloud emittance and optical depth over the Tropical Western Pacific (TWP) (Manus Island and Nauru) Cloud and Radiation Testbed (CART) sites on a routine basis using the lidar/radiometer (LIRAD) method. Current operation of the micropulse lidar (MPL), infrared thermometer (IRT), and frequent sonde flights should allow near-continuous LIRAD retrieval of these quantities. We present early LIRAD analysis of cirrus optical depth, emittance, backscatter-to-extinction ratio, and related quantities at Manus Island and describe some of the modifications made necessary by use of the MPL and IRT as compared to high-power lidar and narrow-beam radiometers.

Lidar Calibration and Cloud Boundary Detection

Before the LIRAD algorithms may be employed, the lidar signal must be calibrated against a reference atmosphere, and the upper and lower boundaries of the cloud must be determined. Initial attempts to calibrate and detect cloud boundaries using techniques similar to those in Young (1995) were unsuccessful due to the higher noise level of the MPL compared to a high-power lidar and the small number of data points available in clear air regions above and below the cloud. (The MPL unit at Manus Island has a vertical resolution of 300 m.) An alternative method of finding the cloud boundaries and the signal offset was developed to overcome this difficulty.

From the lidar equation, the measured MPL voltage for backscatter received from a region below cloud is given by

$$V(r) = K\,M(r) + V_0 \tag{1}$$

while from a region above the cloud, the equation is

$$V(r) = K\ t^2c\ (r_b, r_t)\ M(r) + V_0 \tag{2}$$

where K is a calibration gain, $M(r) = b_M(r)\ \tau^2_M\ (0,r)\ /r^2$ is the modeled signal from a purely molecular atmosphere (including transmittance through the air below τ^2_M and the $1/r^2$ dependence), V_0 is the offset voltage, and $\tau^2_C(r_b,r_t)$ is the transmission within the cloud.

In practice we define two clear-air calibration regions: one below the cloud and another one above the cloud. These two regions are chosen in such a way that they are free from any broken cloud or variable aerosol layers. For the customary single-window fit, we can write for the low (high) window over N_1 (N_2) points

$$y = m_{1,2}\ x + n \tag{3}$$

Due to the fact that most of the lidar shots display a noisy signal for the top region, a two-window fit was applied ($N_1 + N_2$ points)

$$Y = M\ X + N \tag{4}$$

where y and Y stand for the measured signal; x and X for the reference signal; n and N for the offset; and $m_{1,2}$ and M for the gain. It follows that for the two-window fit the offset is

$$N = \frac{(Y)(X^2) - (YX)(X)}{(X^2) - (X)^2} \tag{5}$$

where angle brackets denote the arithmetic mean. Introducing the variable $c = N_1 / (N_1 + N_2)$, we can express the one-window offset in terms of the two-window offset:

$$n = N + c(1-c)m_1\left(1 - \frac{m_1}{m_2}\right)\frac{(x_2)(x_1^2) - (x_1)(x_2^2)}{(X^2) - (X)^2} \tag{6}$$

and note that

$$\frac{m_1}{m_2} = \tau_c^2(r_b, r_t) \tag{7}$$

The offset n is obtained by the offset determined from the two-window fit plus a correction (always positive) that depends on the windows' characteristics, low window gain, and cloud transmittance. In order to determine the correction factor, a preset value (0.85) for transmittance is assumed. This approach considerably reduces the effect that noise casts over the offset values as well as the gain, which is determined by a more customary single-window fit below the cloud.

A modified reference signal is used for finding the cloud boundaries:

$$M(r) = \frac{\beta_M(r)\tau_M^2(0,r)}{r^f} \tag{8}$$

In this case the exponent f is set to 2.16. This accounts for the different gains in the two windows and also produces a fit that is slightly above the real one, having the effect of "cutting" the noise level in the high window region. Using this "new" reference signal, a two-window fit gives us the gain and offset to be used to compute the difference between measured signal and reference. We define a threshold value using the difference between reference signal at top of the high window and bottom of the low window, and use the following procedure to decide if a cloud is present: First, find the maximum in signal and check if this is greater than the threshold. From this point, go up and down until the signal goes to zero (or close); these are the cloud boundaries. (If not, then no cloud is present.) Second, label the region as cloud if either the difference between top and bottom is greater than a preset limit (e.g., 200 m) or the average of the signal in these boundaries is greater than some percentage of the threshold. Third, redefine the low and high window region limits if necessary and repeat.

Results applying this new procedure are shown on Figures 1, 2, and 3. In Figure 1, the measured signal, the reference fit and the cloud boundaries are represented. Due to the low resolution of the lidar in this case (300 m), the boundaries may be less accurate (Figure 2). But when the resolution is high (30 m), the boundaries of the clouds are very well defined (Figure 3).

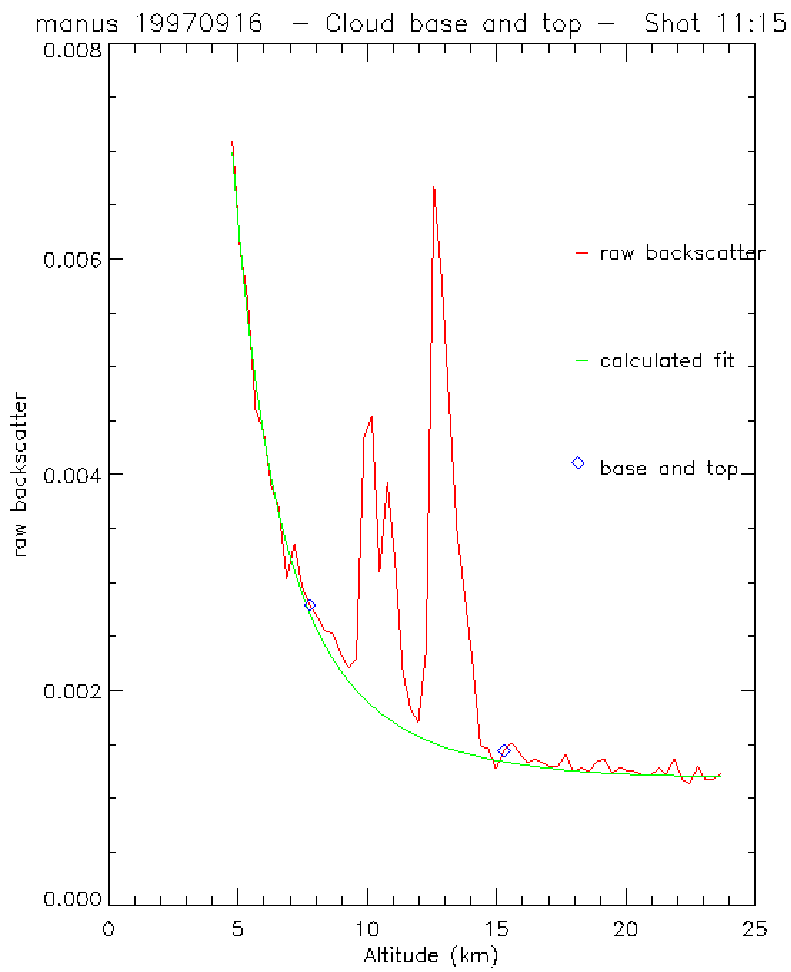

Figure 1. A single profile of raw lidar backscatter at Manus Island, together with the modified reference signal fit and the resultant cloud boundaries.

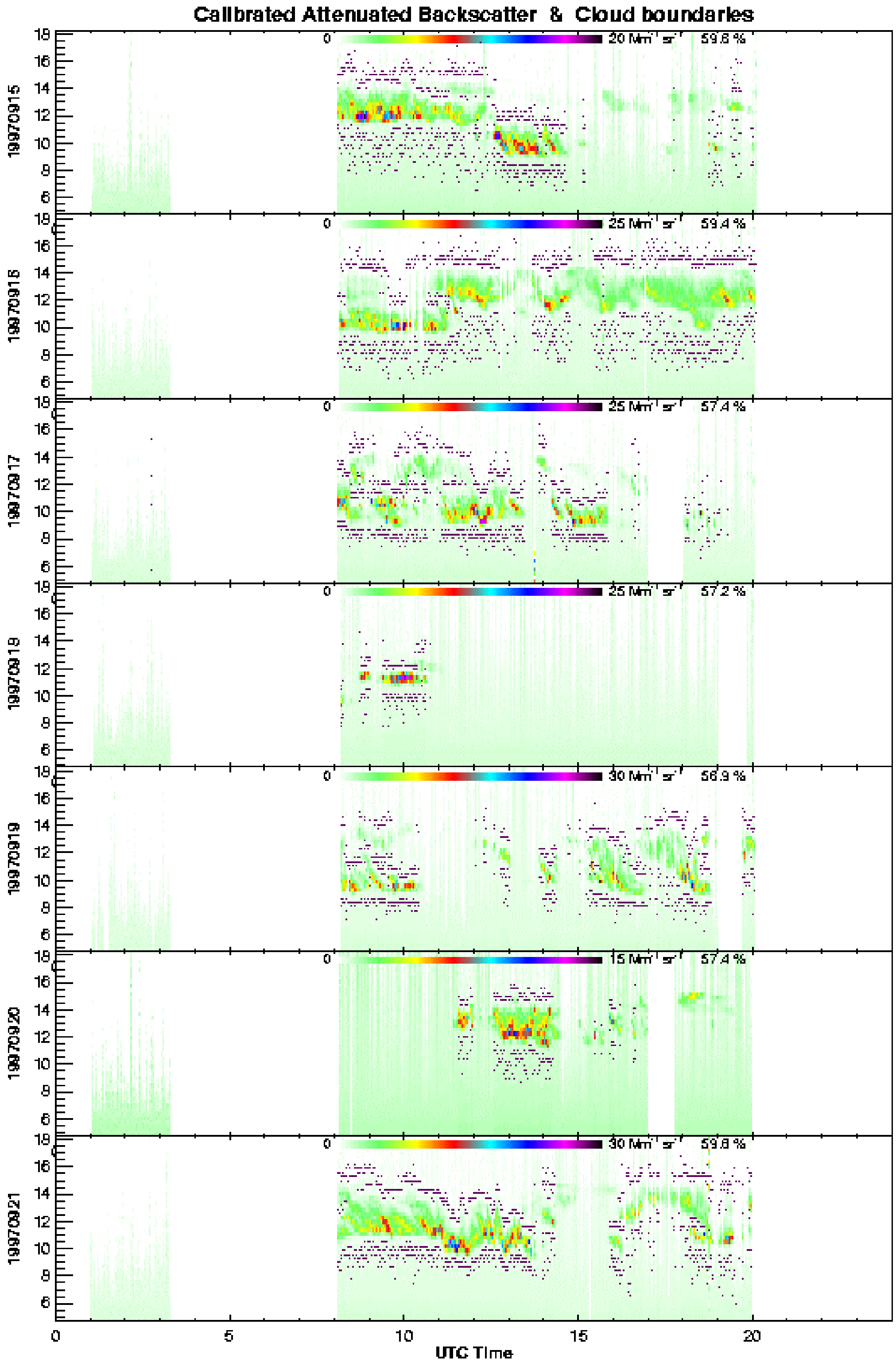

Figure 2. Seven days of calibrated MPL backscatter at Manus Island from September 1997, together with the retrieved cloud boundaries.

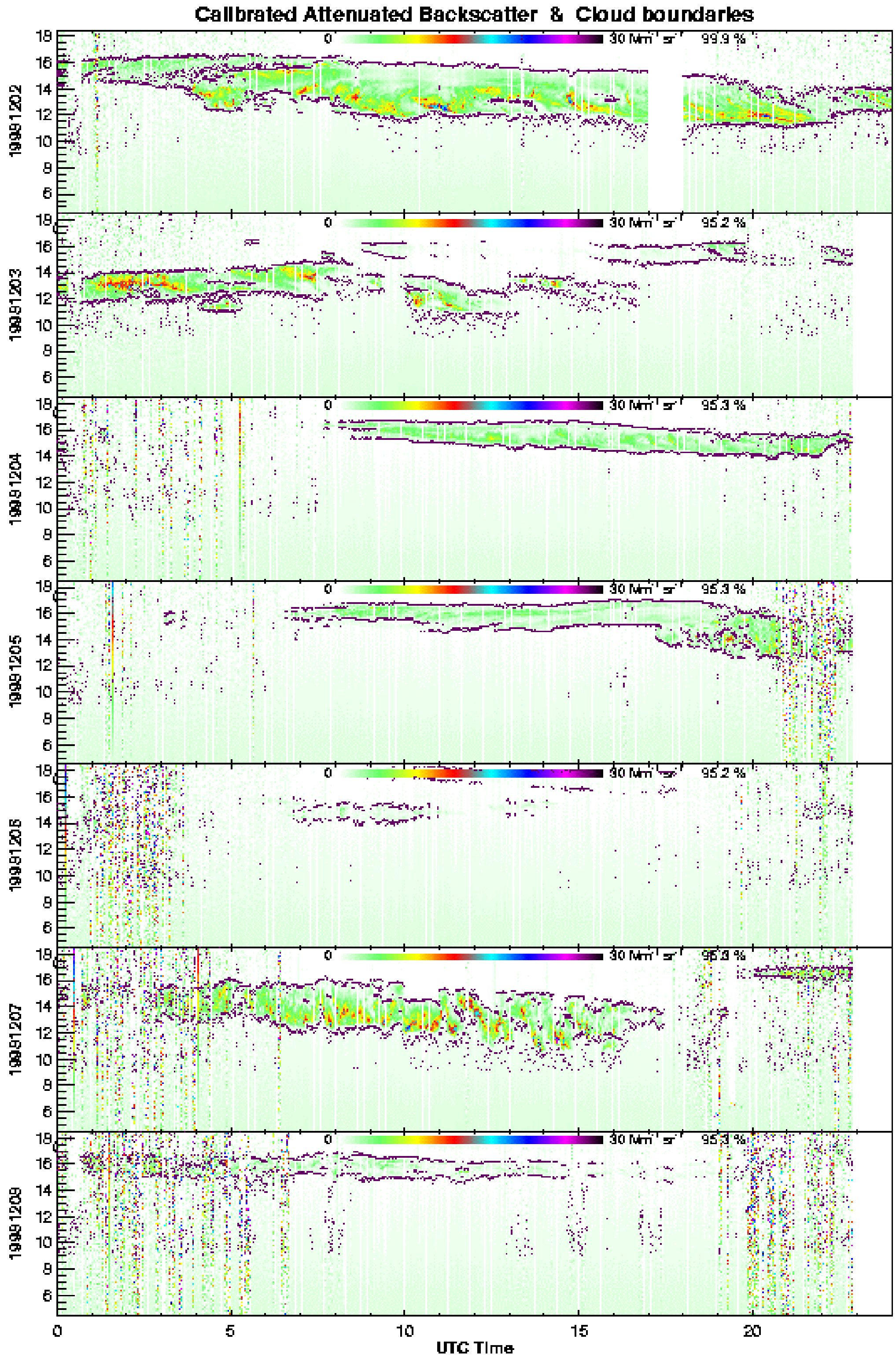

Figure 3. Seven days of calibrated MPL backscatter at Nauru from December 1998, together with the retrieved cloud boundaries. The Nauru MPL has 30-m vertical resolution.

This new approach allows us to determine multiple cloud layers (although in the figures only the “main” layer is represented), but is also sensitive to noise. We use additional tests to reject some shots as too noisy and also reject shots having low clouds.

LIRAD Analysis

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. 1998a) and equatorial cirrus (Platt et al. 1998b). 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.

Aside from the differences in calibration and cloud boundary determination described above, the other main difference in LIRAD analysis arises from the relatively wide field of view of the IRT. This results in a smoothing of the IR radiance values with time, but this should not have a major impact over long time periods.

Figure 4 shows various LIRAD quantities and results for a single day at Manus Island. We note that an approximate sonde profile had to be used due to a gap in sonde data over this period.

Conclusion

Initial runs of calibration and LIRAD algorithms on MPL data from the TWP-Manus site look good for nighttime periods, and we look forward to expanding trials to other CART sites. Upgrading the MPL units to high resolution (30 m) should improve the calibration, as indicated by the Nauru data, and may allow results to extend further into the daytime hours.

Acknowledgments

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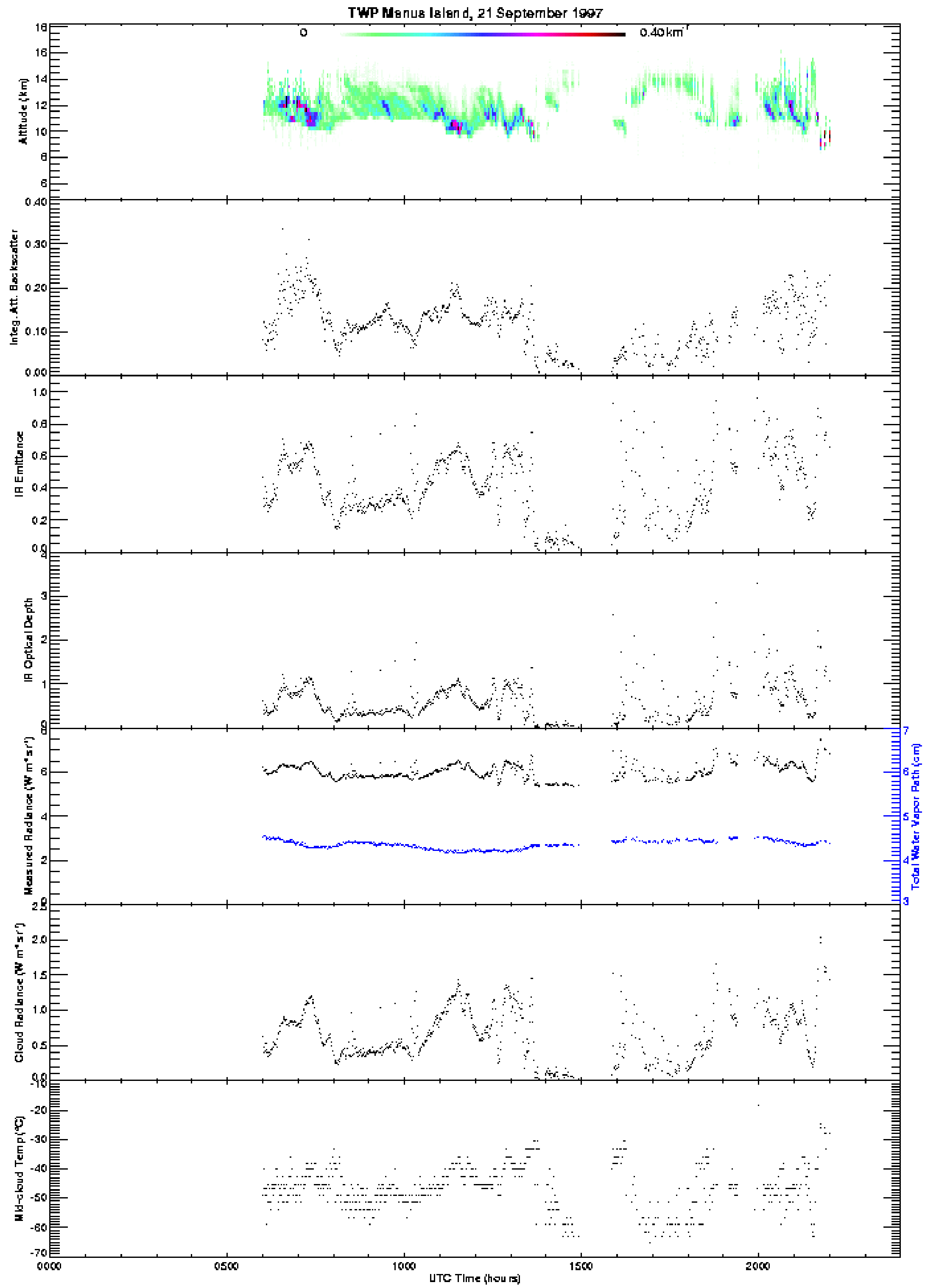

Figure 4. LIRAD quantities for September 21, 1997, at Manus Island: (a) lidar backscatter, (b) integrated attenuated backscatter, (c) IR emittance, (d) IR optical depth, (e) measured IR radiance and water vapor path, (f) retrieved cloud radiance, and (g) mid-cloud temperature.

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