Narrow-Beam Fast Filter Radiometry and the Use of the Lidar/Radiometer Method in the Atmospheric Radiation Measurement Program

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Introduction

A central goal of the Atmospheric Radiation Measurement (ARM) Program is to characterize the cloud properties in columns of atmosphere above the centres of the ARM Cloud and Radiation Testbed (CART) sites. Techniques developed at the CSIRO Division of Atmospheric Research over the past decade or two are very relevant to this ARM concept. The basis of the techniques, which have come to be known collectively as the Lidar/Radiometer (LIRAD) method, is to use two independent groundbased observations of clouds. A laser radar, or lidar, measures the cloud height, structure and particle phase. A narrow-beam filter radiometer measures the cloud infrared (IR) radiance. By combining the lidar and radiometer observations with a radiosounding of temperature, accurate information on cloud infrared emittance can be obtained. If the cloud is semi-transparent, which is often the case for high cirrus ice clouds, then the cloud IR optical depth and profile of IR absorption coefficient can also be obtained.

The secret of success in the technique is to use a radiometer with a narrow field-of-view compatible with that of the lidar (~10 mR or 0.5 degree) and with a response time fast enough to follow the observed rapid fluctuations in cloud emission, which can often occur as different clouds come into view. The radiometer axis should also be aligned with the lidar and the two axes placed as close together as possible so that lidar and radiometer are looking effectively at the same volume of cloud.

An infrared narrow beam filter radiometer is ideal for this purpose. For a filter width of about 1 μm wavelength and a suitable detector, such a radiometer can yield a response time of about one second, which will follow most cloud fluctuations with minimum lag.

The LIRAD Method

The use of narrow beam filter radiometers with lidars goes back some considerable time. The CSIRO Mark I radiometer was designed and constructed in 1970 (Platt 1971). Since then, improved versions (Mark II and Mark 111) have been constructed (Platt et al. 1987). Using the LIRAD method, much information has been obtained on the optical properties of cirrus (e.g., Platt et al. 1987, Platt and Harshvardhan 1988), as well on midlevel clouds (e.g., Platt and Bartusek 1974, Platt et al. 1978).

Basically the LIRAD method is a means of obtaining two independent pieces of information on clouds, one in the visible spectrum and one in the infrared. In principle, using the theoretical relationship between visible and infrared optical properties, one can then determine the total spectral radiative properties of the clouds, to an accuracy which is quite acceptable at present, as LIRAD has proven to be the only reliable method of obtaining such data.

In LIRAD, the infrared radiometer measures the cloud radiance continuously in a narrow region of the spectrum (10.84 ± 1 μm in the Mark I to Mark III radiometers. Mark II and III also had capability for 8-13 μm measurements). Using suitable spectral data combined with radiosonde ascents, the cloud radiance is corrected for atmospheric transmittance and emission from water vapour, ozone, and carbon dioxide. The cloud infrared emittance is then calculated from the lidar profile using coincident radiosonde data. The cloud infrared absorption coefficient is assumed to be proportional to the lidar backscatter coefficient and, using a radiative transfer equation, the constant of proportionality is adjusted until the observed and computed radiances are equal. This process produces both averages and profiles of absorption coefficient and emittance.

A plot of the integrated attenuated lidar backscatter coefficient versus infrared emittance also gives a numerical value of the isotropic backscatter to extinction ratio, modified by multiple scattering, which can then be used to retrieve the true profile of cloud backscatter coefficient. The process is then iterated to retrieve optimum values of infrared emittance. The method also gives a figure for the ratio between visible extinction and infrared absorption coefficients. This can be compared with theoretical predictions using different particle sizes (e.g., Platt 1979). A plot of infrared absorption coefficient against mid-cloud temperature is shown in Figure 1, the result of many observations on cirrus clouds taken over one year.

A polarization diversity lidar also gives data on depolarization ratios, which in turn give information on the extent of cloud glaciation. A comparison of past data on mid-latitude and tropical clouds forming at low temperatures (Platt et al. 1987) indicates consistent differences between values of depolarization ratio Δ, with tropical clouds giving the lower values (Δ = 0.3 at -60°C) compared with mid-latitude clouds (Δ = 0.4 at -60°C). This aspect requires further investigation.

The Use of LIRAD in ECLIPS

The use of LIRAD is illustrated briefly in terms of some data obtained recently in the Experimental Cloud Lidar Pilot Study (ECLIPS) project. (See WCRP 1988).

Figures 2 and 3 show, respectively, the cloud boundaries and plot of integrated lidar backscatter versus infrared emittance for an altocumulus cloud observed during ECLIPS2. Such data are being analyzed further at present to obtain the optical properties of different cloud types observed.

Improved Filter Radiometer

An improved narrow-beam fast filter radiometer has been developed for use with the LIRAD method, or similar observations, in the ARM Program. The characteristics of this radiometer are shown in Table 1.

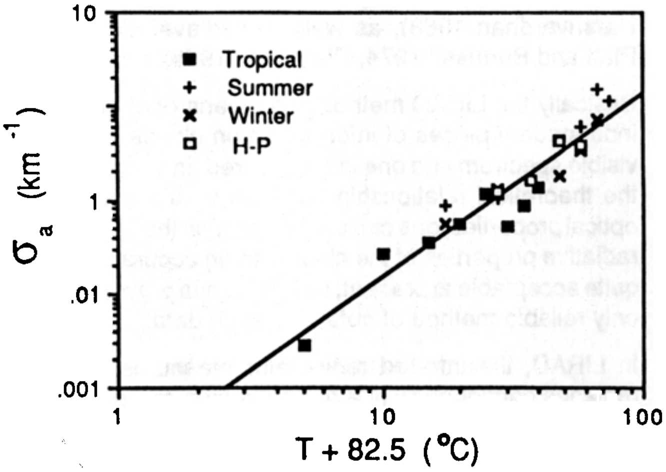

Figure 1. The variation in average infrared absorption coefficient (σ_a) at 10.84 μm wavelength with midcloud temperature (T) for a year's data on mid-latitude cirrus (after Platt and Harshvardhan 1988).

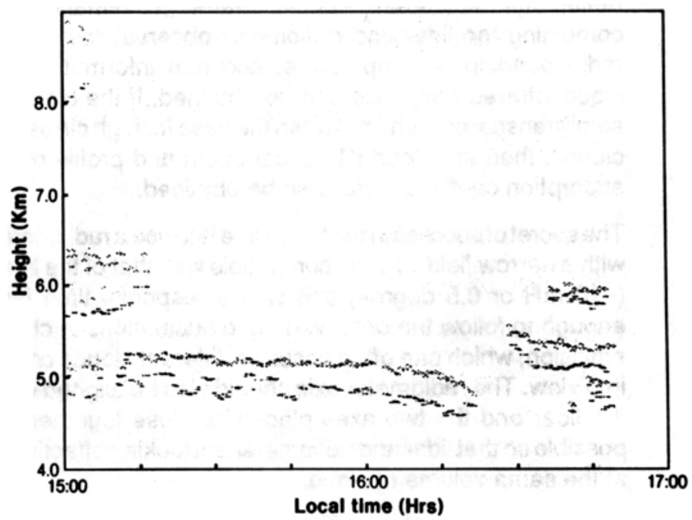

Figure 2. Cloud boundaries retrieved from lidar data for an altocumulus cloud on 20 June 1991, during ECLIPS.

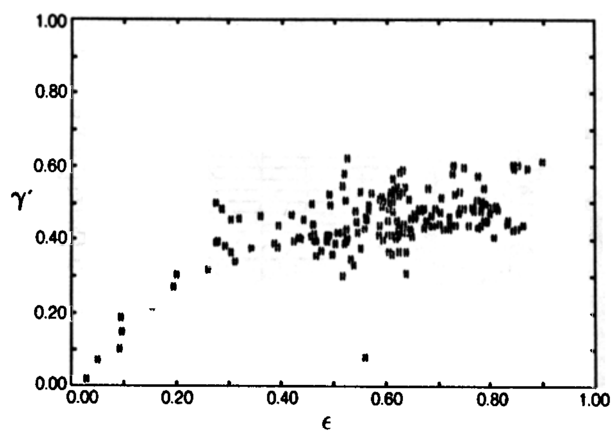

Figure 3. Integrated lidar backscatter (γ^1) plotted against infrared emittance (ε) at 10.84 μm for the same cloud as Figure 2.

A schematic of the optical lay-out of the instrument is shown in Figure 4. The optics comprises a simple Newtonian system with a primary mirror diameter of 5 cm and a primary focal length of 25 cm. After the field aperture, the radiation is collimated by an off-axis paraboloid, passes through a filter, and is focused finally on the HgCdTe detector. In the primary aperture, a chopper at 200 Hz chops the input radiation against a blackbody which occupies half the aperture and is controlled at 40°C. This method of chopping is inherently very stable, as the chopper blades give only an unchopped contribution to the radiation at the detector. The aperture consists of a variable iris which effectively varies the field aperture from 3 to 30 mR.

Table 1. Characteristics of the ARM narrow-beam radiometer.

Focal length		250 mm
Primary mirror diameter		50 mm
Effective aperture		9.05×10^2 mm^2
Detector		HgCdTe 1 mm sensor
Field aperture		3 to 30 mR
Spectral channels	(1)	8.62 ± 0.40 μm
	(2)	10.86 ± 0.50 μm
	(3)	12.04 ± 0.55 μm
Minimum detectable radiance		2×10^{-3} Wm^{-2} sr^{-1} hz$^{-1/2}$

A 45 degree gold-plated mirror at the input allows vertical or slant-path viewing and also rotates through 180 degrees to view a liquid nitrogen blackbody source or through 90 degrees to view an ambient temperature blackbody. The radiometer is fully computer-controlled, and data are recorded automatically on disk.

The use of three spectral regions across the 8-13 μm atmospheric window region allows investigation of the cloud characteristics over a region where the refractive indices of ice and water both vary, but in a different manner, thus allowing additional information on cloud phase and particle size, at least when the cloud is semi-transparent.

The ARM Pilot Radiation Observation Experiment (PROBE)

The Division of Atmospheric Research took part in ARM's TOGA COARE[a] PROBE experiment at Kavieng, New Guinea (2.5°S, 150.8°W) in January - February, 1993. This afforded an opportunity to use the new radiometer alongside the CSIRO Mark II radiometer in a direct comparison. The Division's 0.532 μm lidar was also used, and the data obtained on cirrus clouds, as well as some altocumulus, will be analyzed with the LIRAD method. The PROBE will also provide excellent radiosonde data every six hours, together with continuous microwave data of water vapour column and cloud liquid water column observations from the National Oceanic and Atmospheric Administrations's (NOAA) Wave Propagation Laboratory (WPL). The water vapour column data will be invaluable in allowing for any variations in water vapour radiance and transmittance at times between radiosonde observations.

A preliminary analysis of the data indicates the variability of the cirrus and its considerable geometrical depth at times and also the persistence of the cirrus cover.

(a) Tropical Ocean Global Atmosphere/Coupled Ocean Atmosphere Response Experiment.

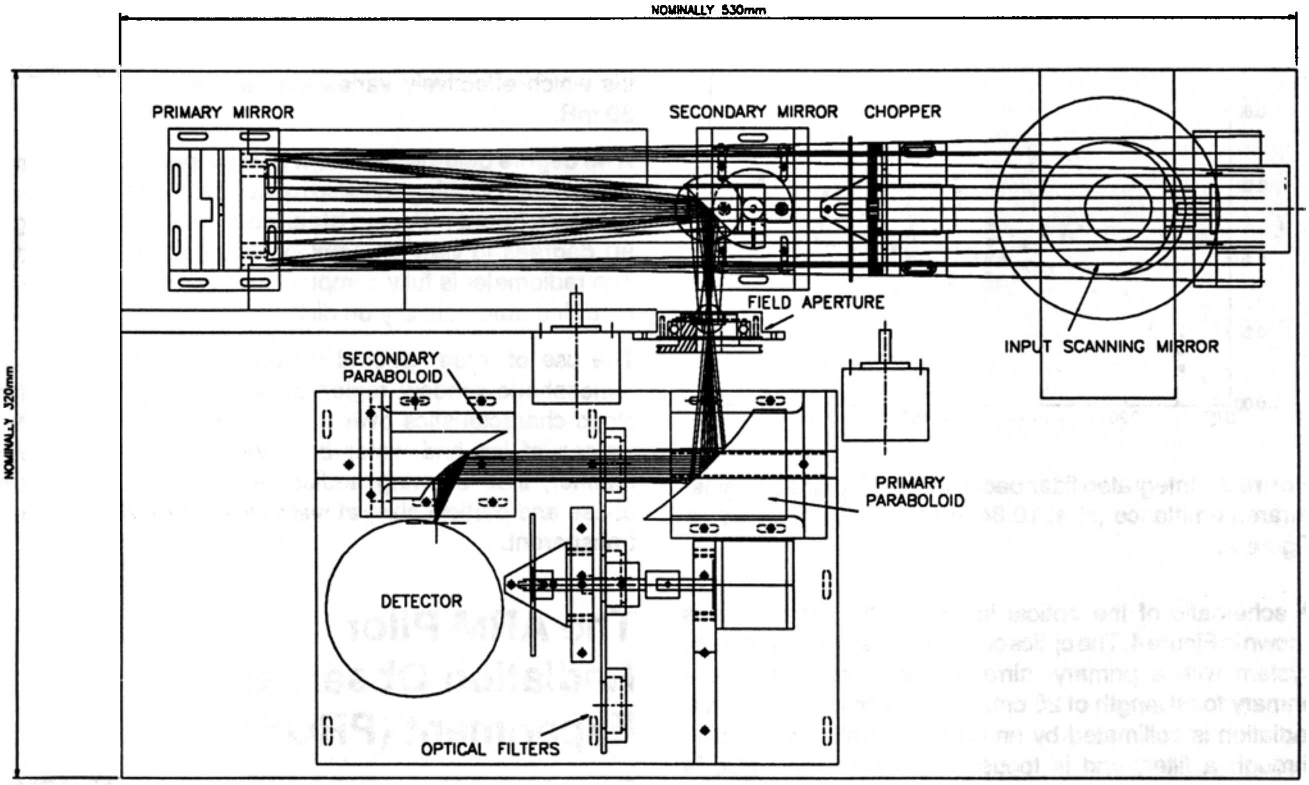

Figure 4. Schematic of the CSIRO/ARM filter radiometer optical system.

Particularly interesting was an apparent diurnal variation in both the cirrus cover and the optical depth with a maximum at about midday.

The ARM filter radiometer was run for about 70% of the time on the 8.62 µm filter; however, for some periods, the radiometer was run with the 10.86 µm filter enabling a direct comparison with the Mark II radiometer which used a 10.84 µm filter . Such a period is shown in Figure 5. As the input radiance is chopped against a 40°C blackbody, the zero radiance when viewing liquid nitrogen actually gives a large negative signal; whereas, the zero voltage occurs when the input radiance is from a 40°C blackbody. The responses of the two radiometers to various clouds are quite evident. The water vapour radiance is large, which is typical for the tropics. Periodically, there are either cirrus radiances or larger cumulus radiances superposed.

Also evident is the superior behaviour of the new ARM radiometer. The two radiometer apertures were equal in the comparison; however, the ARM and Mark II time-constants were 1 second and 5 seconds, respectively. By looking at the signal and noise levels during the calibration episodes in more detail, we calculate the minimum detectable radiances (MDR) of the two instruments as 4.9 x 10^{-3} Wm^{-2} sr^{-1} $hz^{-1/2}$ (ARM) and 6.8 X 10^{-2} Wm^{-2} sr^{-1} $hz^{-1/2}$ (CSIRO Mark II). The former is about twice the predicted value in Table 1.

A lidar profile of tropical cirrus is shown in Figure 6. This shows a typical deep layer extending through 6 km altitude.

Analysis of the data will provide a valuable comparison data set for future ARM CART observations in the tropical west Pacific region.

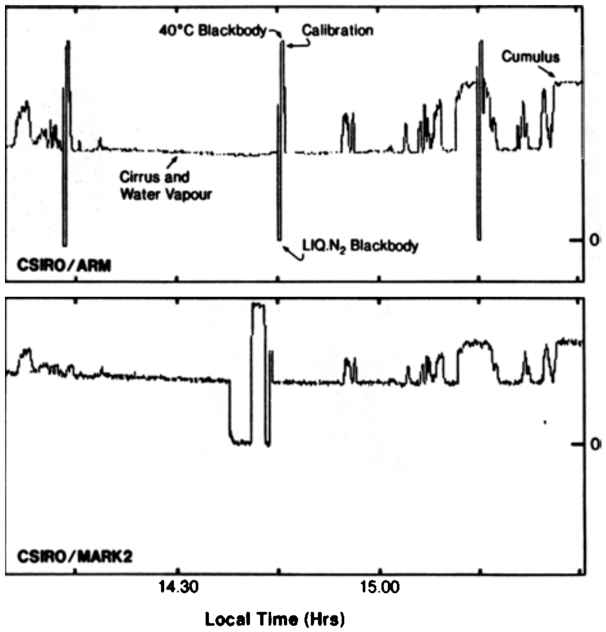

Figure 5. Comparison of the signal and noise output from the CSIRO Mark II and ARM radiometers for an observation period during PROBE. As the radiance is chopped against a 40°C blackbody, maximum negative signal is obtained when viewing a liquid nitrogen blackbody.

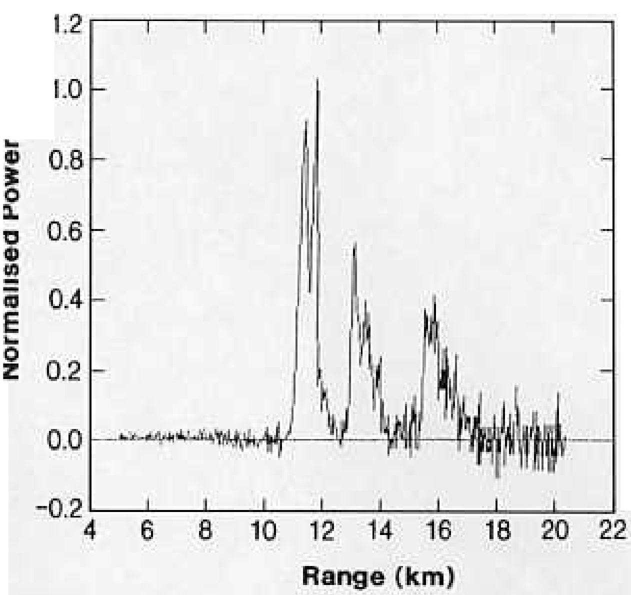

Figure 6. Lidar backscatter profile of tropical cirrus during PROBE.

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