Retrieval of optical and microphysical properties of clouds from space-based lidar data.

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We consider here what cloud properties can be retrieved using a two-wavelength lidar such as that proposed for the MDS-2 lidar, ELISE. The use of two wavelengths in cloud detection can be used for preserving sufficient dynamic range to cover clouds from very thin cirrus to dense tropical mesoscale systems. Thus if the 532 nm channel gain is sufficient to bring aerosol and molecular backscatter returns on scale, then the 1064 nm channel can be used in lower gain to achieve non-saturated conditions in dense clouds. As cloud particles are generally larger than either wavelength, then backscatter intensities are comparable.

As well as the obvious application of measuring cloud top height and base, it is a distinctive advantage if the climatically important quantity of optical depth can also be retrieved. Retrieval of optical depth at the lidar wavelength can be accomplished for semi-transparent clouds by comparing the backscatter directly below cloud base and above cloud top with a nearby cloudless profile, or with a molecular profile that has been generated from temperature data. Problems can be caused by the presence of aerosol, but reasonable retrievals can be still be achieved (1).

The cloud transmittance was determined through a cirrus cloud in the Lidar Inspace Technology Experiment (LITE) instrument flown aboard Space Shuttle Discovery in September 1994. A good correlation was found between values of $\gamma'(\pi)$ and the two-way transmittance through the cloud, as shown in Figure 1, indicating that the technique is sound. In Figure 1, the integrated attenuated cloud backscatter $\gamma'(\pi)$ is related to the two-way transmittance τ_e^2 by (e.g., 2):

$$\gamma'(\pi) = \frac{k}{2\overline{\eta}}(1 - \tau_e^2), \qquad (1)$$

Where k is the backscatter to extinction ratio and $\overline{\eta}$ is an effective multiple scattering factor.

The cloud optical depth can also be estimated, including optically thick clouds, by measuring the solar bi-directional reflectance from the cloud. This reflectance is obtainable in principle from the background voltage on the DC-coupled LITE detector output. This background offset was subtracted automatically and stored in real-time before the lidar signals were amplified. Figure 2 illustrates the offset voltage plotted against time as LITE passed over typhoon Melissa. Also plotted is the distance-height image. Increases in solar reflectance are accompanied by enhancements in background noise level. The RMS noise is also closely correlated with the offset voltage. The noise voltage was used to recover those regions of the offset voltage where saturation was occurring. The RMS noise voltage fitted to the offset voltage is shown in Figure 3.

The DC offset voltage can then be converted to units of solar radiance. Using known figures for incoming solar flux at the lidar wavelength, the bi-directional reflectance can then be calculated. The optical depth can then be retrieved through radiative transfer calculations. The method is being tested on the data described above. Similar techniques have been used from aircraft (3).

It can be observed from equation 1 that when τ_e^2 tends to zero, a value of k can be retrieved, providing that $\overline{\eta}$ can be estimated. This method has been used on LITE data to investigate changes in k in attenuating tropical clouds (4). An example is shown in Figure 4, where a large mesoscale system is shown as a distance-height image of attenuated backscatter. The cloud was completely attenuated above cloud base, as judged by the absence of any surface reflection. Values of $\gamma'(\pi)$ plotted on the same distance axis are also shown. Unusually high values of $k / 2\eta$ were measured. The origin of these high values is still being investigated. The values at either end of the plot are more typical of cirrus at the altitudes shown, assuming a value of $\overline{\eta}$ calculated from theory (2).

Techniques such as those described above will enable additional information to be derived from single-channel lidar data. The addition of a detector channel in the lidar that will detect the fraction of depolarized radiation in the return will similarly give information on cloud phase. Ice clouds are strongly depolarizing, but water clouds give negligible depolarization. Multiple scattering will gradually increase a depolarized signal in water clouds as optical depth increases, but such behavior is easily identifiable. Multiple scattering of photons in the lidar beam is particularly strong at space lidar ranges. This can change the effective pulse penetration and corresponding optical depths dramatically. If the multiple scattering is not taken into account the measured value of δ_c can be less than half the true value.

2. References

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3. Spinhirne, J. D., W. D. Hart and D. L. Hlavka, 1996: Cirrus infrared parameters and shortwave reflectance relations from observations. *J. Atmos. Sci.*, **53**, 1438 - 1458.

4. Platt, C. M. R., D. M. Winker and M. A. Vaughan, 1998: Backscatter characteristics of the top layers of some tropical mesoscale convective systems. *J. Appl. Meteor.*, Submitted for publication.

3. Figures.

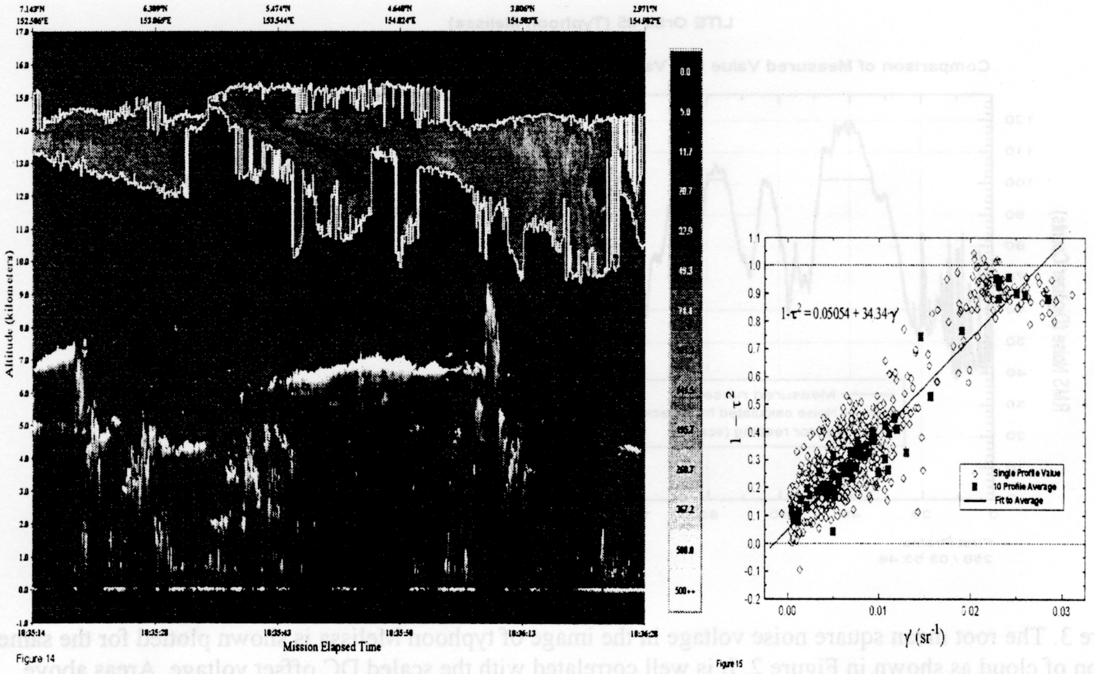
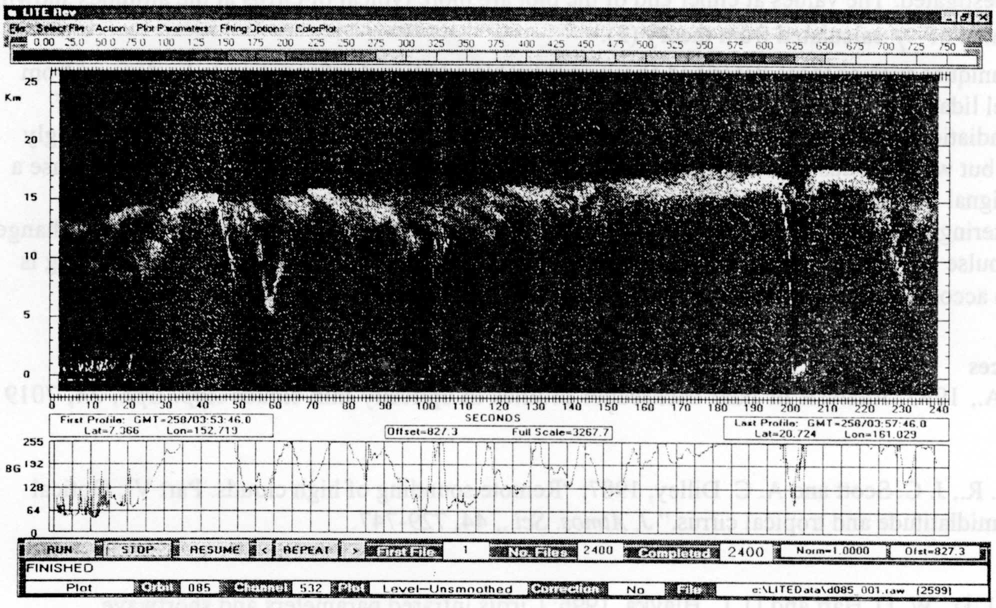


Figure 1. Cloud LITE distance-height image of clouds in the tropical west Pacific (Left) and a plot of $1-\tau^2$ versus $\gamma'(\pi)$ for the cirrus cloud marked out in white in the left-hand figure (Right).



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FINISHED

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Figure 2. Distance - height image of LITE attenuated backscatter across Typhoon Melissa. The solar radiance can be obtained from LITE data from the DC offset voltage. This is plotted below the distance-height image. It is also seen to be correlated with the solar noise voltage. The typhoon eye is seen to the right of the image. It was fortuitous that the LITE track passed right over the eye.

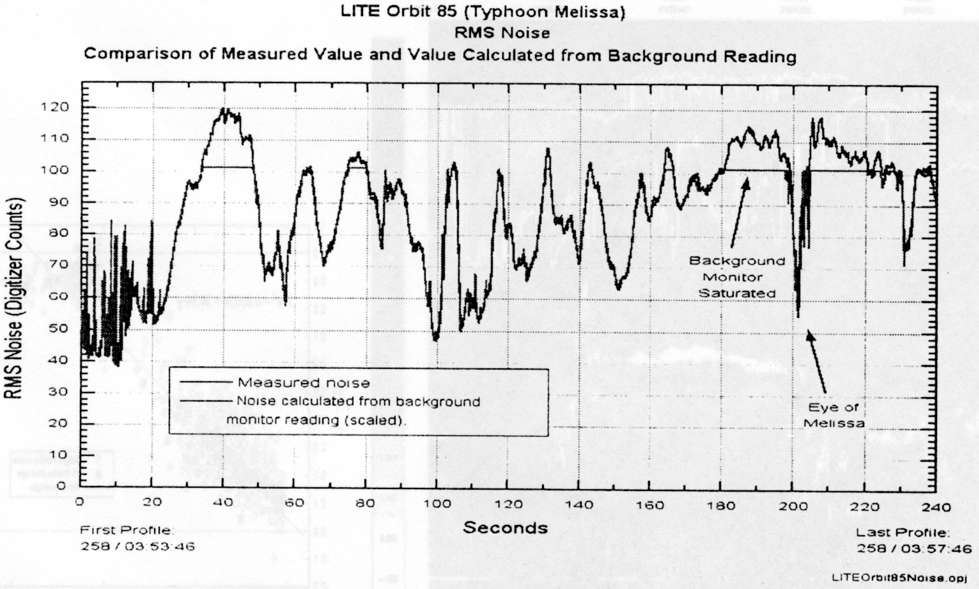

Figure 3. The root mean square noise voltage in the image of typhoon Melissa is shown plotted for the same section of cloud as shown in Figure 2. It is well correlated with the scaled DC offset voltage. Areas above the horizontal lines, where the offset was saturating, have thus been recovered and show a high solar bi-directional reflectance.

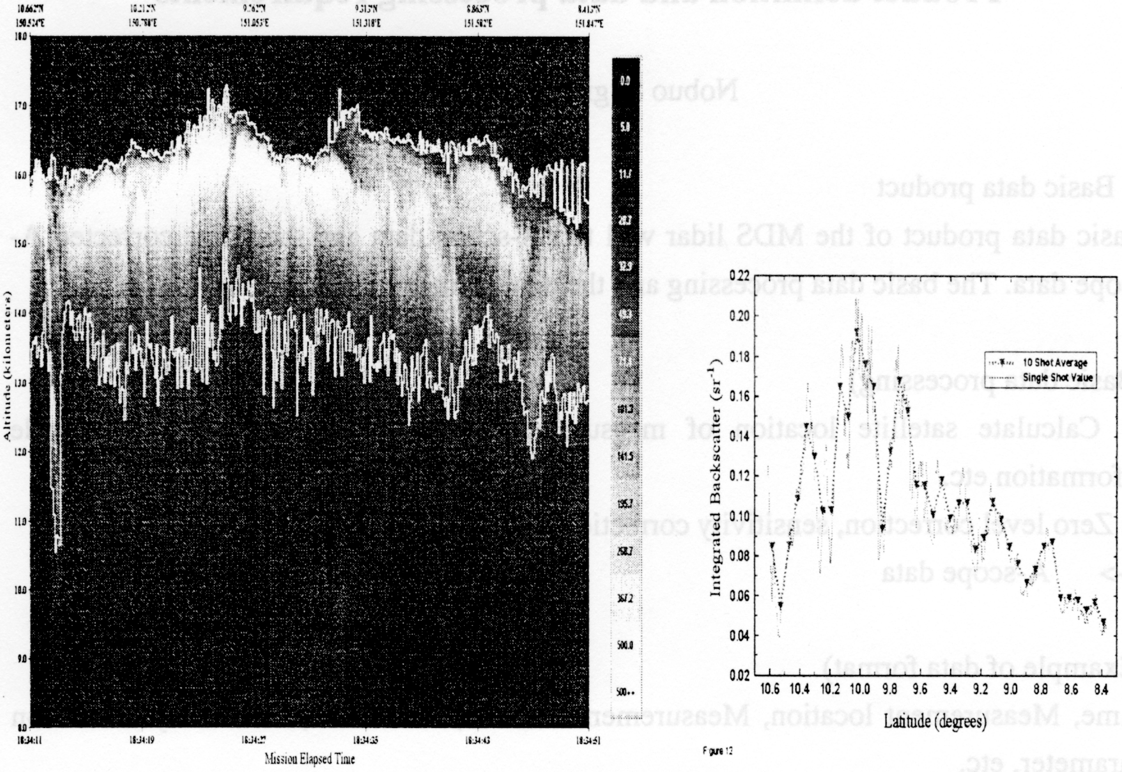

Figure 4. LITE distance-height image of attenuated backscatter from a large tropical mesoscale convective system, 420 km across, and situated some 10 degrees north of the equator in the West Pacific ocean. The cloud is completely attenuating and has a top height varying between 16 and 17 km. On the right is shown a plot of the integrated attenuated backscatter across the same region. The large variations in $k/2\overline{\eta}(\gamma'(\pi) when\ \tau_e \rightarrow 0)$ indicate changes in the cloud microphysics, and, possibly, effects of variations in multiple scattering factor $\overline{\eta}$.