SOLAR RADIANCE AND ALBEDO OF CLOUDS FROM SPACE LIDAR

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ABSTRACT

The background seen by a space lidar pointed towards earth during daytime orbits consists of the reflected solar radiance from terrestrial objects. This radiance appears as a constant background on each lidar backscatter profile. When orbiting over clouds, the radiance can give a measure of the cloud reflectance or albedo. Components from the earth's surface are minimal for highly reflecting clouds over the sea. The background radiance is measured at precisely the time that the atmospheric profile is obtained, allowing for accurate analysis of the scene. In the case of bright clouds, a bi-directional cloud albedo can be calculated. The background radiance also causes an increase in noise imposed on the lidar profile, and a measurement of the route mean square (RMS) noise value also gives the background signal. This paper demonstrates the technique by estimating the solar albedo over a large hurricane transited by The Lidar In-space Technology Experiment (LITE) lidar. Some results are also presented of cloud properties from analysis of GOES satellite data along the LITE orbit.

1. INTRODUCTION

The reflection of solar radiation from clouds has a considerable cooling effect on the climate. Without clouds the earths mean temperature would be much hotter at about 30 degrees C. Thus it is important to understand how clouds reflect solar radiation under different conditions and optical depths. There are now sophisticated methods of computing solar reflectance and bi-directional effects, but the optical depths of real clouds are not well known, and three dimensional and inhomogeneous effects cause problems.

The solar reflectance can also be obtained observationally from calibrated radiances of clouds from geostationary and orbital satellites, as is demonstrated in the International satellite Cloud Climatology Project (ISCCP).

This paper demonstrates that solar reflectance can also be obtained from space lidar returns. The unique advantage of lidar is that cloud height and vertical structures can also be obtained at precisely the same time.

2. THE LITE FLIGHTS

The Lidar In-space Technology Experiment (LITE) flew on Space Shuttle *Discovery* for ten days from September 9th to 19th, 1994. The experiment carried a three – wavelength high – power pulsed Neodymium-Yag lidar, transmitting at wavelengths of 1054, 532 and 355 nm. The shuttle was in an inclined orbit of 57 degrees. Numerous backscatter profiles were obtained in various regions of the earth divided between nighttime and daytime orbits during the 53 hours allotted to the experiment. The LITE package also contained a wide field of view camera.

LITE was pointed towards the earth, away from the nadir, at an angle of about 5 degrees to minimize potentially intense specular reflections from water surfaces and oriented ice crystal plates.

3. SOLAR SIGNAL IN THE LIDAR RETURNS

The LITE lidar transmitted pulses at a frequency of 10 per sec, giving an atmospheric profile at horizontal distances at the surface of 740 m. At a telescope aperture of 1.1 mrad the spot size seen at the surface was 250 m. Each profile was captured digitally and archived before transmission of the signals to surface receivers at various locations.

The receiver photomultiplier detectors were DC-coupled to the following amplifiers so that for each lidar return during daytime episodes, the background solar radiance appeared as a DC offset on the backscatter profile. The background noise level on the lidar returns increased and varied markedly over clouds due to solar radiance reflected back to the LITE receiver. Thus the receiver acted as a solar radiometer at the time of each pulse. The resultant DC background offset was removed from the signal at source and archived separately, and was available for analysis.

The route mean square (RMS) noise level was also observed to vary on each lidar return, increasing over clouds. When the RMS noise was plotted against the DC offset, a very good correlation was obtained. This indicated that the solar radiance from clouds could be measured at the time of each lidar shot for daytime periods, provided that a calibration of radiance in terms of background counts was available.
The solar albedo and therefore bi-directional reflectance from the ocean is generally less than 0.05 except in the specular region of sun glint. Thus when situated over the ocean, the background solar radiance was effectively equal to the cloud radiance over relatively dense clouds.

4. REFLECTANCE OVER HURRICANE MELISSA

As an example of the techniques, analysis of the solar background signal at 532 nm from the LITE lidar profiles was performed for a pass over the deep clouds of Hurricane Melissa [1]. Melissa was classified as a category 5 hurricane situated east of the Philippines on 15th September 1994. The orbital path over the hurricane is shown in Fig 1. The orbital

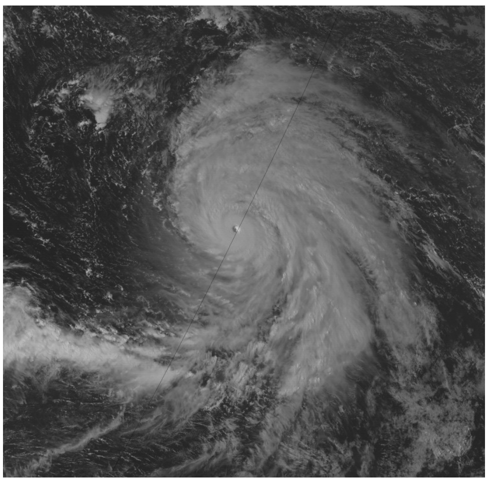

Fig 1. GMS image of hurricane Melissa showing the LITE orbit crossing part of the eye.

footprint fortuitously crossed the eye of the hurricane. The lidar backscatter in a distance-height image over the hurricane is shown in Fig. 2. Complete attenuation of the lidar pulse occurs within 1 to 2 km in

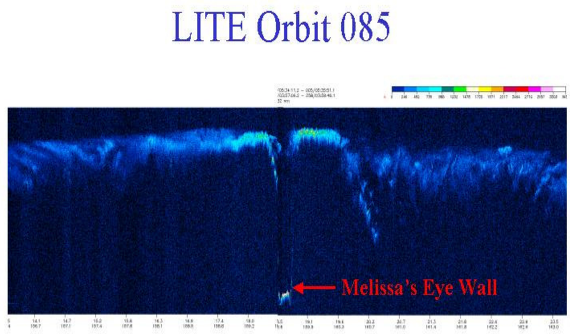

Fig 2. Distance – height lidar backscatter image of hurricane Melissa. The eye of the hurricane is also shown

most regions, and the eye of the hurricane is shown clearly. The archived DC background values were used to construct the relative solar radiance over Melissa. However, the receiver background monitor (but not the lidar backscatter signal) saturated in regions of high solar radiance. But these regions could be recovered using the RMS signal from the background noise, which did not saturate. Fig. 3 shows that the RMS noise signal was well correlated with the DC background signal, except where the latter saturated at high values. Values above 100 counts show the RMS values only, the DC background monitor saturated at higher values. Thus a complete picture of radiance over Melissa was available.

4.1 Bi-directional reflectance and albedo

The lidar receiver was not calibrated to the incoming background radiance, so that the solar reflectance, and thus bi-directional albedo, could not be calculated directly. The albedo values were thus calculated from calibrated values from the GMS satellite values using an ISCCP normalisation to radiance units of $Wm^{-2}sr$ and converted to reflectivity by standard methods [2]. A plot of the calculated albedo against the lidar-derived solar radiance along the satellite orbital path across Melissa is then made. Fig 4 shows the GMS reflectance values plotted against the RMS solar noise. The eye wall crossing time of LITE was 0357Z compared to the GMS image time of 0425Z. Thus the observed scatter would be expected in the data.

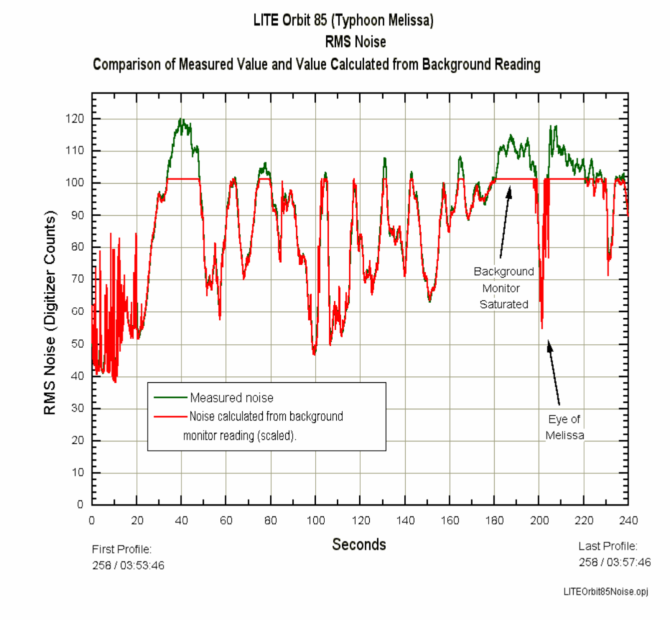

Fig 3. The DC background counts along part of hurricane Melissa scaled to the RMS counts. The DC background saturates above 100 counts. Otherwise, the correlation is very good.

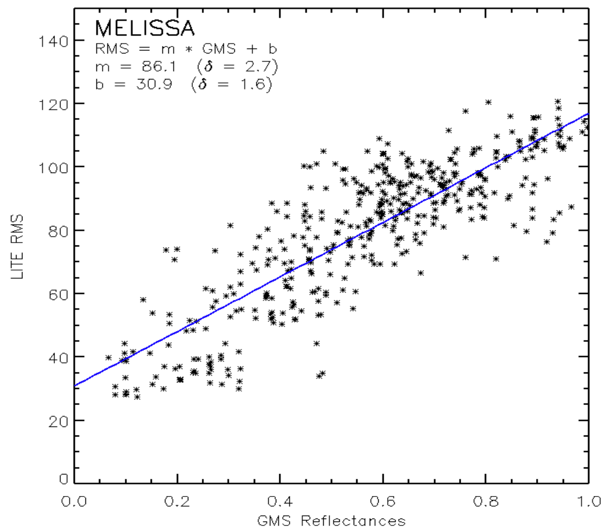

Fig 4. A plot of the GMS reflectance values measured along the orbit against the RMS noise counts.

The resultant isotropic albedo over Melissa is shown in Fig. 5. The position of the eye is shown near the centre of the diagram. The great horizontal extent of the hurricane is apparent. The highest albedo is in regions around the eye and also at a hurricane out flowing cloud band to the south of the eye. The value over 100 indicates high reflectance from the eye wall. The bi-directional reflectance is shown in Fig. 6. The integrated lidar backscatter was found to be very high in regions near the eye wall [1], giving values of cloud particle backscatter to extinction ratio which were higher than encountered in any other cirrus ice cloud system, but these were not closely related to the albedo values.

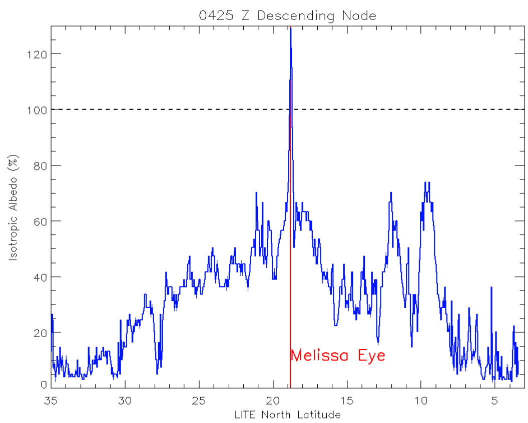

Fig 5. The isotropic albedo over hurricane Melissa showing the spike caused by reflection from near the eye wall.

5. CLOUD OPTICAL DEPTH ALONG A MELISSA ORBIT

The cloud optical depth can be deduced from the cloud albedo using theoretical radiative transfer calculations for an isotropic reflecting cloud. Optical depths for hurricane Melissa can then be estimated, and compared approximately with values obtained from lidar retrievals. Such estimations need further work, as the cloud structure is by no means isotropic.

The optical depths and effective radii of some cloud systems along the Melissa track were obtained from GOES data [3]. At the same time, the cloud tops and penetration depths were obtained from LITE lidar profiles. In this case the 0.65 μm and 3.9 μm channels were used. An example is shown in Figure 7. The LITE data show clearly the cloud heights and penetration depths and some of the complex atmospheric profiles.

6. CONCLUSION

This paper shows how solar bi-directional radiance can be measured with respect to orbit time at each lidar

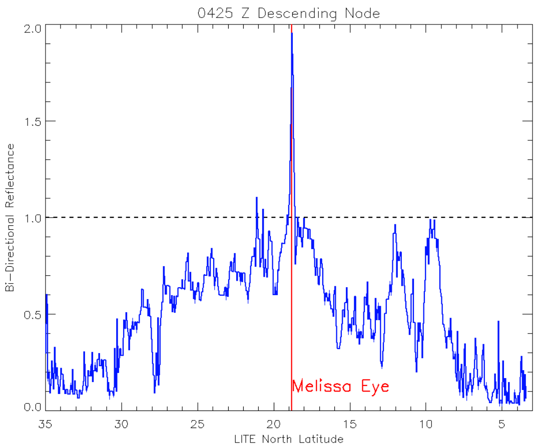

Fig 6. The bi-directional reflectance over hurricane Melissa

return, using either the RMS noise level or the DC offset in the following amplifier. This reflectance can be related to cloud structure and for semitransparent cirriform clouds, the scene underneath the cloud can be identified.

The method has potential for measuring solar radiances from complex scenes using the Cloud Aerosol Lidar Pathfinder Satellite Observations (CALIPSO) satellite data. The infrared channels in the IR radiometer will enable infrared and visible properties of complex scenes to be measured simultaneously (e. g., Fig. 7).

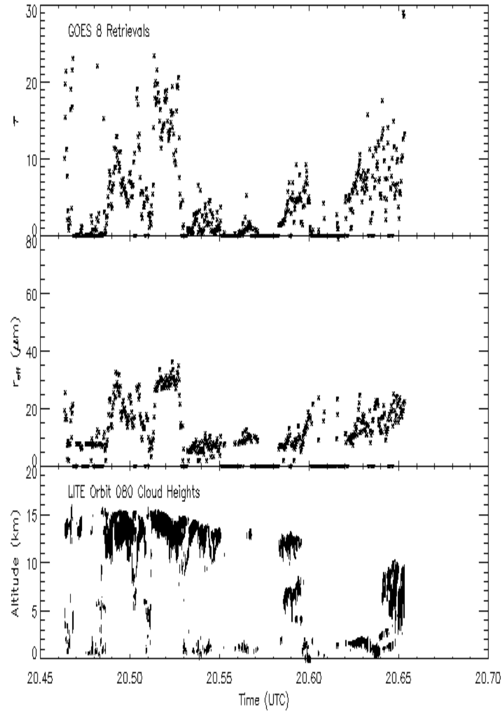

Fig. 7. The optical depth, effective radius and cloud altitude along part of the LITE orbit 80 in a tropical region from GOES satellite imagery.

7. REFERENCES

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