CALIPSO Polar Stratospheric Cloud and Stratospheric Aerosol Measurements

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1. Introduction

This paper describes the capabilities of the Cloud Aerosol Lidar Infrared Pathfinder Satellite Observation (CALIPSO) satellite for classifying and measuring polar stratospheric clouds (PSCs)[1] and stratospheric aerosols. The method is to find distributions of backscatter for PSCs and stratospheric aerosols and then use CALIPSO detection sensitivities for various averaging lengths to determine the amount of averaging necessary to allow CALIPSO to detect one of these features. Once the averaging lengths necessary are determined, a comparison of these lengths to the estimated size of the features in the stratosphere will be used to determine the best combination of averaging lengths that should be implemented. The methods discussed here apply for a stratosphere with aerosol loading on the level of early year 2000 and higher. Stratospheric aerosols will be classified into types or subtypes using depolarization and color ratio data.

Data form the SAGE Ozone Loss and Validation Experiment (SOLVE) will be used to determine distributions of backscatter, color ratio, and aerosol depolarization ratio for polar stratospheric clouds and stratospheric aerosols. The data used are from 19 separate flights spanning the dates of December 2, 1999 to March 15, 2000 over the Arctic stratosphere from the altitude range of 16 to 27 km, where polar stratospheric clouds are usually found. Therefore, the PSC measurement opportunities determined by this paper will be conservative since there are many more PSCs in the Antarctic during winter.

2. CALIPSO

CALIPSO[2] will be launched in early 2004 into a 705 km, 98.08 inclination orbit. The lidar is a 3-channel (1064 nm, $532_{\|}$ nm, and $532_{\perp}$ nm) system with a 1 m receiving telescope. Other instruments on the spacecraft include an Infrared Imaging Radiometer (IIR) and a Wide Field Camera (WFC). The coverage for CALIPSO is shown in Figure 1.

Table 1. Characteristics of the CALIPSO lidar, wide-field camera, and infrared imaging radiometer.

Lidar

Laser	2 ND: YAG @ 110 mJ
Wavelength	532 nm, 1064 nm
Repetition Rate	20.16 Hz
Telescope	1.0 m diameter
Polarization	532 ‖ and ⊥

Wide Field Camera

Wavelength	645 nm
Spectral Width	50 nm
IFOV	125 m
Swath	60 km

Infrared Imaging Radiometer

Wavelength	8.7, 10.6, 12 μm
Spectral Resolution	0.8 μm
IFOV	1 km
Swath	64 km

3. Defining PSCs and stratospheric aerosols

All SOLVE data between 16 and 27 km are partitioned into PSC, aerosol, or unusable data. Data points containing PSCs are defined in Table 2. Temperatures below 195 K are thought to be necessary for sustaining PSCs.

Table 2: Parameter ranges required to define a data point as a PSC

Parameter	Minimum	Maximum
532 nm Scattering Ratio	1.12	10.0
1064 nm Scattering Ratio	1.12	100.0
532 nm/1064 nm backscatter ratio	0.5	16.0
Temperature (K)	170.0	195.0

Data points containing aerosols are defined in Table 3. These ranges cover all points not covered in Table 2 for temperatures between 170 and 300 K, 532 nm/1064 nm backscatter ratios between 0.5 and 16, 532 nm scattering ratios between 1 and 10 and 1064 nm scattering ratios between 1 and 100. All data points outside of these ranges are considered unuseable because they are outside the ranges expected or because the signal may be saturated.

Table 3: Parameter ranges required to define a data point as an aerosol

Parameter	Minimum	Maximum
For temperatures between 170-195 K: 532 nm Scattering Ratio 1064 nm Scattering Ratio	 1.0 1.0	 1.12 1.12
For temperatures between 195-300 K: 532 nm Scattering Ratio 1064 nm Scattering Ratio	 1.0 1.0	 10.0 100.0
532 nm/1064 nm backscatter ratio	0.5	16

4. Determining averaging lengths

Figures 2 and 3 shows the SOLVE backscatter distributions for clouds at 532 and 1064 nm, respectively, in the 16 to 27 km altitude range and given the filters applied in Table 2. The best averaging lengths are those that allow a high percentage of these cloud backscatters to be observable by CALIPSO. The averaging is then applied in various proportions in the horizontal and vertical to optimally resolve the geometrical average size cloud with nearly constant optical properties. Table 4 shows the minimum detection sensitivity for CALIPSO at night for various horizontal and vertical averaging lengths and the percentage of SOLVE cloud backscatters that would be detectable. Averaging lengths inside the bold line allows greater than 90% of the clouds to be detected by CALIPSO.

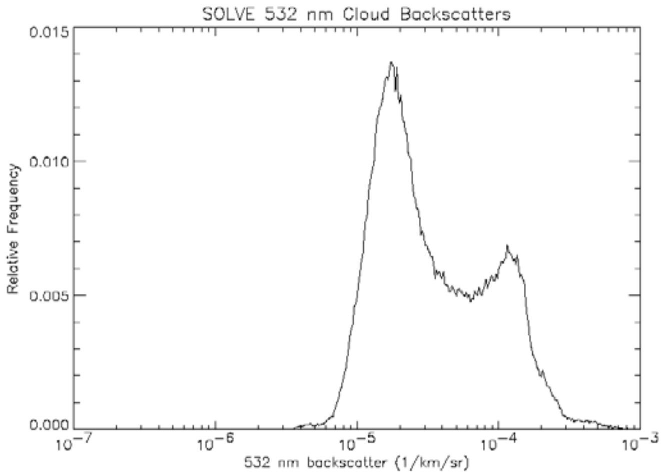

Figure 2. Backscatter histogram at 532 nm for all SOLVE data points that meet the characteristics given in Table 1.

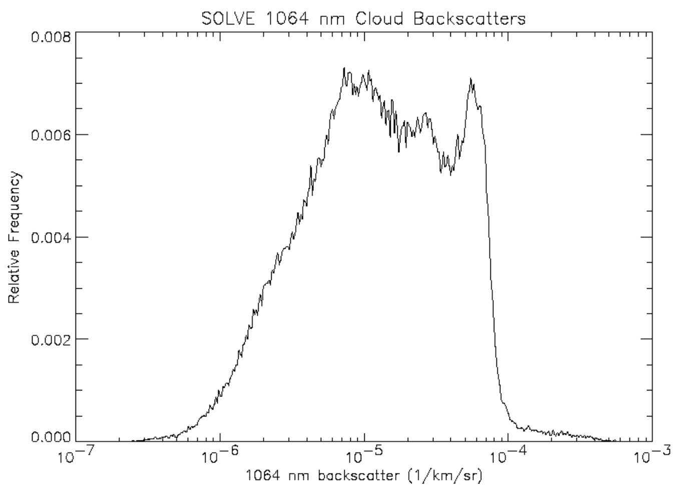

Figure 3. Backscatter histogram at 1064 nm for all SOLVE data points that meet the characteristics given in Table 1.

Table 4: CALIPSO minimum detectable backscatter at 20 km for various horizontal and vertical resolutions. The percentage of PSCs observed during SOLVE that would be observable by CALIPSO are in parentheses. The bold line outlines the averaging lengths that give a greater than 90% detection rate.

Vertical Resolution	Wavelength	Horizontal Resolution			
		5 km	20 km	80 km	240 km
60 m	532 nm	2.1×10^{-4} (2.56%)	8.2×10^{-5} (22.76%)	3.5×10^{-5} (42.20%)	
180 m	532 nm		4.201×10^{-5} (37.61%)	1.944×10^{-5} (65.35%)	1.086×10^{-5} (93.30%)
540 m	532 nm		2.272×10^{-5} (57.13%)	1.086×10^{-5} (93.30%)	6.15×10^{-6} (99.65%)
60 m	1064 nm	6.2×10^{-4} (0.00%)	3.1×10^{-4} (0.14%)	1.5×10^{-4} (0.64%)	
540 m	1064 nm		1.042×10^{-4} (1.10%)	5.204×10^{-5} (12.79%)	3.003×10^{-5} (26.36%)
1080 m	1064 nm		7.364×10^{-5} (3.34%)	3.678×10^{-5} (21.30%)	2.123×10^{-5} (35.64%)

CALIPSO has the capability of distinguishing between polarizing and nonpolarizing clouds, and clouds that contain large or small particles if the signal-to-noise ratio permits. For the SOLVE measurements, more than 90% of the clouds were found to be larger than 150 km in the horizontal and 1 km in the vertical. Based on the results in Table 4, 80 km horizontal averaging and 540 m vertical averaging would be the best averaging lengths to use to observe PSCs with CALIPSO.

Figure 4 shows the aerosol volume depolarization ratio for all PSCs observed during SOLVE. Two relative maxima appear in the plot: at 0.01 and 0.3. These two maxima are produced by nondepolarizing and depolarizing PSCs, respectively. Analysis shows that it will be possible to distinguish depolarizing and nondepolarizing clouds or aerosols with scattering ratios greater than 1.3 using a horizontal averaging length of 80 km and a vertical averaging length of 1080 m. Color ratios of 532 nm/ 1064 nm backscatter will be used to distinguish PSCs with large and small particles. If the PSCs observed during the SOLVE flights are representitive, however, only a small percentage (34%) will be observable by CALIPSO using a horizontal averaging length of 240 km and a vertical averaging length of 1080 m. These averaging lengths are too large and, therefore a breakdown by size will be difficult.

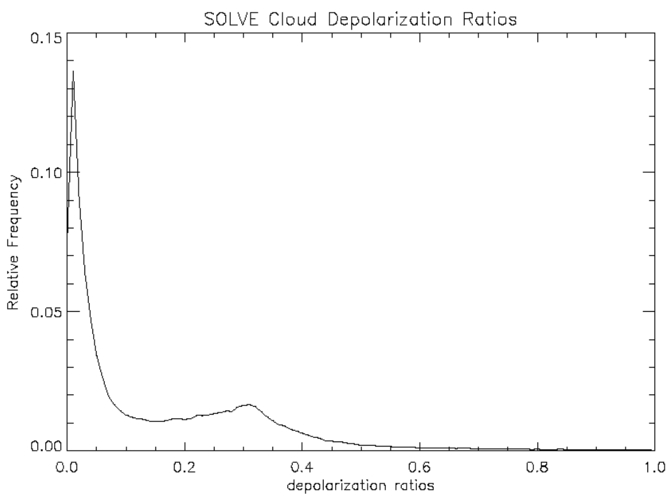

Figure 4. Aerosol Depolarization histogram for all SOLVE PSCs data points as defined in Table 2.

5. Implications of a high stratospheric aerosol loading

At this time stratospheric aerosol optical depths are at very low values. For example, SAGE II data indicate a value of about 0.001 at 1.0 µm wavelength. These optical depths are the lowest values ever measured by SAGE II or its predecessors[3]. During the 10-day shuttle flight of LITE in 1994, however, this value was approximately 0.01 and the lidar backscatter ratios at 532 nm were of the order of 1.1. If during the CALIPSO mission, scattering ratios of greater than 1.1 exist because of a new volcanic eruption, then higher resolution stratospheric aerosol measurements will be possible with CALIPSO and the aerosol plume can be tracked as it spreads.

6. Summary

This paper describes the potential for detecting and classifying PSCs and stratospheric aerosols using CALIPSO observations. The orbit provides measurement opportunities that will be unprecedented and not previously possible using airborne and other satellite techniques.

7. References

1. McCormick, M. P., H. M. Steele, P. Hamill, W. P. Chu, and T. J. Swissler, "Polar Stratospheric cloud sightings by SAM II, Journal of Atmospheric Science, 39, 1387-1397, 1982.
2. Winker, D. M., "The CALIPSO mission", 21st International Laser Radar Conference proceedings, 2002.
3. McCormick, M.P., J.Anderson, M. Hill, "Mt. Pinatubo aerosols: An historical perspective determined from remotely sensed measurements", AGU Fall Meeting proceedings, 2001