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CO_2 Lidar Observations of Mount Pinatubo Debris: FIRE II and Longer-Term Measurements

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Introduction

The volcanic debris in the stratosphere from the June 1991 eruption of Mt. Pinatubo first appeared over the NOAA Wave Propagation Laboratory (WPL) field site near Boulder, Colorado (40.15° N, 105.23° W), in July of 1991. The presence of the Pinatubo cloud has allowed us to characterize both the tropospheric and stratospheric aerosol backscatter using the NOAA/WPL CO_2 Doppler lidar. The lidar has measured vertical backscatter profiles at $\lambda = 10.59\ \mu m$ for over a decade (Eberhard and McNice, 1986). Analysis of this dense set of profiles reveals the effects of atmospheric and microphysical processes during the buildup and decay of Mt. Pinatubo's clouds. Further information on the NOAA lidar, specifically calibrations using a hard target, can be found in Post and Cupp (1990).

We present results of those measurements for June 15, 1991, through December 31, 1992. During that period of longer-term measurements, WPL took part in FIRE II (First ISCCP[=International Satellite Cloud Climatology Project] Regional Experiment II), from November 12 through December 8, 1991, measuring vertical backscatter profiles almost daily.

One of the mechanisms for purging stratospheric aerosols is tropopause folding (Post, 1986), which occurs in cold-core extratropical cyclones. Tropospheric mass loading occurs during folding events (Shapiro and Keyser, 1990), which can substantially increase the amount of ice nuclei in the upper troposphere (Sassen, 1992), and may affect the formation of cirrus in that region. Spring and fall are prominent times for tropopause folding events because of the migration of the subtropical and polar jet streams during the transition seasons. Sassen (1992) has suggested that the volcanic aerosols from Pinatubo played a role in the formation of cirrus during FIRE II, particularly during a period of moist subtropical flow on December 5-6, 1991.

Longer-Term Measurements

Figure 1 shows the time series of backscatter profiles taken by the CO_2 system from June 1991 through December 1992 (profiles were obtained at the field site near Boulder, except for several periods when the lidar system was in White Sands Missile Range, New Mexico, and Coffeyville, Kansas). The increase in range into the stratosphere that occurred with the first appearance of the cloud in July 1991 is very clear from this time series. From July 1991 until January 1992 the stratospheric backscatter steadily

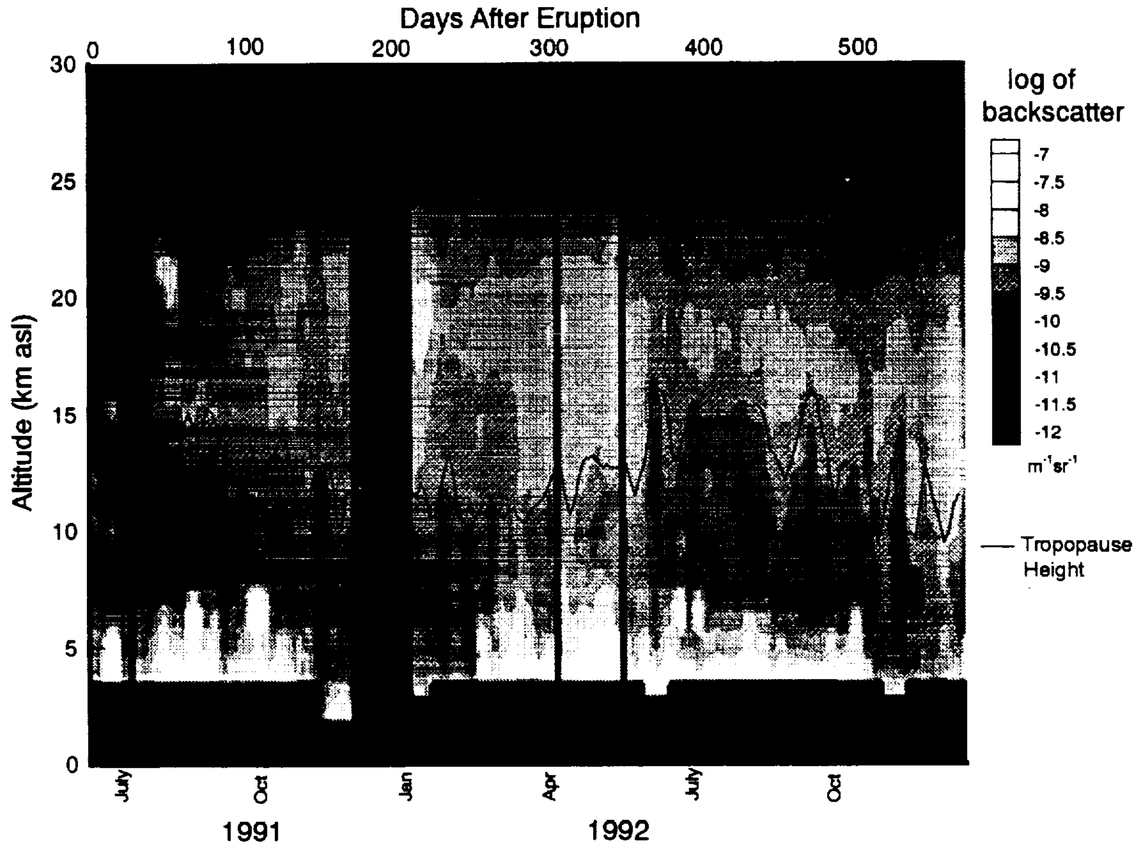

Figure 1. Time series of lidar backscatter β (m^{-1} sr^{-1}) profiles for June 15, 1991, until December 31, 1992. The height of the tropopause (solid line), determined from NWS soundings, is also included. Note the increase in stratospheric backscatter after July 1991.

increased; this is observed as a wedge-shaped broadening of the region of high backscatter centered on 17 km MSL. The high-backscatter portion of the cloud extended up to 23 km and downward to 11 km MSL by the end of 1991. Simultaneous with the appearance of stratospheric debris, tropospheric backscatter increased markedly, and it has remained well above nonvolcanic levels since.

FIRE II Observations

The measurements taken during FIRE II occurred in a period when the volcanic cloud was beginning to advect substantially toward higher latitudes. The time series of integrated backscatter observed by the NOAA lidar during FIRE II is shown in Fig. 2. The intervals of integration were from 6 km ASL to the tropopause level (upper troposphere), and from the tropopause to 22 km ASL (lower stratosphere). Tropopause levels were determined from the National Center for Atmospheric Research (NCAR) CLASS soundings at Coffeyville, Kansas. The integrated stratospheric backscatter fluctuates over the period; the trend is for slightly increasing backscatter. The tropospheric backscatter fluctuates much more, and there are short periods when enhancements are greater than 1 order of magnitude in that region. Several periods are of note: November 18-19, which has a drop and increase in backscatter in

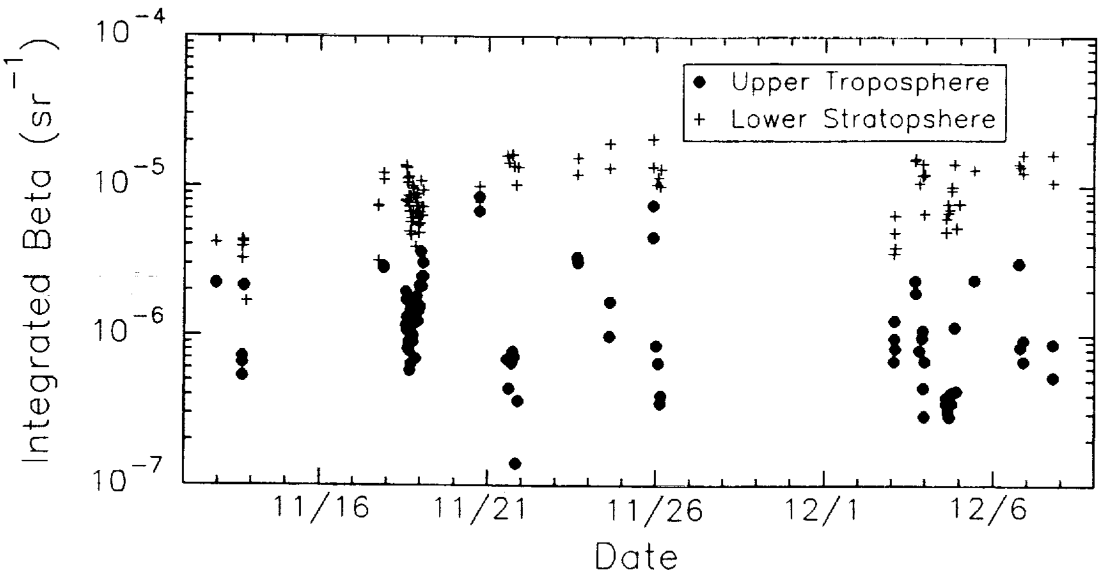

Figure 2. Integrated backscatter for the upper troposphere and lower stratosphere during the FIRE II field experiment (November 12 to December 8, 1991). The tropospheric integration was done from 6 km MSL to the tropopause, and the stratopsheric integration from the tropopause to 22 km MSL. The height of the tropopause was determined from NCAR CLASS soundings at Coffeyville, Kansas.

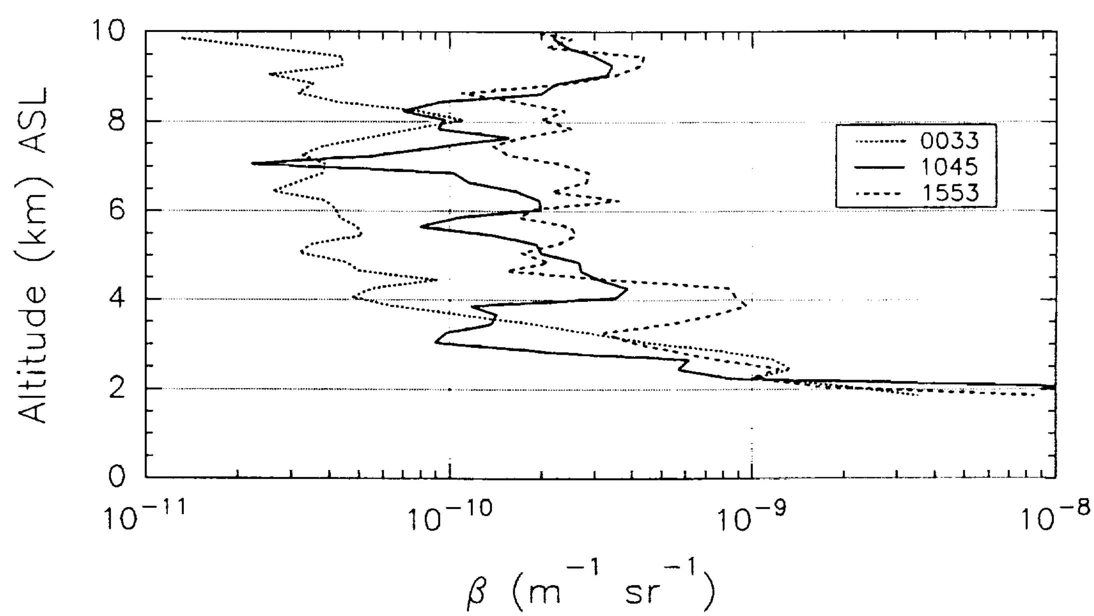

Figure 3. Lidar tropospheric backscatter profiles from Coffeyville, Kansas, on December 5, 1991, at 0033 UTC (short dash), 1045 UTC (solid), and 1553 UTC (long dash). Note the increase in backscatter above 4 km MSL, especially between 0033 and 1045 UTC.

the upper troposphere over a short time period; November 24-26, which has several sharp fluctuations in the upper troposphere; and the December 5-6 case (mentioned earlier) which is a possible tropopause fold case.

The December 5-6 case is a candidate for a tropopause folding event for several reasons, the most convincing is the increase in upper tropospheric backscatter observed on December 5. The moist subtropical flow observed during this case was due to the northward migration of the subtropical jet and to the amplification of a long wave trough to the west which brought southwesterly flow aloft over the project area. Figure 3 shows tropospheric backscatter profiles taken at three different times on December 5. There is a substantial enhancement in backscatter in the region above 4 km ASL over the 15 hour period between the first and last profile. Caution must be used in interpreting these data as a tropopause fold without more supporting evidence. Specifically, an in-depth case study of the meteorological conditions that were present on December 5-6 would substantiate the synoptic conditions that were present. It is quite possible that the tropopause folding occurred upstream, and the airmass then advected over Coffeyville causing the increased backscatter observed in the profiles. In a more recent case, a tropopause folding event was observed by the WPL lidar at the Boulder site on September 25, 1992 (Post et al., 1993). The lidar-measured backscatter increased by up to 2 orders of magnitude from 5 to 10 km MSL at that time. The upper tropospheric enhancement for the December 5-6 case was an order of magnitude weaker than for the September 25, 1992, case.

Summary

CO_2 lidar observations from the FIRE II field program show fluctuations in the upper tropospheric backscatter that are likely enhanced by the volcanic debris from the June 1991 eruption of Mt. Pinatubo. The FIRE II measurements occurred during a period when the volcanic cloud was spreading northward into the midlatitudes and increasing in depth. Tropopause folding is the primary mechanism for tropospheric mass loading by stratospheric debris, and several periods of enhanced integrated backscatter in the upper troposphere served as possible cases to study this. In particular, backscatter profiles taken on December 5-6, 1991, showed a 1 order of magnitude enhancement from 4 to 10 km MSL over a 15 hour period. Further research on the meteorological conditions, particularly the synoptic-scale environment, is needed to more fully understand the impact of the volcanic clouds during FIRE II.

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