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EVOLUTION OF THE PINATUBO VOLCANIC CLOUD OVER HAMPTON, VIRGINIA

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INTRODUCTION

A series of eruptions of the Philippine Mt. Pinatubo volcano (15.1°N, 120.4°E) in June 1991 climaxed in cataclysmic eruptions on June 15-16, which greatly perturbed the stratospheric aerosol layer. These eruptions produced an estimated total aerosol mass loading of ~30 megatonnes, which is over twice the amount produced by the eruptions of El Chichon in 1982 (McCormick and Veiga, 1992). Lidar measurements taken at 694 nm by the 48-inch lidar system at Langley Research Center (LaRC) in Hampton, Virginia (37.1°N, 76.3°W), show the vertical distribution, intensity, and spread of the Pinatubo aerosol layers over this mid-latitude location. The peak stratospheric aerosol burden, which occurred in late February 1992, is equivalent to an optical depth of approximately 0.24 at 694 nm. In the subsequent 22 months, the stratospheric loading has decreased with an 1/e decay time of about 11 months. The magnitudes, transport times, and decay rates of the volcanic aerosol layers produced by the eruptions of Pinatubo and El Chichon (late March - early April 1982) are compared.

48-INCH LIDAR SYSTEM

Nearly continual ground-based ruby lidar measurements have been taken at LaRC since May 1974. These lidar measurements provide high-resolution vertical profiles of aerosols in the stratosphere and upper troposphere. The system, built around a 48-inch receiving telescope and a ruby laser, has evolved over the years and provides a valuable long-term record of the mid-latitude stratospheric aerosol (Fuller et al., 1988; Woods et al., in press).

The telescope primary and secondary mirrors were polished and recoated, and the system was moved from a trailer to an indoor laboratory in late spring of 1991. Near weekly observations commenced on June 13, just 2 days before the Pinatubo eruption. A new data acquisition system became operational on August 6, a few days after the first aerosol layers from the Pinatubo eruption were observed. The new system employs 12-bit CAMAC-based digitizers controlled by a SUN workstation. A 10 Hz Nd:YAG laser, which can be operated at 1064 nm and 532 nm with photon counting, was added to the system in late 1992. The data presented here were taken with the ruby laser, emitting nominally 1 joule per pulse at a wavelength of 694 at a repetition rate of 0.15 Hz.

OBSERVATIONS

The lidar scattering ratio, defined as the ratio of total (aerosol plus Rayleigh) backscattering coefficient to Rayleigh backscattering coefficient, is the primary parameter derived from the analysis of the lidar measurements. The Rayleigh backscattering coefficient is estimated from pressure and temperature profiles measured by rawinsondes launched at Wallops Island, Virginia (120 km northeast of the lidar system). Lidar profiles, consisting of approximately 100-200 laser shots, are averaged to a vertical resolution of 0.15 km, and normalized to a scattering ratio of 1 above or below the aerosol layer. All profiles are adjusted iteratively for transmission losses due to aerosol extinction.

An aerosol layer from Pinatubo was first detected at LaRC on August 3, 1991. The last observation prior to this date on July 18 showed background conditions. Clouds prevented observations between July 18 and August 3. Between August 3, 1991, and December 22, 1993, 89 sets of lidar measurements at 694 nm were taken and analyzed, showing the vertical distribution, intensity, and spread of the Pinatubo aerosol layers over this mid-latitude location. Figure 1 shows a representative sample of scattering ratio profiles obtained on 30 of the measurement dates. As can be seen in the figure, low altitude layers (< 20 km) from Pinatubo were the first to arrive over LaRC. Isentropic backtrajectories at 400 K (~ 15 km) indicate transport associated with a tropospheric anticyclonic cell over North America. This transport path is analogous to the movement of Pinatubo aerosol over East Asia in early July 1991 (Trepte et al., 1993). The first sighting of a layer above 24 km occurred on August 28.

During the first year after the eruption, the magnitude and vertical distribution of the aerosol layers varied widely from one measurement date to the next; however, a general increase in the amount of aerosol loading was observed throughout the fall and winter. Pinatubo aerosol layers above 30 km were first detected on October 31, 1991. During the winter and spring seasons the scattering ratio profiles could be normalized only above 30 km, since there was a significant amount of aerosol in the troposphere. Typical minimum tropospheric scattering ratios were greater than 1.2, a value that corresponds to the maximum stratospheric scattering ratio obtained just prior to the eruption of Mount Pinatubo. The lidar measurement on February 20, 1992, showed the largest enhancement, with a peak scattering ratio of 34 at 22.4 km. Isentropic backtrajectories at 525 K (~ 23 km) indicate that the high-altitude layer, which was not present in such intensity a few days earlier, originated over North Africa and circumnavigated the vortex before passing over Hampton. The stratospheric aerosol loading produced by this layer, in conjunction with

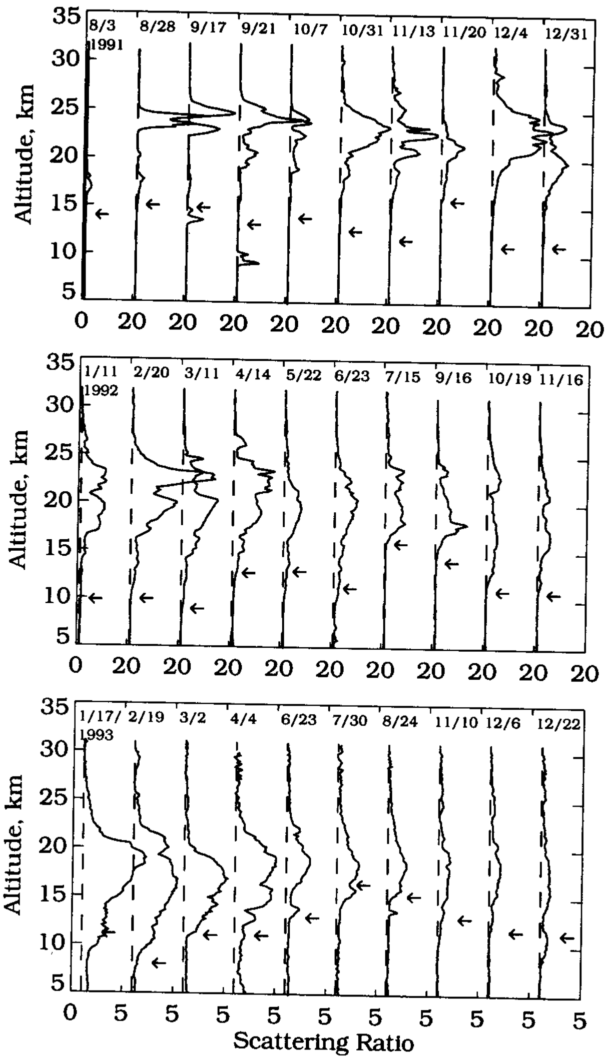

Fig. 1 Lidar scattering ratio profiles taken at 694 nm by the LaRC 48-inch lidar system between August 3, 1991, and December 22, 1993. Arrows denote tropopause altitude.

the more persistent aerosol at lower altitudes, was the highest ever observed at LaRC (see below).

Beginning in about May of 1992, peak scattering ratios decreased significantly as the layer became more Gaussian in shape. This is likely a result of additional meridional and vertical aerosol mixing. The sharp layer detected at 17.8 km on September 16, 1992, is thought to be from the eruption of Mr. Spurr in Alaska on August 18, 1992. The 1993 profiles were plotted on a different scale to accentuate the reduced scattering ratios. During the winter and spring of 1993 minimum tropospheric scattering ratios were once again greater than 1.2. The peak in scattering ratio for the second winter was 7.2 and occurred on January 17, 1993. The peak scattering ratios declined rapidly during the summer and fall of 1993, reaching a minimum of about 2 in December 1993.

A contour plot of scattering ratio versus altitude and time (months since eruption on June 15) is shown in Figure 2. This figure includes all of the lidar profiles obtained through December 22, 1993, and illustrates the gradual descent and broadening of the Pinatubo aerosol layer during the first 10 months, followed by a gradual decrease in intensity. The top of the aerosol layer, defined arbitrarily by a scattering ratio greater than 2, continued to decline in altitude after the first year, whereas the altitude of the bottom of the layer, defined in the same way, varied with the height of the tropopause.

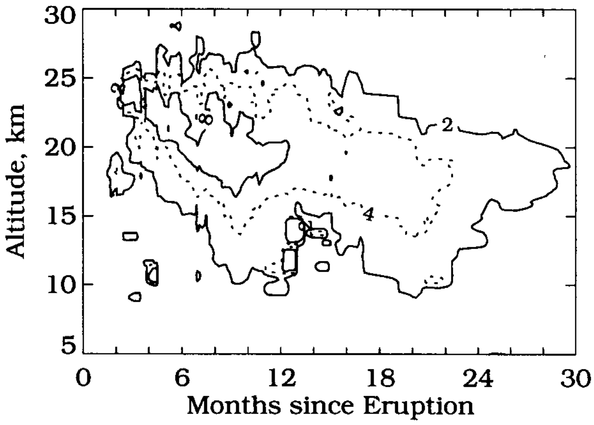

Fig. 2 Contour plot of 48-inch lidar scattering ratio vs. altitude and months since eruption of Mt. Pinatubo on June 15, 1991.

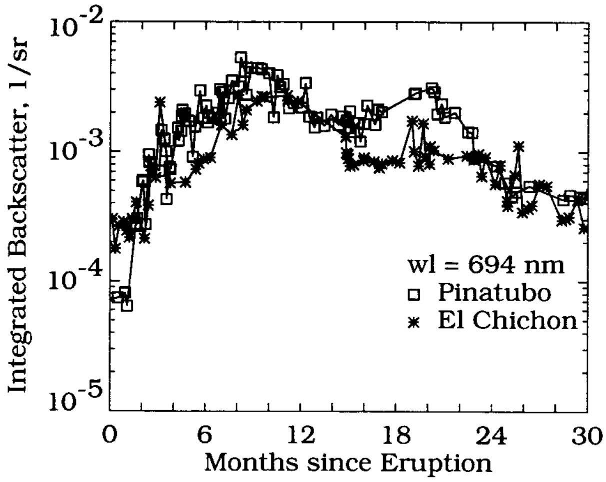

Fig. 3 Time history of integrated stratospheric aerosol backscatter measured at LaRC following the eruptions of El Chichon and Pinatubo.

The integrated aerosol backscatter, defined here as the integral of the aerosol backscattering coefficient from the tropopause to 30 km, provides a good measure of the stratospheric aerosol column loading. Figure 3 compares the history of integrated backscatter at LaRC following the eruptions of Pinatubo and El Chichon (17.3°N, 93.2°W), which are at similar latitudes. The increase seen is due mostly to the poleward transport of the aerosols from their initial concentration in the tropics. In the first few months, some of the increase is due to gas-to-particle conversion of the original SO_2 vapors. The background aerosol level preceding the eruption of El Chichon was higher than the level preceding Pinatubo due to several smaller volcanic eruptions in 1980 and 1981. The first volcanic aerosol layer from El Chichon reached Hampton on May 10, 1982, approximately 42 days after the first major eruption on March 28, 1982, whereas the first volcanic aerosol layer from Pinatubo was measured 48 days after the eruption. Although somewhat coincidental, these transport times are very similar, especially since the first Pinatubo aerosol layer may have arrived a few days earlier, unobserved. The behavior of the integrated backscatter during the first 100 days after each eruption is similar. However, between 4 and 10 months after the eruptions, the Pinatubo integrated backscatter consistently exceeds the values measured after El Chichon. The largest Pinatubo integrated backscatter, 0.0053 sr^{-1}, occurred on February 20, 1992, 250 days after the eruption. This is approximately twice the maximum loading due to El Chichon, which occurred 245 days after the eruption. Although the integrated backscatter is similar between the 10th and 15th months following the eruptions of Pinatubo and El Chichon, the Pinatubo integrated backscatter is once again consistently higher for about the next 7 months. The Pinatubo integrated backscatter reached a relative maximum of 0.0031 sr^{-1} on February 19, 1993, almost exactly one year after the absolute maximum. This is roughly twice as large as values seen in the summer of 1992, evidence of significant poleward winter transport from the equatorial reservoir (Kent, 1986).

An aerosol optical model was formulated using the size distribution from a six-channel dustsonde launched on February 13, 1992, at Laramie, Wyoming (41° N). By assuming the aerosol characteristics determined from the dustsonde flight to be representative of the bulk of the Pinatubo volcanic cloud, a factor for converting integrated backscatter to optical depth was calculated to be 45 sr (Deshler et al., 1993). Using this conversion factor, a peak optical depth over Hampton of about 0.24 at 694 nm was calculated. In a similar manner, the peak optical depth over Hampton after El Chichon was computed to be about 0.13 (Fuller et al., 1988).

Obviously the 1/e volcanic aerosol decay time at a particular location will depend upon many factors: altitude, location, and intensity of eruption; time period covered; and atmospheric transport mechanisms, such as phase of the quasi-biennial oscillation (QBO) and strength of eddy activity. As Figure 3 illustrates, the decay time is also highly seasonally dependent. With this in mind, the 1/e decay times for the 22 months following their respective peak loadings are approximately 11 months for both Pinatubo and El Chichon. These results are in agreement with the 1/e decay time for global mass loading calculated from the Stratospheric Aerosol and Gas Experiment (SAGE) II for a similar period after Pinatubo.

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