GEOPHYSICAL RESEARCH LETTERS, VOL. 21, NO. 6, PAGES 429-432, MARCH 15, 1994

SAGE II Observations of a Previously Unreported Stratospheric Volcanic Aerosol Cloud in the Northern Polar Summer of 1990

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Abstract. Analysis of aerosol extinction profiles obtained by the spaceborne SAGE II sensor reveals that there was an anomalous increase of aerosol extinction below 18.5 km at latitudes poleward of 50°N from July 28 to September 9, 1990. This widespread increase of aerosol extinction in the lower stratosphere was apparently due to a remote high-latitude volcanic eruption that has not been reported to date. The increase in stratospheric optical depth in the northern polar region was about 50% in August and had diminished by October 1990. This eruption caused an increase in stratospheric aerosol mass of about 0.33×10^5 tons, assuming the aerosol was composed of sulfuric acid and water.

Introduction

Major volcanic eruptions that inject sulfur dioxide (SO_2) into the stratosphere are an important source of sulfuric acid (H_2SO_4) aerosols in the stratosphere. The injected SO_2 is converted to H_2SO_4 vapor through oxidation with OH radicals. The newly formed H_2SO_4 may then either nucleate to form new particles or condense on pre-existing aerosol. Both of these microphysical processes increase the mass loading and surface area of sulfate particles in the atmosphere. Depending on the strength and location of the eruption, the enhanced stratospheric aerosols may play a significant role in the destruction of ozone and in radiative processes that affect climate. For instance, Hofmann and Solomon [1989] showed that heterogeneous reactions on both background and volcanic aerosols can play an important role in the partitioning of reactive nitrogen species, and may have been responsible for at least a portion of the ozone reduction observed in early 1983 following the eruption of El Chichon. Theoretical studies have shown that a major eruption, such as the recent Pinatubo eruption, may cause rapid and substantial O_3 loss [Prather, 1992].

The Stratospheric Aerosol and Gas Experiment (SAGE) and its successor, SAGE II, are satellite experiments whose primary design purpose was to measure stratospheric aerosol extinction [*McCormick*, 1987]. Both experiments also measure ozone and nitrogen dioxide, and SAGE II measures water vapor as well. SAGE and SAGE II provide "global coverage" from about 78°S to 78°N which varies depending on the season. SAGE operated from February 1979 to November 1981; SAGE II is still operating since its launch in October 1984. The launch of these satellite systems has greatly enhanced our capability to detect and study volcanic clouds in the stratosphere. A list of volcanic clouds detected by SAGE and SAGE II is shown in Table 1.

In 1982, when no SAGE instrument was available for measurement, an anomalous visible limb radiance was measured by the Solar Mesosphere Explorer (SME) indicating a thick stratospheric aerosol cloud of unknown origin [*Clancy*, 1986]. The resulting "mystery cloud" was subsequently traced to the eruption of Nyamuragira (1.42°S, 29.20°E) on December 26, 1981 [*Schnetzler et al.*, 1991]. Analysis of SAGE II aerosol extinction in 1990 shows evidence for another instance of a stratospheric aerosol cloud of unknown origin. The source of this cloud is suspected to be a remote high latitude volcano. The SAGE II extinction measurements are reported here.

Observations and Discussions

Time series of 1.02 μm aerosol extinction at latitudes between 50°N and 60°N, and between 60°N and 80°N in 1990 for altitudes between 13.5 km and 18.5

Paper number 93GL03376
0094-8534/94/93GL-03376$03.00

km are shown in Figures 1(a) and 1(b), respectively. Time series of 1.02 μm aerosol extinction at latitudes between 50°N and 60°N in 1989 for the same altitude range are shown in Figure 1(c). The anomalously large zonal variation of aerosol extinction near day 210 at altitudes lower than 18.5 km is obvious in Figures 1(a) and 1(b). The anomalous increase in extinction was not readily apparent at lower latitudes (figure not shown) nor in 1989 (see Figure 1(c)). The observed increase in extinction in the northern polar summer of 1990 is even more significant considering the fact that aerosol extinctions at mid- and higher latitudes are, in general, lower in summer months than in winter months. This feature of stratospheric aerosols was discussed by [*Yue et al.*, 1991] and is also obvious at low altitudes in these figures. It should be noted that the anomalous increase of aerosol extinction occurred at several altitudes higher than the tropopause and was detected over a period from Julian day 209 to 252. Since these aerosol clouds occurred in summertime, they cannot be polar stratospheric clouds (PSCs). Cirrus clouds usually occur intermittently and at altitudes around and below the tropopause. Since the observed anomalous increase of aerosol extinction was at altitudes several kilometers higher than the tropopause and occurred over an extended time period, we conclude that the aerosol cloud was not cirrus, but instead was due to an unreported volcanic eruption. In fact, all anomalous increases in extinction observed by SAGE and SAGE II at altitudes much higher than the tropopause that are not PSCs can be traced back to a volcanic origin (See Table 1).

Aerosol optical depth was computed from the aerosol extinction profiles by integrating upward from 2 km above the tropopause to 30 km. Using the tropopause plus 2 km as the lower limit eliminates the possibility of thin cirrus contamination in the extinction profile. The variation of optical depth with time for different latitudes observed by SAGE II during its early years of observation have been reported by several investigators [*Yue et al.*, 1991; *Brogniez and Lenoble*, 1991]. The variation of optical depth with time from 1988 to 1990

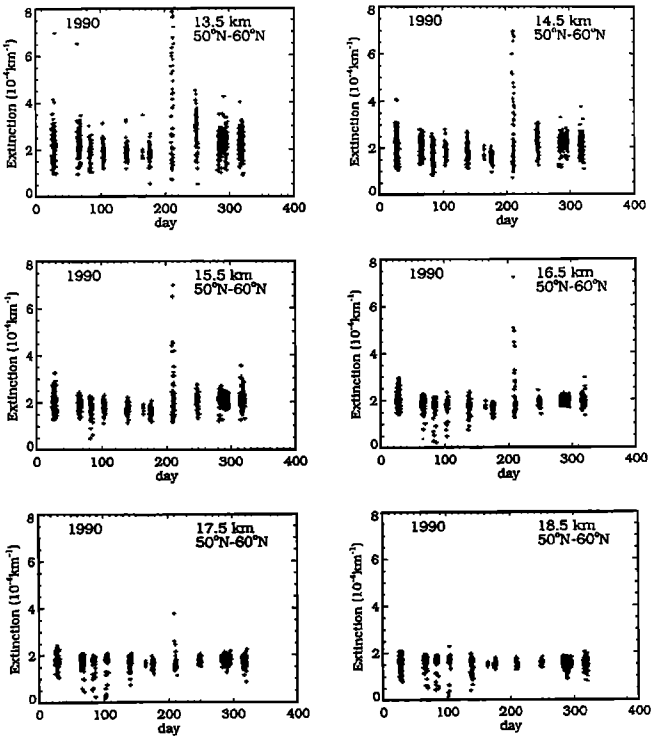

Figure 1(a). Aerosol extinctions at 50°N-60°N in 1990.

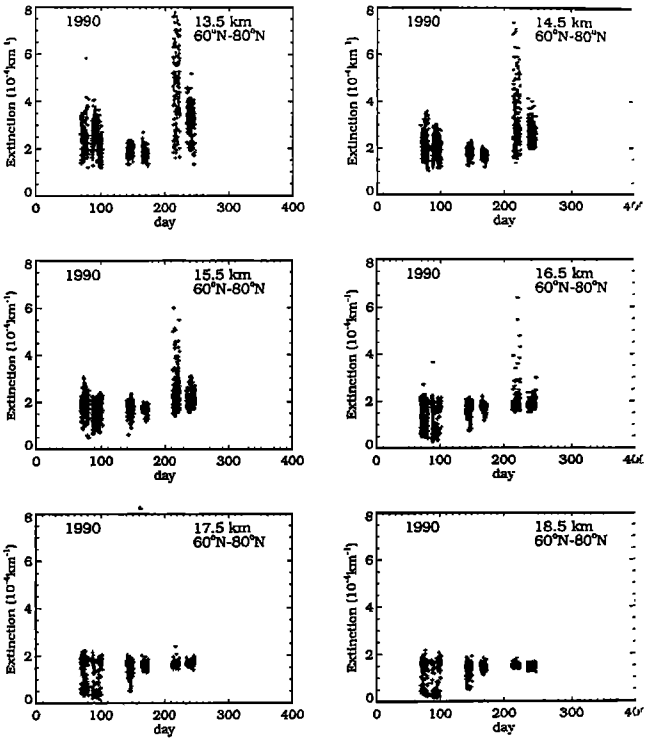

Figure 1(b). Aerosol extinctions at 60°N-80°N in 1990.

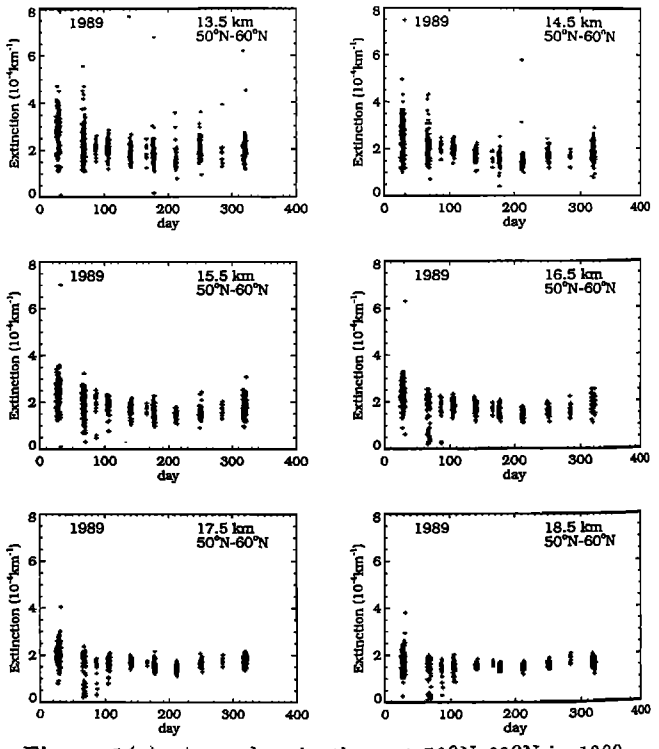

Figure 1(c). Aerosol extinctions at 50°N-60°N in 1989.

Table 1. SAGE and SAGE II Obsaervations of Stratospheric Volcanic Clouds

Date	Volcano	Reference
4/17/79	Soufriere	McCormick et al. [1981]
11/13/79	Sierra Negra	Kent et al. [1984]
5/18/80	St. Helens	Kent et al. [1984]
10/7/80	Ulawun	Kent et al. [1984]
4/27/81	Alaid	Kent et al. [1984]
5/15/81	Pagan	Kent et al. [1984]
11/13/85	Ruiz	Yue et al. [1991]
9/26/86	Etna	Brogniez et al. [1991]
2/10/90	Kelut	Yue et al. [1992]
6/15/92	Pinatubo	McCormick et al. [1992]

for several latitude bands in the Northern Hemisphere is shown in Figure 2. Since SAGE II conducts measurements infrequently at latitudes poleward of 60°N, there is no optical depth data at polar latitudes for some months in Figure 2. The seasonal variation of optical depth with maxima in winter and minima in summer for 1988 and 1989 is obvious in this figure. For latitudes 40°N to 50°N, the optical depths in the summer of 1990 were similar to the previous summer and are yearly minima. However, for latitudes north of 50°N, there was a significant increase in optical depth in the summer months of 1990. As observed by [Yue et al., 1991], there were great increases of aerosol optical depth following the eruption of Ruiz in November 1985 and the temporal variation of optical depth consisted of two components: a seasonal variation and an exponential decay. The relative large values of optical depth at the beginning of 1988 were obviously due to the presence of Ruiz aerosol. Comparing optical depths at 40°N-50°N in 1989 and 1990 shows that the exponential decay component of optical depth was quite small due to the nearly complete removal of Ruiz volcanic aerosols by 1990. Thus, the average background optical depths for latitudes poleward of 50°N during the summer months of 1990 can be assumed to be approximately the same as 1989 and equal to 0.0017. Since the observed optical depth was about 0.0025 in 1990, the material injected by the eruption pointed out here is equivalent to about 50% of background stratospheric aerosols in regions poleward of 50°N. The volume of air in this region is only about 0.117 of the entire atmosphere. If we consider the background sulfate aerosol loading to be 0.57 x 10^6 tons as estimated by Kent and McCormick [1984], the stratospheric aerosol mass loading from this unidentified cloud is about 0.33 x 10^5 tons, assuming a standard H_2SO_4 - H_2O aerosol.

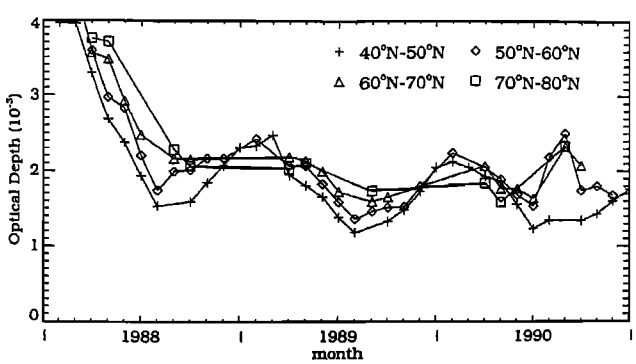

Figure 2. Temporal variation of optical depth.

Since the latest day of SAGE II observation before the anomalous extinction increase in the high-latitude Northern Hemisphere was June 26, 1990, we can speculate that the unreported volcanic eruption occurred in late June or early July 1990. We do not know the composition of the observed aerosol cloud. SO_2 gas from the eruption requires some time to be oxidized to H_2SO_4 and either nucleate new particles or condense on the surface of the pre-existing particles. Since the observed aerosol clouds are at relatively low altitudes, reached maximum aerosol extinction about 1 month after the eruption, and had a short residence time of less than 2 months, the aerosol cloud may have been predominantly volcanic ash.

Unfortunately there were no lidar or in situ measurements in mid 1990 at high latitudes. Hofmann [1990] reported an aerosol layer centered at 17 km on August 6, 1990, over Laramie, Wyoming, which is about 41°N. The concentration of particles with a radius greater than 0.15 μm was about 3 cm^{-3} in contrast with the background value of 0.5 cm^{-3}. A week later, a similar layer centered at 16 km was detected. By that time, the particle concentration was reduced to 1.5 cm^{-3}. The only large explosive eruption reported before that date was February 10, 1990, when Kelut in Indonesia produced a large cloud that reached the coast of Australia 1400 km away. SAGE II observations show that the main Kelut cloud was transported to the Southern Hemisphere [*Yue and Poole*, 1992], and no lidar observation of aerosols from the Kelut eruption has been reported in the Northern Hemisphere. We speculate that the enhanced aerosol layers observed by Hofmann [1990] were of the same origin as the aerosol cloud reported here. SAGE II did not observe high aerosol extinction at latitudes near Laramie probably because the cloud was too thin and only had a relatively small horizontal extent.

Since this eruption occurred in summer in the northern polar region and reached only 17.5 km, no significant temperature or climatic perturbations would have been expected. The data presented in this paper demonstrate that a satellite instrument sensitive to aerosol can detect a volcanic eruption that may escape detection by other remote or in situ measurements. The spread of volcanic aerosols from the eruption of Ruiz has been used to study the dynamics of the stratosphere [*Yue et. al*, 1993]. The stratospheric cloud reported in this paper may provide another opportunity to study the stratospheric transport, especially at high latitudes.

Summary

Analysis of aerosol extinction profiles obtained by SAGE II reveals that there was an anomalous increase

of aerosol extinction below 18.5 km at high northern latitudes during the summer of 1990. It is suggested that this aerosol cloud may have been due to an unreported volcanic eruption that most likely occurred in late June or early July 1990 at a location poleward of 60°N. The observed aerosol cloud remained in the polar region north of 50°N for less than 2 months and caused about a 50% aerosol mass loading increase. The total stratospheric mass loading due to this eruption was about 0.33×10^5 tons, assuming a standard sulfuric acid - water aerosol composition.

Acknowledgments. The authors would like to thank the anonymous reviewers for their constructive comments and suggestions including the possible explanation of the observed cloud characteristics.

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(Received July 27, 1993; revised October 27, 1993; accepted December 1, 1993.)