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LIDAR OBSERVATIONS OF THE EL CHICHON AEROSOL AT A SOUTHERN LATITUDE STATION

B. R. CLEMESHA*
D. M. SIMONICH*

RESUMEN

Las mediciones por lidar efectuadas en São José dos Campos (23°S, 46°W) muestran que la nube de polvo había alcanzado esta latitud a mediados de julio de 1982. La primera medición efectuada después de la erupción mostraba dos capas con tasas de dispersión de 1.8 y 2.7 a 18 y 24 km de altitud, respectivamente, al compararlas con los valores de pre-inyección de alrededor de 1.2. Estos valores se refieren a la longitud de onda de 5890 Å, y son para un perfil obtenido el 9 de julio. Las mediciones hechas en los meses subsiguientes mostraban fluctuaciones grandes, particularmente en la capa superior, donde la tasa de dispersión variaba entre 1.2 y 5. La capa inferior variaba mucho menos que la superior, con el resultado de que la dispersión de fondo integrada, una medida de la carga de aerosol estratosférico, permaneció aproximadamente constante hasta fines de agosto, cuando aumentó de alrededor de 3×10^{-4} SR^{-1} a alrededor de 1×10^{-3} SR^{-1}. Posteriormente a esta fecha, el aerosol integrado oscilaba a alrededor de un valor de 8×10^{-4} SR^{-1} hasta mediados de marzo de 1983, decreciendo desde entonces a alrededor de 5×10^{-4} SR^{-1}. Con el tiempo, la altura de la capa superior disminuyó de manera bastante uniforme hasta fines de noviembre, cuando alcanzó 20 km; para entonces ya se había mezclado con la capa inferior. En 1983 la capa se mostró de nuevo como una estructura bifurcada con un pico inferior cercano a los 18 km y uno superior de 2 a 4 km más arriba.

* *Instituto de Pesquisas Espaciais - INPE - Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq 12200 - São José dos Campos, São Paulo, BRASIL*

ABSTRACT

Lidar observations at São José dos Campos (23°S, 46°W) show that the El Chichón dust cloud had reached this latitude by mid-July, 1982. The first measurement made after the eruption showed two layers with scattering ratios of 1.8 and 2.7 at 18 and 24 km respectively, as compared with pre-injection values of about 1.2. These values refer to a wavelength of 5890 Å, and are for a profile obtained on July 9th. Measurements made in subsequent months showed large fluctuations, particularly in the upper layer, where the scattering ratio varied between 1.2 and 5. The lower layer varied much less than the upper, with the result that the integrated backscatter, a measure of the total stratospheric aerosol burden, remained roughly constant until late August, when it increased from about 3 x 10^{-4} SR^{-1} to about 1 x 10^{-3} SR^{-1}. Subsequent to this date the integrated aerosol oscillated around a value of about 8 x 10^{-4} SR^{-1} until mid-March 1983, since when it has decreased to about 5 x 10^{-4} SR^{-1}. The height of the upper layer decreased fairly uniformly with time until late November, when it reached 20 km, by which time it had merged with the lower layer. In 1983 the layer has again shown a bifurcated structure with a lower peak close to 18 km and an upper one 2 to 4 km higher.

Lidar observations of the atmospheric scattering profile at 5890 Å have been made at São José dos Campos (23°S, 46°W) since 1972. These measurements have been made with the basic purpose of studying the atmospheric sodium layer (Kirchhoff and Clemesha, 1973; Simonich *et al.*, 1979; Clemesha *et al.*, 1982) but at the same time have provided information on stratospheric scattering. Results up to 1977 have been presented by Clemesha and Simonich (1978), who also described the lidar system and the data analysis technique used, and observations of the El Chichón aerosol cloud, up to November 1982, have been reported by Clemesha and Simonich (1983). Until the end of 1982 virtually all stratospheric measurements were made with a 2 km range resolution. As from January 1983, the photon counting receiver range bin was decreased to 1 km in order to provide more detail in the aerosol profiles. Most measurements have been made with the lidar pointing vertically, although in some cases zenith angles up to 20° have been used in experiments to observe the spatial variations of aerosols and sodium (Clemesha *et al.*, 1981a, 1981b). Where such oblique measurements were made, the data obtained were interpolated at 2 km vertical intervals to make the resulting profiles compatible with the bulk of the scattering data. Fitting of the experimental profiles to the scattering expected from the molecular atmosphere is usually done between 36 and 40 km, although it is occasionally necessary to use lower heights in the case of a noisy profile. It should be noted that fitting below 36 km can lead to an underestimate of the aerosol component, as is evidenced by the fact that we occasionally encountered aerosol ratios as high as 1.2 at 34 km, even before the El Chichón injection. Although it is sometimes possible to obtain a fit both above and below the aerosol layer, excess scattering is frequently present all the way down to the lowest height measured (typically 10 km). A small error may be introduced into our derived scattering ratios by the use of a fixed molecular atmosphere, rather than simultaneous balloon measurements. We estimate that this error does not exceed 0.05 in the scattering ratio (Clemesha and Simonich, 1978). For the scattering ratios typically encountered for the background aerosol, extinction of the lidar beam in the stratosphere is negligible. In the case of the recent measurements reported here this is not the case, and extinction should be allowed for. Based on the findings of Pinnick *et al.* (1980), we assume a ratio of 65 between the extinction and volume backscattering coefficients, and correct for the extinction by an iterative procedure. In some cases the two-way extinction for the lidar amounts to more than 20%.

In order to place the aerosol enhancement reported here in perspective we show, in Figure 1, monthly average volume backscattering coefficients integrated from 17 km to 27 km, for the period 1972-1983. The extinction scale in Figure 1 is calculated on the basis of the ratio of 65 between extinction and backscattering coeffi-

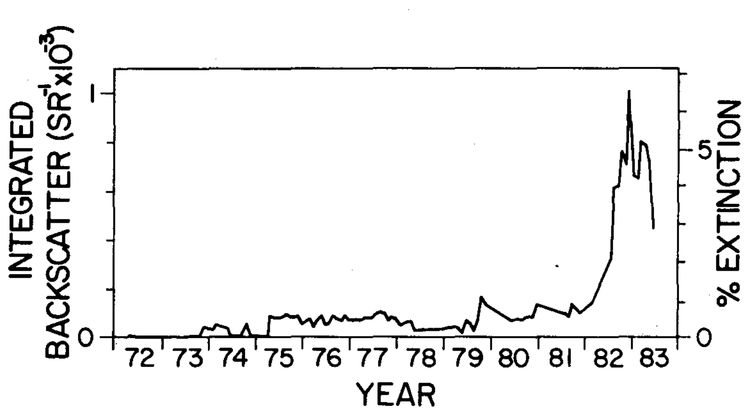

Fig. 1. Monthly mean integrated backscatter, 17–27 km, March 1972 to June 1983.

cients. Before the El Chichón event the monthly average integrated backscatter never exceeded 2×10^{-4} SR^{-1}. An increase to a level of just under 10^{-4} SR^{-1} in April 1975, attributable to the October 1974 eruption of the Volcán del Fuego in Guatemala (Clemesha and Simonich, 1978), is clearly visible in the figure. Subsequent to the Fuego injection the aerosol content of the stratosphere over Sao José dos Campos appears to have been maintained at a fairly constant level by a number of minor injections. During this time, however, no sharply peaked layer, of the sort observed in 1975 and characteristic of a recent injection, was observed. High scattering ratios observed towards the end of 1979 may have been caused by the La Soufrière eruption in April 1979. The St. Helens event in 1980, which produced strong scattering layers in the Northern Hemisphere (McCormick, 1981), resulted in no obvious increase at our location, although it may have helped maintain the integrated backscatter in the region of 10^{-4} SR^{-1}, which is well above the pre-Fuego level. This level of scattering persisted at least until November 1981. Unfortunately, weather conditions during local summer at our location make it difficult to operate the lidar, and only two profiles were obtained during the first semester of 1982, one on March

10th and the other on April 1st. These are both very noisy profiles, and can be considered only as providing an upper limit to the aerosol scatter. They are sufficient, however, to show that no major increase in the stratospheric aerosol burden had occurred by April 1st.

The first accurate profile for 1982 was obtained on July 9th, and showed a peak scattering ratio of 2.7 at 24 km. Except for an isolated event in 1979, this represented, at the time, the highest scattering ratio observed during our 10 years of observations. In considering the values of backscattering ratio measured by our lidar, it should be remembered that what we really measure is the integrated backscatter over the 2 km height interval which corresponds to the range bin of our photon counting receiver. In the case of narrow scattering layers, characteristic of recent injections, the peak scattering ratio would frequently be larger than our measured value. This limited height resolution does not, of course, affect the accuracy of the integrated backscatter. The subsequent time development of the layer is shown in Figures 2 and 3. In Figure 2 we show the variation with height and time of the scattering ratio, and in Figure 3 we show the 17 to 27 km integrated backscatter and the peak scattering ratio. In Figure 2a, in order to make it possible to compare the 1983 1 km resolution data with the 1982 2 km resolution data, the former has been averaged in 2 km intervals. In Figure 2b the 1983 data is plotted with the full 1 km vertical resolution. The profiles plotted in Figure 2 have been smoothed in height and linearly interpolated at 3 day intervals. The dates on which the original profiles were obtained are indicated by the tick marks on the time scale.

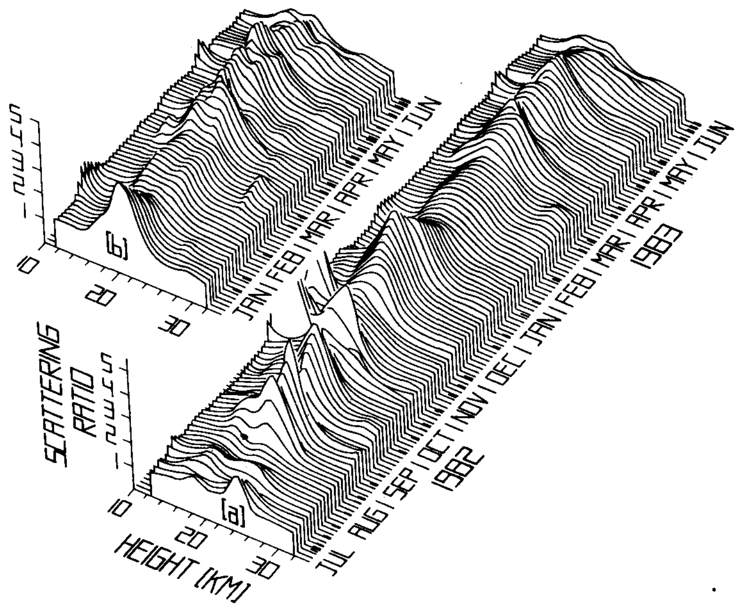

Fig. 2. Height/time variation of scattering ratio (a) 2 km height resolution data, July 82 to June 83; (b) 1 km height resolution data, January to June, 83.

The profile observed on July 9th is bifurcated, with peaks at approximately 18 km and 24 km. This bifurcation of the layer continued to be evident until mid-August, when a rapid increase in the amplitude of the upper layer occurred. Even after this date the lower layer continued to be visible as a ledge in the profile. Until the end of 1982 the upper layer showed large variations of scattering ratio, from a minimum of 1.3 on July 22, when it virtually vanished, to a maximum of over 5 on August 25th. These oscillations are most clearly seen in Figure 3b, which shows the maximum scattering ratios between 16 and 26 km. The oscillations in the integrated scattering, shown in Figure 3a, are smaller than those in the peak ratio because the former parameter contains a proportionately larger contribution from the lower layer, which varied much less than the upper one. The oscillations in scattering ratio show some signs of having a period of about 1 month, which could be interpreted

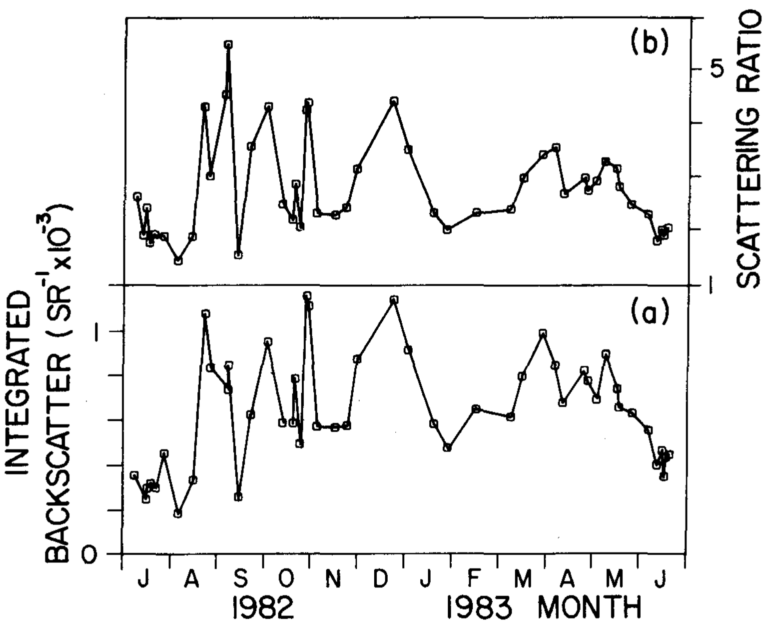

Fig. 3. Variation with time of (a) integrated backscatter, 17–27 km, (b) peak scattering ratio; January 82 to June 83.

as resulting from the circumnavigation of the globe by a dust cloud. On the other hand, the zonal winds at 20 km would be expected to reverse in September/October, so this is probably an oversimplification.

Although the initial arrival of the El Chichón aerosol at our latitude must have been prior to July 9th, the greatest increase in integrated aerosol did not occur until mid-August. Our highest measured values, corresponding to extinctions of about 7.5%, occurred in late October and December, but, as can be seen from Figure 3, these are not significantly greater than the values reached in August. In general, then, the total aerosol appears to have built up to a level of about 8×10^{-4} SR^{-1} integrated backscatter, corresponding to about 5% extinction, by late August 1982, and oscillated about this level until early May 1983. Since May the scattering appears to have fallen significantly, and by early July 1983 it corresponded to an extinction of about 3%. As would be expected, the oscillations about the mean have decreased in amplitude with time.

The vertical distribution of aerosol concentration has varied considerably during the period covered by the observations presented here. Our first measurement, 3 months after the injection, showed 2 distinct peaks in scattering ratio at 18 km and 24 km. This is in agreement with northern hemisphere observations such as those by Hofmann and Rosen (1983) at 27.5°N; Hirono and Shibata (1983) at 33°N and Adriani *et al.* (1982) at 42°N. During the following months the upper peak decreased in height and increased in amplitude until, by the end of 1982, it dominated the layer at a height of 20 km. From February 1983 on the layer has again shown a tendency to bifurcation, although without the distinct separation between the peaks seen shortly after the initial injection. With regard to the reappearance of a double peaked structure in 1983, it should be remembered that the improved height resolution in the 1983 data makes such structure easier to distinguish as compared to the 1982 measurements. Since February 1983 the distribution has typically shown a peak at about 18 km changing little in amplitude or height, and a second more variable peak a few km higher. In this distribution the lower peak appears to represent the "steady state" layer which results from the effects of sedimentation above the tropopause and eddy diffusion below, while the upper layers are produced by continuing *in situ* production and/or advection processes.

Between July and November of 1982 the upper layer decreased in height at an average rate of 0.03 cm sec^{-1}. This, interpreted in terms of sedimentation, would correspond to particles of about 0.3 μm radius with a specific gravity of 2. It is interesting to note, however, that in May and June of 1983 an upward motion of about 0.15 cm sec^{-1} is observable in the upper part of the layer, suggesting the effects of surprisingly rapid convective motions.

By far the greater part of the aerosol scattering which we have observed has been from heights below 25 km, but it is interesting to note that scattering from above this height has generally increased with time during the period of our observations. The accurate determination of small scattering ratios above 25 km is difficult because the lidar signal from such heights is small. In order to overcome this problem we have summed the data from a large number of observations, thus giving photon counts large enough to give the required precision. Where possible, we have summed the data within each month, analysing it as a single profile. During local summer, weather conditions make it very difficult to operate the lidar and, in order to achieve large photon counts, it has been necessary to lump together the data for November and December and January, February and March. The resulting profiles, together with a pre-El Chichón profile, are shown in Figure 4, where we have plotted the scattering ratio as a function of height on a logarithmic scale. The increasing high altitude scattering with time is clearly visible in this figure. At 28 km, for example, the scattering ratio increases from 1.06 in July 82 to 1.26 in June 83, with a pre-injection value of 1.05.

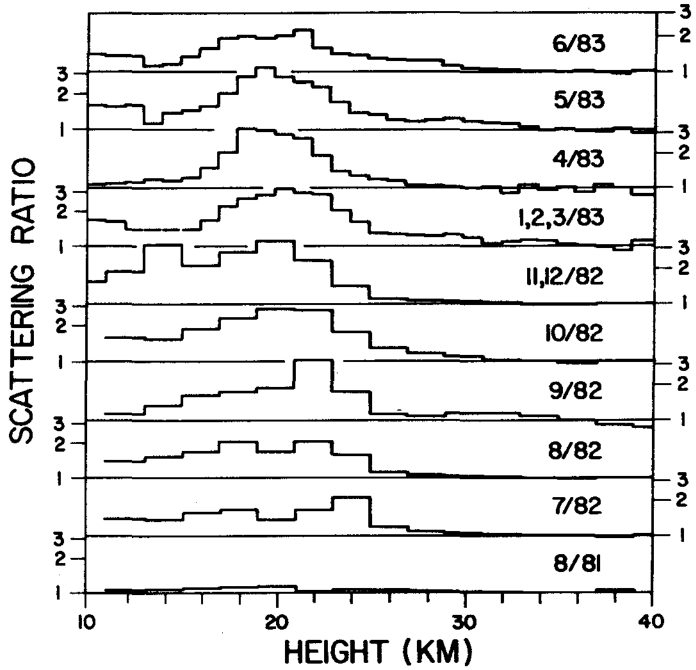

Fig. 4. Scattering ratio as a function of height, averaged over periods of 1 month or more; July 82 to June 83. A profile for August 81 is shown for comparison.

It is possible that the increased scattering from above 25 km results either from newly condensed sulphuric acid particles or from the growth of the already existing population, since sedimentation and coagulation would oppose the upward transport of existing particles. The transport of both sulphuric acid vapour and SO_2 by large scale circulation and eddy diffusion will, on the other hand, lead to decreasing vertical gradients in the mixing ratio of these aerosol precursors, in agreement with the observed changes in the aerosol scattering profile. Against this explanation are the short lifetimes expected for the precursor gases. Liu *et al.* (1983) calculate a lifetime for SO_2 in the stratosphere of the order of 45 days, and Hofmann and Rosen (1983) find a lifetime as short as 10 minutes for gas phase sulphuric acid. An alternative explanation is that meridional transport is more rapid at greater heights. The satellite observations of McCormick (1983) show that the N-S gradient in aerosol concentration is very steep at our latitude, so that a height dependent meridional transport could have a large effect on the vertical distribution of aerosols.

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