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EL CHICHON CLOUD OVER CENTRAL EUROPE

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RESUMEN

El transporte hacia el norte del aerosol estratosférico proveniente de la erupción del volcán mexicano El Chichón en abril de 1982 fue observado por lidar en Garmisch-Partenkirchen (RFA). De junio a octubre de 1982 pudieron observarse dos capas, una por debajo y la otra por encima de los 20 km de altura. De octubre en adelante, una capa se extendió desde la tropopausa hasta alrededor de 30 km de altura. La dispersión de fondo máxima a partir de esta capa se registró durante los dos primeros meses de 1983. Posteriormente, el aerosol de El Chichón aparentemente entró en fase de decadencia. La dispersión de fondo observada fue convertida a valores de profundidad óptica y masa de columna, que alcanzaron sus picos en enero de 1983 con 0.2 a 550 mn y 0.06 g m^{-2}, respectivamente. Comparándola con otras erupciones de largo alcance ocurridas desde 1979, la erupción de El Chichón resulta haber excedido a todas ellas en por lo menos un orden de magnitud.

ABSTRACT

The northward transport of stratospheric aerosol masses originating from the April 1982 volcanic eruption of the Mexican volcano El Chichón has been observed by lidar at Garmisch-Partenkirchen (FRG). From June to October 1982 two layers, one below and one above 20 km, could be observed. From October on one layer extended from the tropopause to about 30 km. Maximum backscattering from this layer was recorded during the first two months in 1983. Thereafter the El Chichón aerosol apparently entered the decay phase. Observed backscattering has been converted to optical depth and column mass values, peaking in January 1983 with 0.2 at 550 nm and 0.06 g m^{-2}, respectively. The El Chichón eruption has also been compared to other high reaching eruptions since 1979, exceeding all of them by at least one order of magnitude.

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INTRODUCTION

The violent eruptions of the Mexican volcano El Chichón (17.3°N, 93.2°W) on March 28 and April 3 and 4, 1982, triggered worldwide a great number of ground-based, airborne and satellite experiments and measuring campaigns. In contrast to the very limited observational possibilities at the time of earlier high reaching volcanic eruptions of global effect to the stratosphere like Agung in 1963 or Fuego in 1974, the stratosphere can presently be regarded as a well observed region.

First observations indicated that until at least four months after the eruption the El Chichón-produced stratospheric aerosol layer was confined to latitudes between the equator and 30°N (Barth *et al.*, 1982; Labitzke *et al.*, 1983). On the other hand, however, midlatitude observations of intense white glare around the sun and intense dawn and dusk coloration at considerable solar depression indicated already in summer 1982 that part of the El Chichón volcanic cloud had moved to northern midlatitudes and that scattering occurred at great heights. Ground-based lidar observations at Hawaii (EOS, 1982) and Japan (Hirono and Shibata, 1983; Iwasaka *et al.*, 1983) soon after the eruption pointed at the great amount of volcanic material that must have reached the stratosphere, the bulk of it deposited between 20 and 30 km.

OBSERVATIONS

The lidar system used at Garmisch-Partenkirchen (47.5°N, 11°E) for stratospheric aerosol observations consists of a coaxial arrangement of pulsed ruby laser (694.3 nm) and 52 cm O Cassegrain telescope, photomultiplier and 64-channel photon counter (detailed description by Reiter *et al.*, 1979). It is usually operated with a 600 m height resolution.

Several eruptions since 1980 caused stratospheric perturbations which could be traced at Garmisch-Partenkirchen like Mount St. Helens (Reiter *et al.*, 1980), and Alaid (Reiter *et al.*, 1981). An unobserved eruption in December 1981 or January 1982 caused a considerable stratospheric aerosol concentration between tropopause and 20 km (Reiter, *et al.*, 1982). This was the situation when the El Chichón eruption significantly affected the stratosphere about four months later.

The leading edge of the El Chichón-produced stratospheric cloud at the observer's position was a peak at 15.6 km recorded on May 3, 1982, superposed to the profile of the unobserved eruption. In Figure 1 some characteristic results of lidar measurements are presented as scattering ratios (ratio of observed total to molecular backscattering, calculated from own radiosonde data), starting in May 1982. During May and June this peak developed into a stable aerosol layer between tropopause and 20 km. In June a second, high altitude layer above 20 km appeared. Dur-

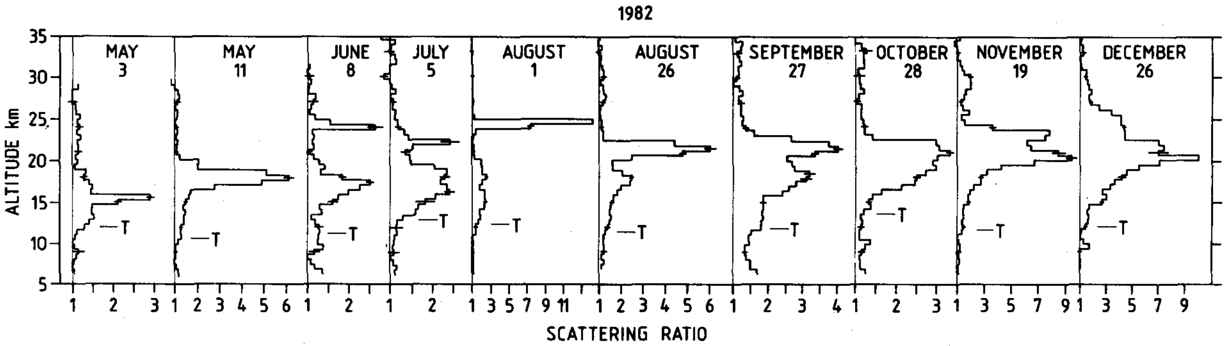

Fig. 1. Selected lidar profiles showing the formation of aerosol layers following the April 1982 eruption of El Chichón. The profiles are extinction corrected. T denotes the local tropopause.

ing September the gap between low and high altitude layer was filled up slowly, and in October both layers had merged into a broad layer extending from the tropopause to about 30 km. This final shape was also observable in 1983, but with reduced intensity.

The double-layer system in 1982 was associated with the summer wind reversal with easterly winds above 18 to 20 km (Figure 2), and the merging of the two layers coincided with the change to the winter wind regime with westerlies throughout

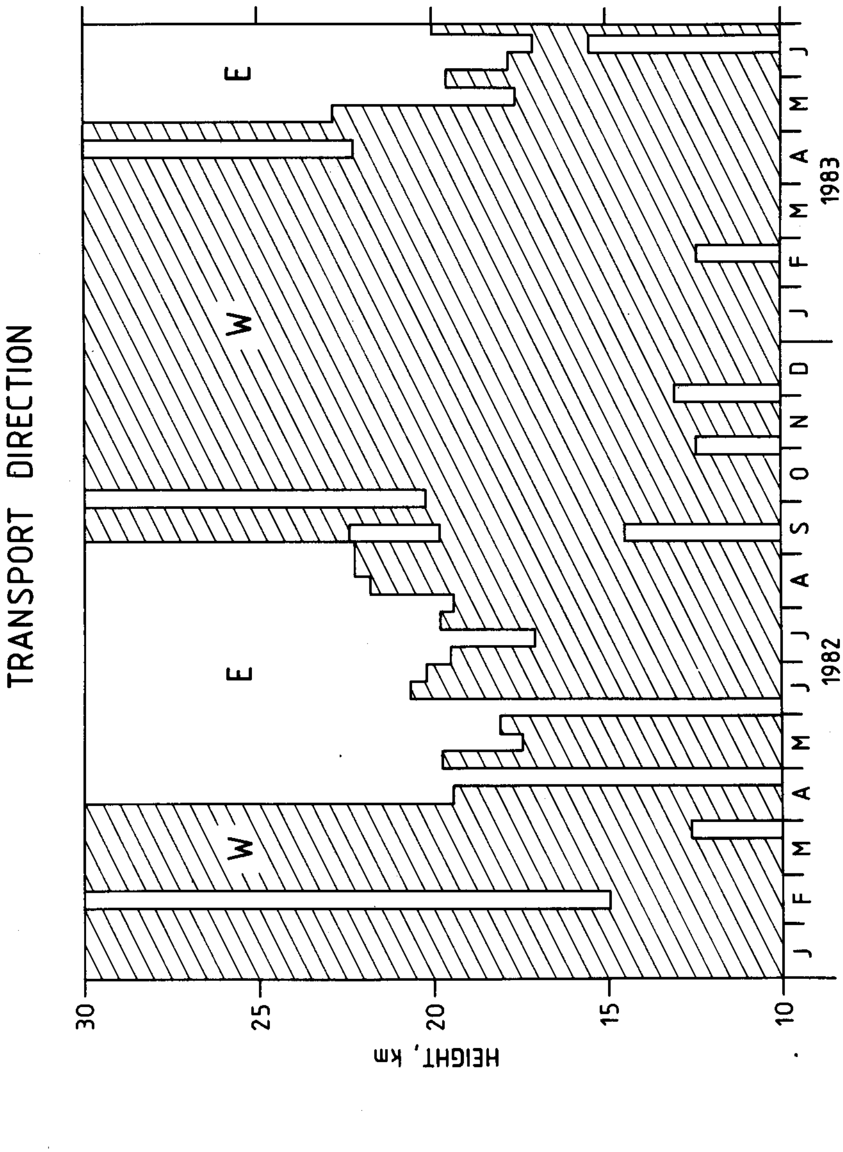

Fig. 2. Zonal wind directions, deduced from the Munich radiosonde as intervals over 10 days (W = westerlies, E = summer easterlies).

the observable height range. The wind directions of Figure 2 are deduced from the Munich radiosonde (100 km to the north of Garmisch-Partenkirchen), and are presented as averages over 10 days.

The isopleths of the scattering ratio in Figure 3 show the time variation of the aerosol layer: its boundaries and maxima, the layered structure during summer 1982, and a general downward trend in 1983, both in intensity and height of the scattering layer. This figure is based on 83 lidar profiles.

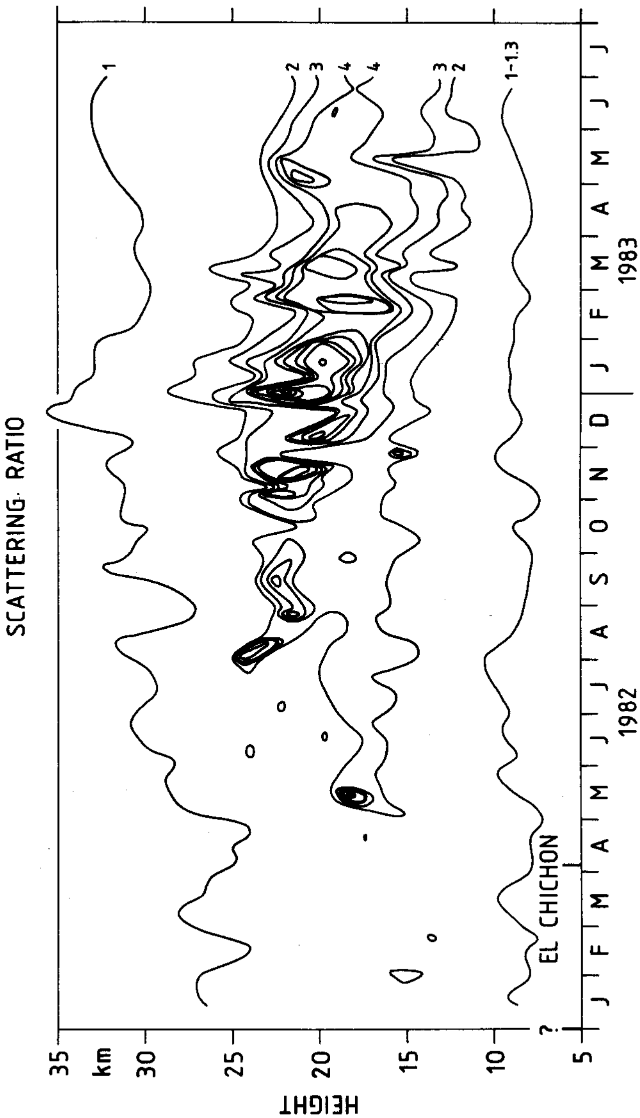

Fig. 3. Isopleths of the scattering ratio, based on 83 backscattering profiles.

The stratospheric aerosol can be described with two characteristic quantities, i.e. the maximum scattering ratio (R_{max}) and the integral particulate backscattering coefficient (integrated between tropopause plus 1 km and top of the layer; Figure 4). The low altitude layer, after the appearance of the initial peak, was characterized during June through October by a very constant R_{max} (about 2.5), the high altitude layer showed a rather variable R_{max} (up to 16). It should be noted, however, that the averaging effect due to the limitation of the height resolution to 600 m

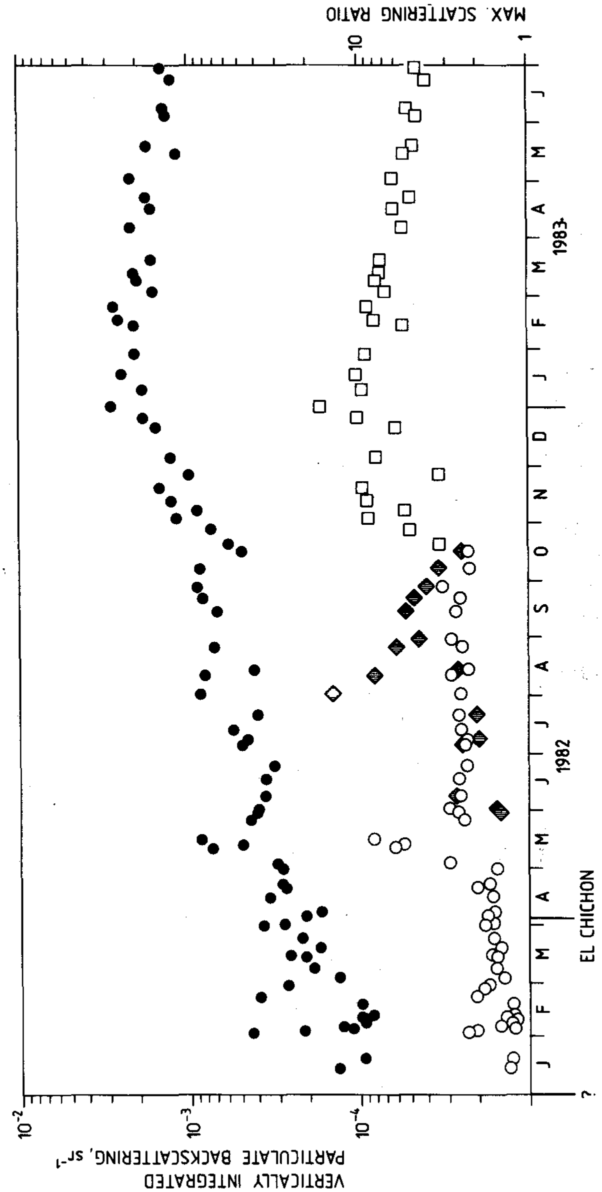

Fig. 4. Time variations of vertically integrated particulate backscattering coefficient.
● sr^{-1}, TP+1 km to layer top (30-35 km)
and maximum scattering ratio
○ R_{max} in layer TP - 20 km
◆ " " " 20 - 25
□ " " " TP - 30

will reduce peak scattering of thin layers. The increase starting in October soon reached a plateau of the scattering ratio with a value of about 10 from November 1982 until January 1983, thereafter the peak ratio declined to a value of about 4 in June 1983. The integral backscattering exhibits an increase until January 1983 and the subsequent decline indicates the entering into the decay phase.

A more detailed information can be obtained by splitting the integral backscattering into three height ranges: 10-20 km, 20-30 km and >30 km. In Figure 5 each interval is presented as a band which envelops all single measurements. The unobserved eruption influenced only the 10-20 km range in early 1982. In this range,

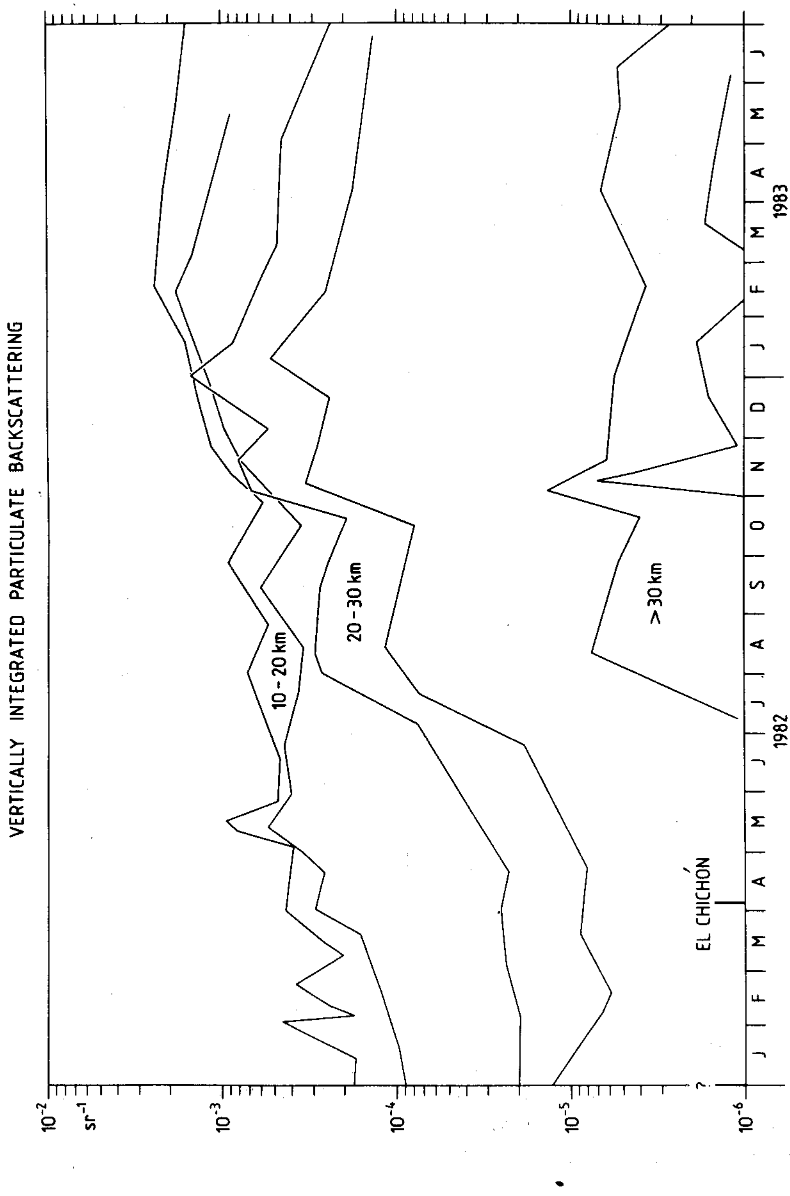

Fig. 5. Time variations of three height ranges of the vertically integrated particulate backscattering coefficient. Each range is presented as a band enveloping all single measurements.

after the initial El Chichón peak and a rather stable period of enhanced backscattering, a steady increase started in October 1982, lasting until February 1983. In the 20-30 km range a first increase starting in June was noted, a second one in October (after the merging of low and high altitude layer), peaking end of December. The overall increase in the 10-20 km range was a factor of about 6 (April 1982 - February 1983) and in the 20-30 km range a factor of about 50 (April 1982 - end of 1982). The increase above 30 km was peaking in November 1982.

DISCUSSION

Based on the measured backscattering values, estimates of the stratospheric mass loading and changes of the radiative properties can be calculated. The conversion of the integral backscattering to optical depth values depends on the knowledge of the backscatter to extinction relation. A conversion factor of 0.015 sr^{-1} has been used, which applies to a 75% H_2SO_4/25% H_2O aerosol under background conditions (Russell and Hake, 1977; Pinnick *et al.*, 1980). This aerosol composition was confirmed by Hofmann and Rosen (1983), who documented the particle growth after the El Chichón eruption. They found, however, an increased number of great particles. Hence midvisible optical depth values presented in Figure 6 might be

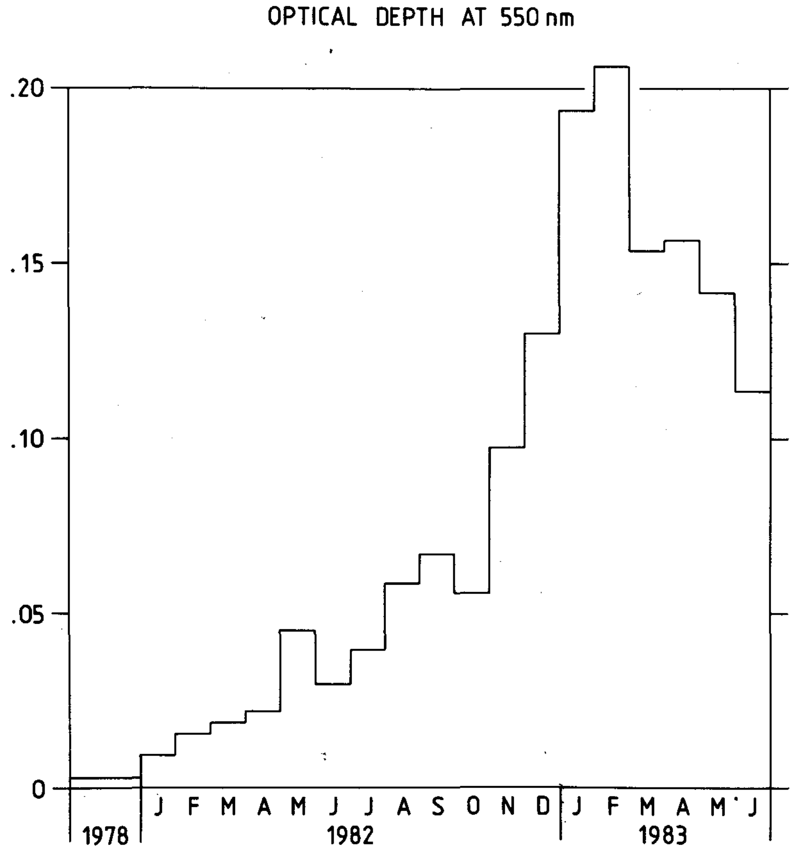

Fig. 6. Time variation of the optical depth at 550 nm.

overestimated. The 1978 level is the background reference, since during 1978 and the year before volcanic activities had not significantly disturbed the stratosphere.

The conversion of integral backscattering to stratospheric masses (column mass, g m^{-2}) in Figure 7 is based on a conversion factor of 0.04 $m^2 g^{-1} sr^{-1}$ (D. Hofmann, private communication). This conversion results from a direct comparison of balloon-borne particle counter data (Laramie, Wyoming) with lidar data (Garmisch-Partenkirchen) during a period of about 200 days following the El Chichón eruption. This comparison overcomes two problems (discussed by Hofmann *et al.*, 1983): enhanced backscattering due to large particles, which are produced in great number following volcanic eruptions, and normalizing of lidar profiles in a region (above 30 km), where particulate backscattering is assumed negligible. Differences in time and geographic position have been disregarded, as well as the possibility of

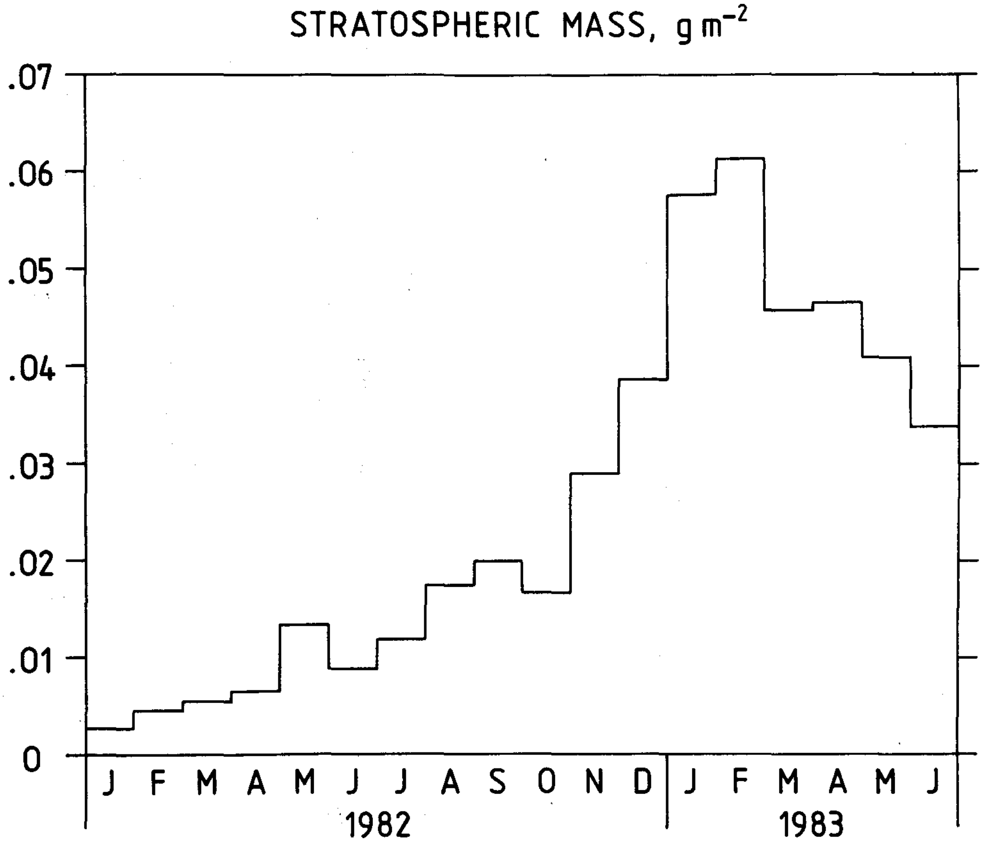

Fig. 7. Time variation of the stratospheric column mass.

a change in the conversion factor during the period following the comparison. Despite these facts a rough estimate of the stratospheric mass loading of the northern hemisphere is presented in Figure 8 by combining lidar observed integral backscattering values of Garmisch-Partenkirchen with published values of other stations.

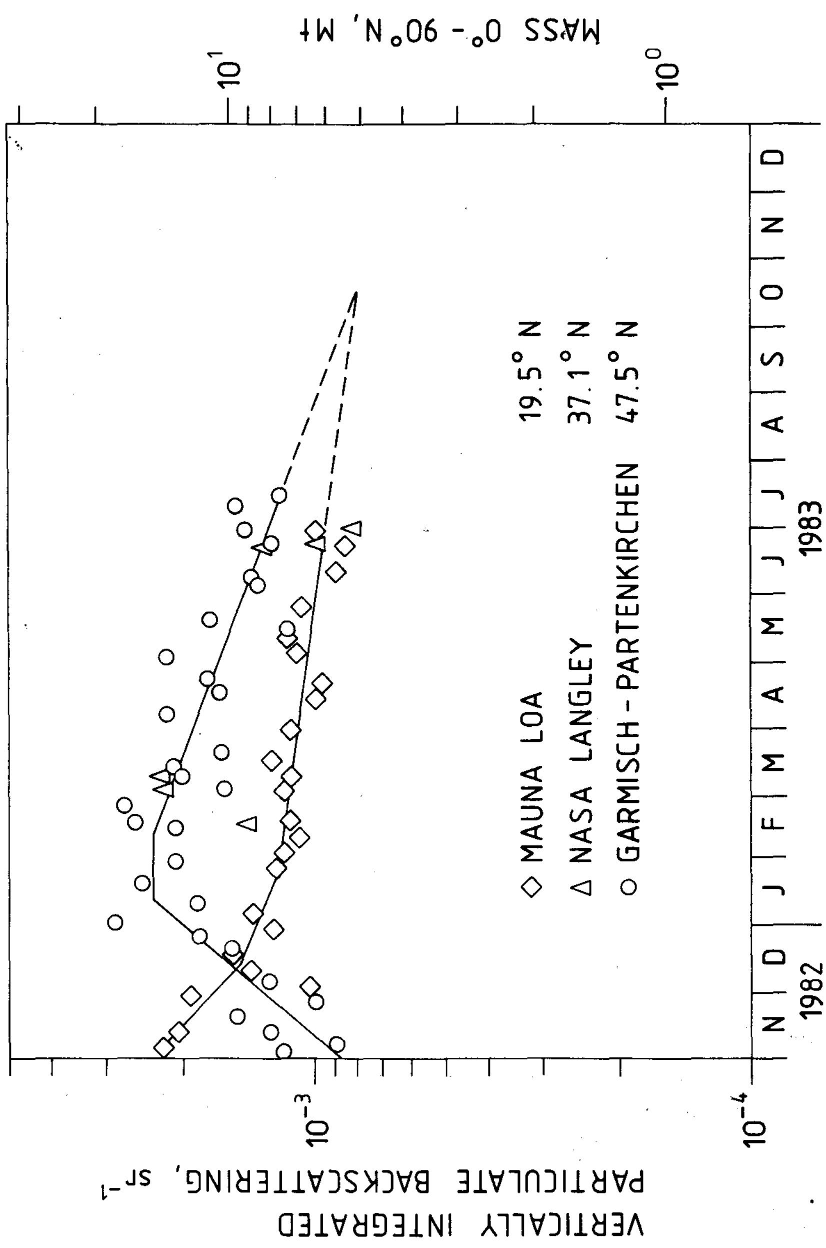

Fig. 8. Lidar observed vertically integrated particulate backscattering coefficient at three stations (Mauna Loa, Hawaii, and NASA Langley, Virginia, values from SEAN Bulletin, 1982 and 1983). The corresponding hemispheric mass is indicated by the scale on the right side.

Mt. Mauna Loa observations (SEAN Bulletin, 1982 and 1983) and Garmisch-Partenkirchen observations have been expressed by smooth curves. NASA Langley values (SEAN Bulletin, 1983) fit reasonably in between. Assuming that Mt. Mauna Loa represents the 0°-30°N latitudinal band and Garmisch-Partenkirchen the 30°-60°N band (thus covering 87 % hemispheric surface), the intersections of the curves indicate periods of a fairly homogeneous hemispheric aerosol distribution. At the first intersection in December 1982 a north hemispheric mass of almost 10 megatonnes would result. The extrapolated curves should once more intersect in October 1983, again suggesting homogeneity. 5 megatonnes of hemispheric mass can be predicted for that time, indicating a 50 % hemispheric mass loss in about 10 months.

COMPARISON

A description of the stratospheric perturbation caused by the El Chichón eruption would be incomplete without comparing it to other volcanic events. The eruptions of the volcanos Sierra Negra in 1979 (Galapagos), St. Helens in 1980 (USA), Alaid in 1981 (USSR), the unobserved eruption late in 1981 or early in 1982, and the El Chichón eruption, all observed by lidar at Garmisch-Partenkirchen, are superposed in Figure 9, where integrated backscattering is plotted versus time, the date of the

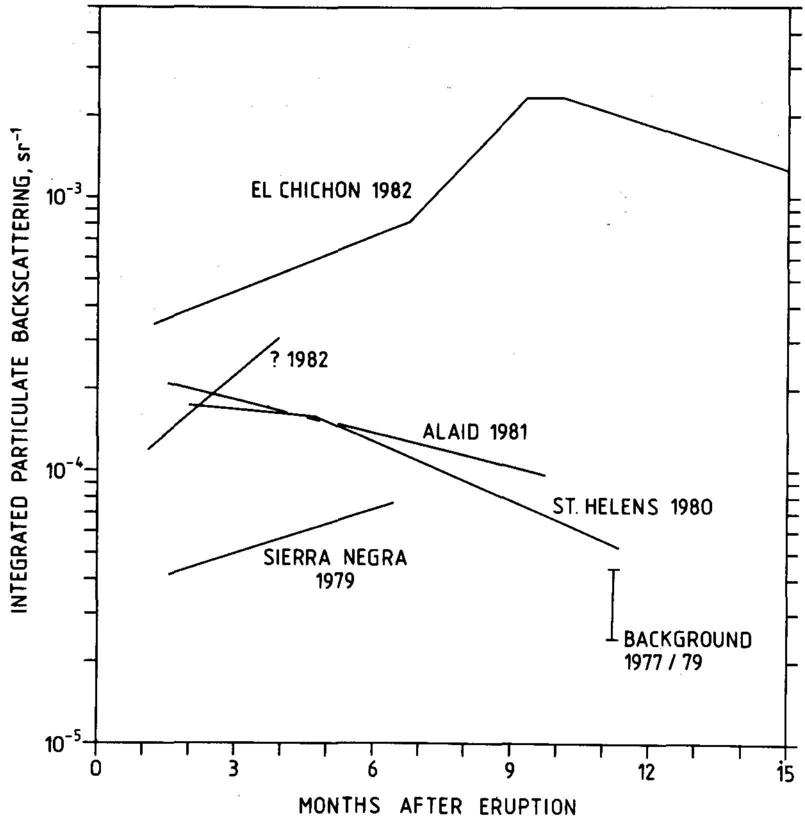

Fig. 9. Lidar observations at Garmisch-Partenkirchen: comparison of recent volcanic eruptions.

respective eruption serving as the origin of the time scale. This graph demonstrates the effects of high latitude eruptions (St. Helens, 46.2°N; Alaid, 50.8°N) and low latitude eruptions (El Chichón, 17.3°N; Sierra Negra, 0.8°S; and obviously the unobserved eruption) at the observer's high latitude position. In the former case the observer records the fast zonal dispersion of the eruption plume and the subsequent recovery of the atmosphere. In the latter case the much slower meridional transport causes a very much increased time lag between eruption and observed aerosol maximum.

This graph also shows that at midlatitudes the El Chichón loading at its maximum was 10 times the peak St. Helens loading and 2 orders of magnitude above the 1977-79 background. The El Chichón values exceed by far those reported for the Fuego eruption in 1974 (Guatemala, 15.5°N; Russell and Hake, 1977), and might correspond with the Agung injection in 1963 (Bali, 8.4°S).

The history of background period and observed eruptions is presented in Figure 10 on a real time scale. The background period 1977-79 is relieved by a period of volcanism. The presently observed accumulation of volcanic debris in the stratosphere not only influences already satellite observations (of e.g. albedo and sea surface temperature); moreover, it can be regarded as a potential impact to the climate (e.g. Pollack *et al.*, 1980; Mass and Schneider, 1977), since even without further supply by volcanism the stratosphere will need years to fully recover to a background level of aerosol loading.

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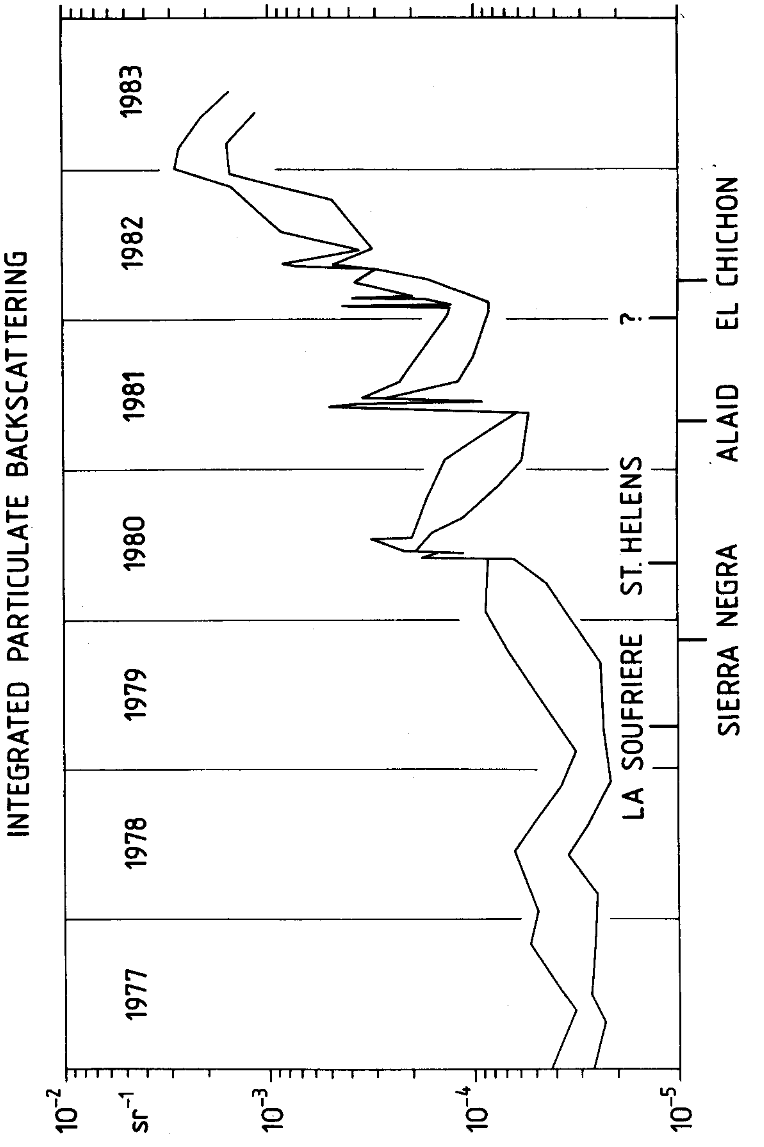

Fig. 10. Time variation of the vertically integrated particulate backscattering coefficient.

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