Tellus (1986), 38B, 67–73

Stratospheric aerosol at 34° S following the 1982 El Chichon and Galunggung eruptions

By J. L. GRAS, E. K. BIGG, C. G. MICHAEL, A. ADRIAANSEN and R. SWINTON,
CSIRO, Division of Atmospheric Research, Station Street, Mordialloc, Victoria, 3195, Australia

(Manuscript received August 27; in final form December 30, 1985)

ABSTRACT

A pronounced increase in stratospheric aerosol particle concentrations was observed from late 1982 through to 1984 at 34° S. Collected particles were predominantly sulfuric acid which was believed to have had its origins in the gaseous emissions of the 1982 eruptions of El Chichon in Mexico and possibly a contribution from Galunggung in Indonesia. Growth of particle size was evident well into 1983. The stratospheric layer of enhanced particle concentrations at 34° S consisted of two sections, an upper more stable layer between altitudes of about 16 and 28 km and a much more variable lower layer between the tropopause and about 15 km.

1. Introduction

It is now well-known that hemispheric or even global scale climate perturbations follow some large explosive volcanic eruptions, in particular those that inject large volumes of sulfur gases into the stratosphere. Hemispheric-mean tropospheric temperatures, as calculated for example by Pollack et al. (1976), may decline by more than 1 °C for several years following these events. Fortunately such eruptions are quite rare. The combined eruptions of the El Chichon volcano in Mexico on March 28, April 3 and April 4, 1982 have been widely acknowledged as one of the few eruption sequences this century likely to have injected enough sulfur gases into the stratosphere to create a possible short term impact on climate. As such, this eruption has particular significance as a means of validating models of the mechanisms which maintain the permanent Junge layer, of stratospheric transport and of the climatic response to increased particle loading in the atmosphere. Although widely studied in the northern hemisphere, where the bulk of the injected material has apparently resided, very little information relating to the stratospheric dust veil from the 1982 El Chichon eruptions has been reported for the southern hemisphere. The spread of dust from the 1982 volcanic eruptions of Galunggung (7.3° S, 108.1° E) and possibly Soputan (1.1° N, 124.7° E) in Indonesia has likewise received very little attention. In this paper we outline data on the variation of the concentration of stratospheric aerosol obtained by direct sampling at 34° S from late 1982 to early 1984.

2. Experimental details

2.1. Instrumentation

Particle collections were made with sampling equipment carried by plastic balloons as described by Gras and Laby (1981) for earlier stratospheric collections. A 1 mm diameter round-jet impactor, driven by a small vacuum pump was used to collect particles directly onto electron microscope grids coated with a nitrocellulose film which is strengthened with an evaporated layer of carbon. This provides a relatively robust, unreactive electron-transparent collecting surface. These grids were mounted on a rotating turntable under the jet to give altitude resolution during the ascent and descent of the balloon. This procedure leaves a "particle impaction trail" approximately one millimeter wide across each grid. On return to the laboratory the grids were shadowed with a gold-palladium alloy at an angle of 26.5° to enable individual particle heights to be determined and then complete cross-sections of the impaction trail were photographed in an electron microscope. For each cross-section the resulting particle images were sized and equivalent pre-impaction sizes determined using the algorithm of Gras and Ayers (1979). This method of collection and analysis is useful for particles with radii between approximately 0.03 μm and 1.0 μm.

Particles in the radius range 0.16 μm to 1.0 μm were sized and counted in-situ with the CSIRO size-spectrometer or CSS, a single-particle white-light-scatter counter described in detail by Gras and Michael (1979). Recent improvements to the pulse analysing system provide discrimination into 256 size channels for calibration purposes. These are grouped into 16 size channels between approximately 0.16 μm and 1.0 μm radius for field recording. As in earlier flights the counter was calibrated with polystyrene latex particles at a minimum of four sizes in the sensing range prior to each sounding.

Very good agreement between impaction sizing as described here and in-situ white-light-scatter sizing was obtained in a previous series of soundings by Gras and Laby (1981) over the radius range of 0.15 μm to 1.0 μm.

2.2. *Observations*

Twilight at 34°S began to show a marked enhancement in coloration sporadically from about May 1982 and with increasing frequency through the southern winter and spring (SEAN, 1982a). From late 1982 and into 1983, visually enhanced twilights occurred fairly regularly.

The first collection of new volcanic particles at 34°S was made on August 9 1982 during a period with a marked increase in twilight coloration. Examination of this collection by electron microscopy revealed a greatly enhanced concentration of large particles ($r \gtrsim 0.1$ μm) throughout the stratosphere and a particularly concentrated layer at approximately 15 km altitude (see Fig. 1b for concentrations of particles with $r > 0.16$ μm measured by impaction).

Most particles clearly indicated sulfuric acid morphology, that is on examination they consisted of a central domed particle with concentric rings of small droplets. In the main layer (at approximately 15 km) there were also a number of large irregular and insoluble particles although the exact altitude distribution of these was not determined. Selected samples were dialysed by placing their collection grids face up on a wet filter and thus allowing soluble components of the collected particles to leach away. This dialysis revealed the presence of many smaller insoluble particles associated with the acid particles.

Cross-sections of the impaction trail (before and after dialysis) were photographed in the electron microscope and the equivalent pre-impaction sizes determined (for the undialysed particles). The altitude distribution of particles with pre-impaction radii larger than 0.16 μm is shown in Fig. 1b for the selected analysis levels. It should be noted that the concentration scale for Fig. 1b is 10 times that of the other profiles in Fig. 1. At the altitude of the layer peak (15 km) the concentration of 16 cm^{-3} is approximately 85 times greater than that at the corresponding altitude in August 1980, the data of the last previous sounding at 34°S (with the CSS described earlier). Concentrations were also enhanced significantly at other altitudes, for example by an order of magnitude at 19 to 22 km. Vertical resolution of the present impaction data is low principally because of the constraints imposed by manually sizing the many thousands of particles collected.

This is not the case in the subsequent in-situ determinations from 29 April 1983 to 24 March 1984 where the CSS data were analysed to give a vertical resolution of 150 m. Altitude profiles of particle concentration for radii greater than 0.16 μm for these soundings are given in Fig. 1c to 1f. Sizes were determined by assuming a real component of refractive index equal to 1.45 and no absorption ($RI = 1.45 - 0i$), in line with the observation that the aerosol was predominantly sulfuric acid and assuming a concentration of 75% acid, 25% water.

A consistent feature in the aerosol layer over this period is the division into two apparently different altitude regimes. The upper or main section contains the maximum particle mixing ratio (taken here to mean the number of particles per mg of air). This upper section extends from about 16 or 17 km to 28 km and has a concentration peak of around 2 to 3 cm^{-3} at around 18 km as shown in Fig. 1. This varies little from sound-

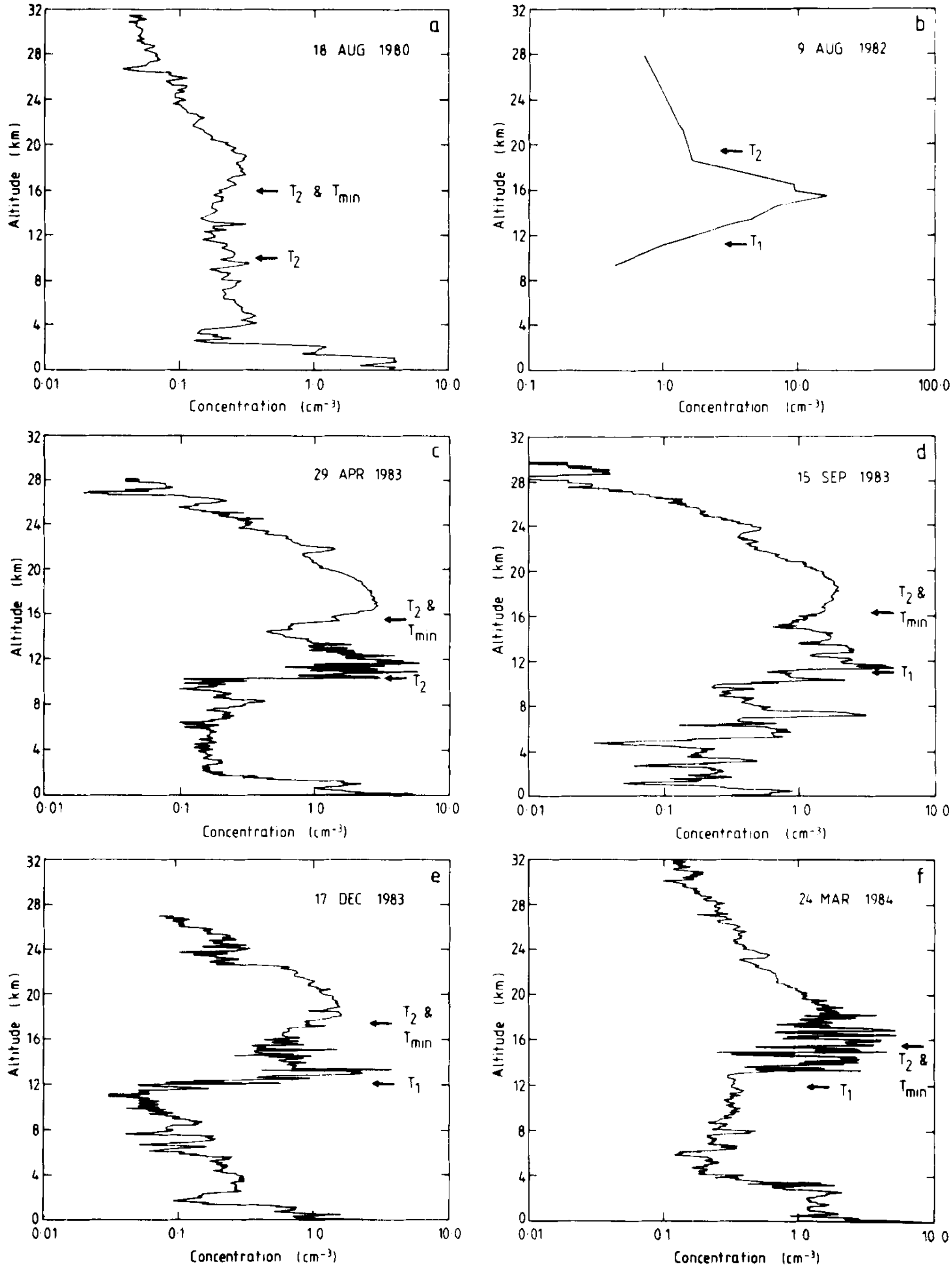

Fig. 1. Variation of concentration (no./cm^3) with altitude for particles with $r > 0.16$ μm. (a) Profile obtained with the CSS in-situ size spectrometer prior to present eruption sequence. (b) First data obtained at 34°S after El Chichon and Galunggung eruptions, by impaction collection. Note that the concentration scale is ten times greater than for the other profiles. (c) to (f) Data obtained on indicated dates with CSS (CSIRO size-spectrometer). Tropopause heights are indicated with a T and the height of the minimum temperature with T_{min}.

ing to sounding, and the layer as a whole is not highly structured but has occasional transient layers embedded in it (a relatively normal feature). In contrast, the lower section from the tropopause up to about 16 or 17 km is clearly associated with much more variable transport as evidenced by the numerous thin, transient layers observed in the CSS data. Concentrations for $r \gtrsim 0.16$ μm in this region vary from the peak of 16 cm^{-3} in August 1982 to around 5 or 6 cm^{-3} in the subsequent soundings. The concentration profile is much more finely structured with numerous thin layers and more variable concentrations. The division of the stratospheric cloud into two broad bands was also observed in in-situ sampling measurements by Hofmann and Rosen (1983) at 27° N through 1982 and also by Clemesha and Simonich (1983) in LIDAR measurements at 23° S. In the LIDAR data, which cover the period up to late November 1982, two layers were evident until about September 1982. Although the initial cause for the development of two apparently distinct layers is not certain, Hofmann and Rosen's suggestion that it was the result of two distinct eruptions of El Chichon is supported by the lack of apparent interaction between the two layers during their spread from at least 27° N to 34° S. However, this argument may be too simple in view of a possible contribution to the stratospheric particle burden in the southern hemisphere from Indonesian volcanic eruptions (see later).

In August 1982 the upper limit to the aerosol layer appeared to be greater than 28 km, the maximum altitude sampled. Subsequently, the main aerosol layer apparently extended only to an altitude of about 26 km, at which point concentrations were close to those observed during earlier, more quiescent periods at these altitudes, until March 1984. In March 1984, however, the layer again extended to a greater altitude with concentrations still elevated above quiescent levels up to at least 32 km. Generally the lower limit to the enhanced layer was close to the tropopause, around 12 km.

A better perspective of the increase in concentration relative to stratospheric particle concentrations over the last decade or so and the subsequent time variation can be obtained from Fig. 2 which gives the column loading of particles (in a 1 cm^2 column) between the altitudes of 16 and 22 km from 1972 to 1984. This altitude band has been used because it contains the bulk of the new volcanic material, is substantially free of the effects of seasonal changes in tropopause height and allows direct comparison with the earlier data of Gras and Laby (1981). From around mid-1976 until late 1980 column loadings in this altitude band had been gradually declining from a peak attained in 1975–76 following the 1974 eruption of Fuego in Guatemala. Column loadings in 1980 were at about or lower than the level previously observed in 1973 and which possibly constitutes the quiescent background at 34°S. Loadings for radii > 0.16 μm increased by approximately one order of magnitude in late 1982, subsequently subsiding but still considerably enhanced relative to the 1980 and 1973 southern hemisphere quiescent levels, as late as March 1984. An even greater relative increase is evident in the loading of particles with radii greater than 0.25 μm, indicating an overall shift to larger particles and decrease in the ratio $N(r \gtrsim 0.15\ \mu m)/N(r > 0.25\ \mu m)$ from a typical pre-eruption value of around 5 to about 2.5. This value is still larger than that observed at 27° N by Hofmann and Rosen (1983) in late 1982 in the main layer peak, at Northern mid and low latitudes where the size ratio was around 1.4. The enhanced aerosol layer at 78°S observed by Hofmann and Rosen (1985) in October 1983 between altitudes of about 11 and 17 km has the same size ratio as that at 34°S during 1983 and is most probably a more southerly advection of the aerosol layer observed at 34°S.

3. Discussion – effects of Indonesian volcanoes

There seems little doubt in view of the studies of Strong et al. (1982) and McCormick et al. (1984) that the principal cause of the enhanced global stratospheric aerosol burden in 1982–1983 was the eruptions of El Chichon in March–April 1982. There is however also a need to recognize that there is probably some contribution from an almost simultaneous (and subsequent) eruption sequence which occurred in Indonesia. Clemesha and Simonich (1983) discussed a possible contribution to lidar backscatter at 23°S in the latter part of 1982 from eruptions of the volcano

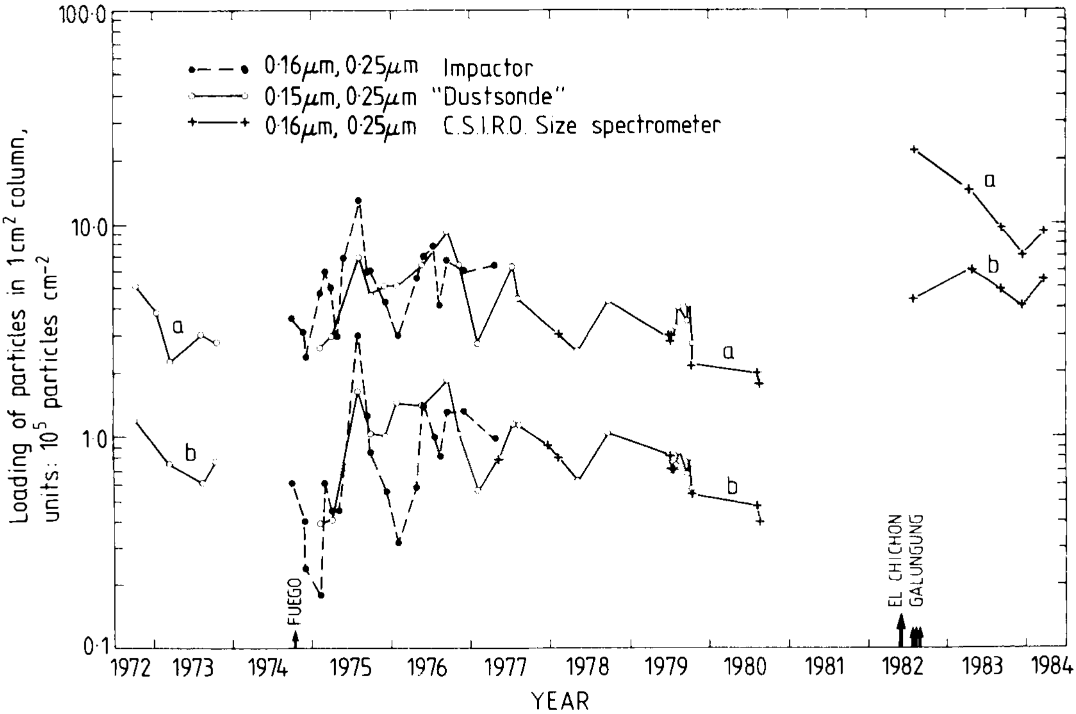

Fig. 2. Time variation of particle (number) loading in a 1 cm² column from 16 to 22 km altitude for particles with $r \gtrsim 0.15$ μm (a) and $r > 0.25$ μm (b) from 1972 to 1984 at 34°S. The dates of the most significant known eruptions for southern hemisphere loadings are indicated.

Galunggung between April 5 and June 25 1982 without being able to draw any definite conclusions. Eruptions of the Galunggung volcano in fact extended from at least April 5 1982 until January 1983. Major reported eruptions (all in 1982) with ash-cloud tops at or near the tropopause included July 13 (>15 km), July 14 (16 km), August 13 (15 km), August 29 (15.5 km) (SEAN, 1982b, c). Also on August 26 1982 Soputan volcano in Indonesia erupted with a reported eruption cloud top higher than 15 km (SEAN, 1982d). Hanstrum and Watson (1983) documented satellite observations of the Galunggung eruption clouds on June 24/25 and July 13/14 1982. In the latter case (where the eruption cloud top reached approximately 16 km), advection south across the north-western Australian coast over the following four days and subsequent eastward advection and dilution over the Australian continent was reported. A significant increase in twilight coloration occurred in eastern Australia (at 34°S) between July 17 and July 21 (SEAN, 1982a) and again approximately 19 days later around August 9 1982 the date of the first sounding reported here. Since the measured westerly component wind speed at the height of the layer observed on August 9 was around 26 ms^{-1} and the value required for a single global circuit at 34°S in 19 days is 20 ms^{-1}, it could be argued that the extremely elevated concentrations of particles observed around 15 km altitude at 34°S in August 1982 were at least partially augmented by material from the July 1982 Galunggung eruptions. On the other hand, there appears to be considerable similarity between the physical properties of the aerosol in this 15 km layer and in the lower layer observed by Hofmann and Rosen (1983) at approximately the same date (21 August 1982) at 27.8° N between about 16 km and 20 km. This includes similar peak concentrations of particles with $r > 0.15$ μm, ~20 cm^{-3}, similar size ratio, $N(r > 0.15\ \mu m)/N(r > 0.25\ \mu m) = 5.6$ at

27.8° N and $N(r > 0.15\ \mu m)/N(r > 0.25\ \mu m) = 6.0$ at 34°S and also the presence of a population of non-volatile or solid particles. In their study of anomalous sea-surface temperatures and comparison of minimum albedos before and after the El Chichon eruption, from satellite derived data, Strong et al. (1982) noted that the belt of latitudes apparently influenced by the El Chichon dust-veil extended southwards to include the Indonesian area in about August 1982. They pointed out the possibility that this was due to the Indonesian eruptions. Examination of their data clearly indicates that on the broad scale this would have been only a minor contribution to the equatorial dust reservoir created by the El Chichon eruptions. However, this still leaves ample scope for a significant (although possibly transient) regional impact of these Indonesian eruptions on the southern hemisphere and possibly extending into the northern hemisphere. Resolution of the relative contributions of these two different sources of volcanic particles can probably only be made clear by obtaining more data on the spatial and temporal variation of optical effects in the southern hemisphere or equatorial regions.

4. Conclusions

Pronounced increases in stratospheric aerosol particle concentrations were observed at 34°S during 1982 to 1984. These particles consisted predominantly of sulfuric acid believed to have had as its origin, sulfur gases emitted in the 1982 eruptions of El Chichon in Mexico and to some as yet undetermined extent, Galunggung and possibly Soputan in Indonesia (or other unreported eruptions). A marked increase in the size of particles as shown by the ratio in the number with radii greater than 0.16 μm to those with radii greater than 0.25 μm was observed well into 1983. This greater average size of particles means that although the number loading of particles with $r > 0.16\ \mu m$ after this eruption sequence at 34°S were similar to those observed following the Fuego eruption the mass loading was considerably greater. As in the northern hemisphere at the same time the stratospheric layer consisted of two relatively separate altitude bands with somewhat different aerosol microphysical properties. The layer with the greatest number mixing ratio extended from about 16 to 28 km. The lower layer which extended from about tropopause level to around 15 km in general contained the highest number concentrations and also showed a much greater altitude stratification and variability with time. This region was clearly influenced by much more variable transport and may also have been influenced to a greater extent by the Indonesian volcanic eruptions than the higher-altitude layer.

REFERENCES

Clemesha, B. R. and Simonich, D. M. 1983. Lidar observations of the El Chichon dust cloud at 23°S. *Geophys. Res. Lett. 10*, 321-324.

Gras, J. L. and Ayers, G. P. 1979. On sizing impacted sulfuric acid aerosol particles. *J. Appl. Meteorol. 18*, 634-638.

Gras, J. L. and Laby, J. E. 1981. Southern hemisphere stratospheric aerosol measurements 3-size distribution 1974-1979. *J. Geophys. Res. 86*, 9767-9775.

Gras, J. L. and Michael, C. G. 1979. Measurement of the stratospheric aerosol particle size distribution. *J. Appl. Meteorol. 18*, 855-860.

Hanstrum, B. N. and Watson, A. S. 1983. A case study of two eruptions of Mt. Galunggung and an investigation of volcanic cloud characteristics using remote sensing techniques. *Aust. Meteorol. Mag. 31*, 171-177.

Hofmann, D. J. and Rosen, J. M. 1983. Stratospheric sulfuric acid fraction and mass estimate for the 1982 volcanic eruption of El Chichon. *Geophys. Res. Lett. 10*, 313-316.

Hofmann, D. J. and Rosen, J. M. 1985. Antarctic observations of stratospheric aerosol and high altitude condensation nuclei following the El Chichon eruption. *Geophys. Res. Lett. 12*, 13-16.

McCormick, M. P., Swissler, T. S., Fuller, W. H., Hunt, W. H. and Osborn, M. T. 1984. Airborne and Ground-based lidar measurements of the El Chichon stratospheric aerosol from 90°N to 56°S. *Geofys. Int. 22*, 187-221.

Pollack, J. B., Toon, O. B., Sagan, C., Summers, A., Baldwin, B. and Van Camp, W. 1976. Volcanic explosions and climatic change: a theoretical assessment. *J. Geophys. Res. 81*, 1071-1083.

SEAN 1982a. Atmospheric optical effects of Galunggung eruption in Australia. *SEAN Bulletin.* (SEAN: Scientific Event Alert Network bulletin, Smithsonian Institution) *17*, no. 7, p. 11.

SEAN 1982b. Galunggung eruption cloud. *SEAN Bulletin 17*, no. 9, p. 11.

SEAN 1982c. Galunggung eruption cloud. *SEAN Bulletin 17*, no. 8, pp. 5–6.

SEAN 1982d. Soputan eruption cloud. *SEAN Bulletin 17*, no. 9, p. 12.

Strong, A. E., Gruber, A. and Varnadore, M. 1982. An assessment of the impact of El Chichon on planetary radiation budget and satellite-derived sea surface temperatures. Proc. of Seventh Annual Climate Diagnostics Workshop, NOAA, Boulder Co., 371–381.