

*ON THE EFFECT OF THE VOLCANIC ERUPTIONS OF
MOUNT AGUNG AND EL CHICHÓN ON THE TEMPERATURE
OF THE STRATOSPHERE*

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RESUMEN

Durante el verano y el otoño de 1982, y también durante el verano y el otoño de 1963, la temperatura a 30 mbar subió más de tres desviaciones estándar sobre el promedio de 18 años en latitudes tropicales. Estos calentamientos se atribuyen a los aerosoles estratosféricos producidos por las erupciones del Monte Agung en marzo de 1963 y de El Chichón en abril de 1982.

ABSTRACT

During the summer and autumn of 1982, and also during the summer and autumn of 1963, the 30 - mbar temperature rose more than three standard deviations above the 18-year average over tropical latitudes. These warmings are attributed to the stratospheric aerosols produced by the eruptions of Mount Agung in March 1963 and El Chichón in April 1982.

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INTRODUCTION

We are focussing our discussions on the temperatures of the 30-mbar level, as this is the highest level for which a long and reliable series of data is available, and also because this is the level where the eruptions of El Chichón produced the largest enhancements in stratospheric aerosols (Labitzke *et al.*, 1983; Mc Cormick and Swisler, 1983).

DATA

The material presented here is based mainly on *daily* hemispheric analyses of the 30-mbar level, using all available radiosonde data. Great care has been taken to make these hand-analyses, which are built up from the 100- and 50-mbar levels, consistent in time and space. The daily maps have been published regularly in our series *METEOROLOGISCHE ABHANDLUNGEN, F. U. BERLIN*, where maps of the standard deviations have been included, starting in 1972.

During summer when the real interdiurnal variations are small, the standard deviations should be an indicator of any noise created by unreliable data. These standard deviations are usually smaller than 1 degree, often smaller than 0.5 degree. Since part of this is due to the *real* interdiurnal variation, we assume that our temperature data may have an error bar of $\sim\pm 0.3$ degrees.

Grid point values, spaced 10 degrees in latitude and longitude (since 1975, 5 degrees) have been extracted from the daily maps and have been combined into monthly mean values, zonal means, etc. Originally, our temperature series started in July, 1964, because the data are considered to be more reliable after July, 1964 when radiosonde data became available from the USSR. But for the investigation of the effect of the volcanic eruption of Mount Agung, we have extended the data series to July, 1962.

ON THE EFFECT OF THE VOLCANIC ERUPTIONS OF MOUNT AGUNG AND EL CHICHON

After the eruption of Mount Agung in Indonesia (8.4°S, 111.5°E) in March 1963, when very much aerosol was injected into the stratosphere, there was already debate on a possible warming of the stratosphere; e.g. Newell (1970) and McInturff *et al.* (1971). However, as no long series of data was available at the time, it was argued that the effect of the quasi-biennial oscillation (QBO) could not be separated clearly.

When we noticed the warming of the stratosphere during the summer of 1982, Figure 1, we did not have the 1963 values for comparison, as our temperature data series originally started in July, 1964. Even so, we readily attributed the warming in the summer 1982 to the very large aerosol load which was introduced into the stratosphere during the eruption of El Chichón in Mexico (17.3°N , 93.2°W) in April, 1982, and we published a short report on this (Labitzke *et al.*, 1983).

Zonal Mean 30-mbar Temperatures

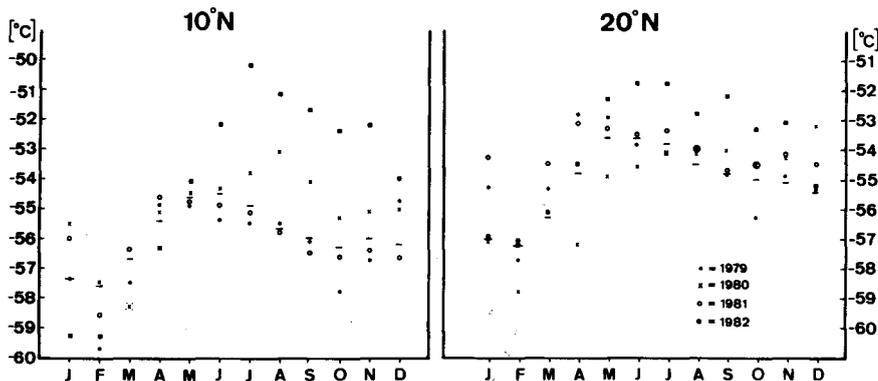


Fig. 1. Annual march of monthly mean 30-mbar temperatures ($^{\circ}$) at 10°N and 20°N , for the years 1979 through 1982.

To obtain a comparison with the Mount Agung event, we analysed the temperatures over the tropics backwards from July 1964 to July 1962. Fortunately, during both summers the phase of the QBO was the same, with prevailing easterlies at the 30-mbar level during the time of the eruption, changing very quickly to westerlies within the next few months, Figure 2. This is of great importance as it simplifies the discussion (Quiroz, 1983).

The frequency distribution of the monthly mean 30-mbar temperatures ($^{\circ}\text{C}$), averaged along 10°N , for the period January 1963 through December 1983 is given in Fig. 3.

Now it becomes obvious that the tropical stratosphere warmed at this level (~ 24 km) after the eruption of El Chichón (\boxplus) as well as after the eruption of Mount Agung (\boxminus) to values more than three standard deviations above the long-term average. Normally, the interannual variability over the tropics is caused by the QBO, but these two periods stand out clearly beyond the warmest values observed before. Both years started with temperatures below the 18-year average, in accordance with the phase of the QBO. During both years the temperatures were above the average in June, but much more so through the period from July till November.

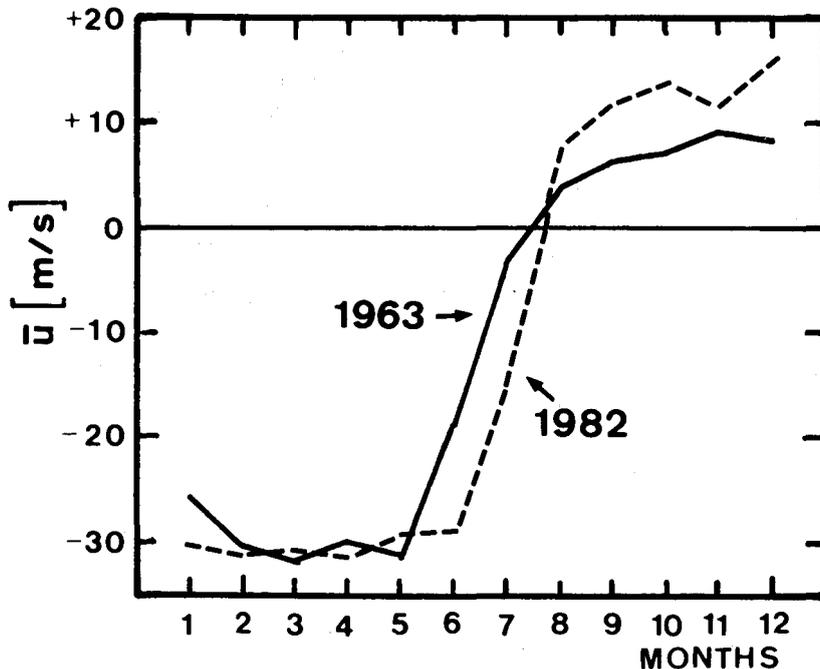


Fig. 2. Monthly mean 30-mbar zonal winds (m/sec) near the equator for the years 1963 and 1982; (1963: Canton Island, $3^{\circ}\text{S}/172^{\circ}\text{W}$; 1982: Singapore, $1^{\circ}\text{N}/104^{\circ}\text{E}$); (from Labitzke and Naujokat, 1983).

For completeness the values for 1983 have been added (■), showing the recovery to values below normal during the summer of 1983.

For a better understanding of the interannual variability of the data, the monthly mean 30-mbar July temperatures, averaged along 10° , 20° and 30°N , are shown in Figure 4a; and for comparison for 50-mbar July temperatures in Figure 4b. They clearly demonstrate the warmings due to the two large volcanic eruptions as well as the recovery afterwards. As regards the phase of the QBO, the values of 1963 and 1982 should be compared with the values of 1977, as only this summer was in a similar phase. There can be no doubt that during these two eruptions much more aerosol was injected into the stratosphere and much higher, than during other eruptions, such as Mount St. Helens (46.2°N , 122.2°W) in May, 1980 (McCormick and Swisler, 1983). Also, the winds in the tropics were such that especially at the 30-mbar level most of the aerosol clouds could encircle the tropics for a long time before spreading slowly to higher latitudes. Both features favoured the warming in the tropical stratosphere, clearly supporting theoretical studies (e.g., Hansen *et al.*, 1978).

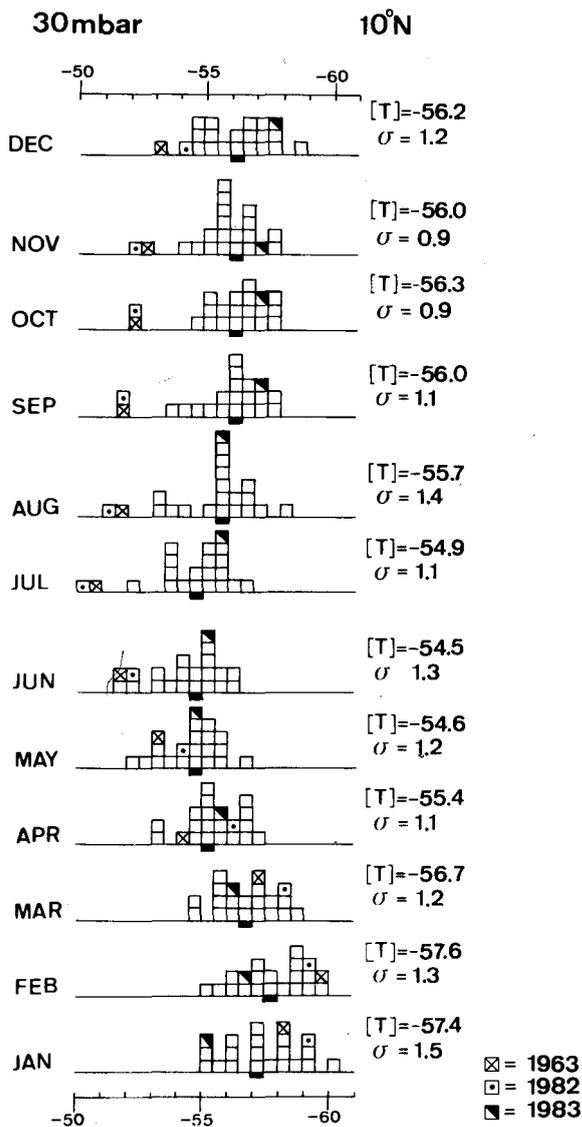


Fig. 3. Frequency distribution of the monthly mean 30-mbar temperatures ($^{\circ}\text{C}$), averaged along 10°N , for the period January, 1963 through December, 1983; the long-term average is based on January, 1964 through December, 1981. The values for 1963 are marked ☒, for 1982 □, and for 1983 ■; (update from Labitzke and Naujokat, 1983).

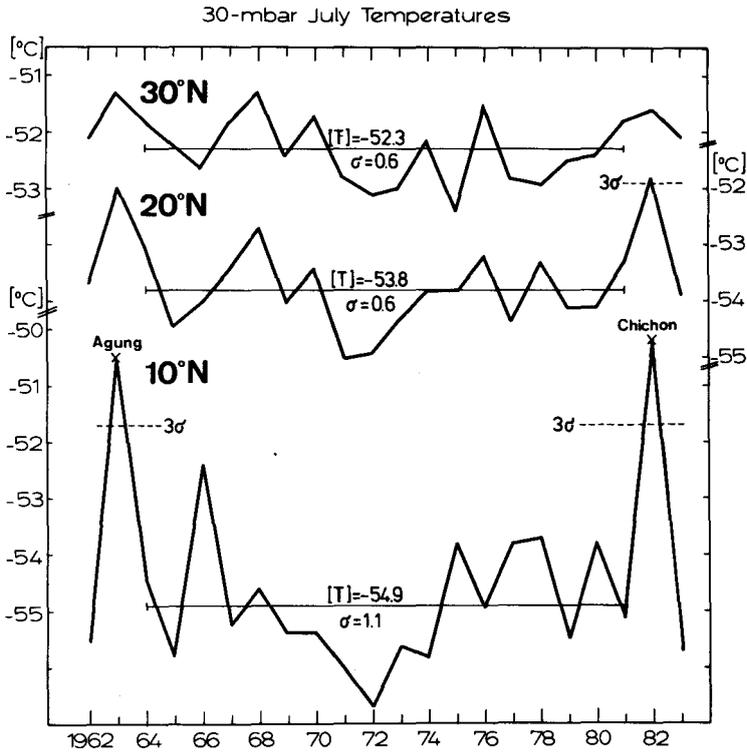


Fig. 4a. Zonal mean 30-mbar temperatures ($^{\circ}\text{C}$) during July at 10, 20, and 30 $^{\circ}\text{N}$, for the period 1962 through 1983. The 18-year average [T] is for the period 1964-1981 (from Labitzke and Naujokat, 1983).

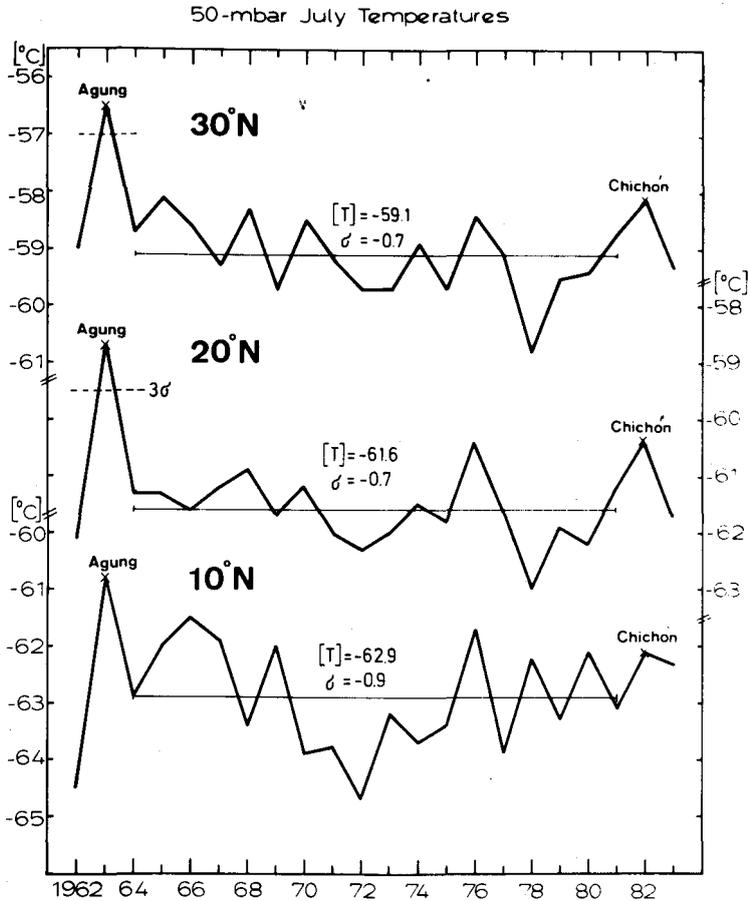


Fig. 4b. As Figure 4a, but for the 50-mbar level.

Comparing Figures 4a and 4b, it is obvious that the warming over the tropics (10°N) was largest at the 30-mbar level after both eruptions. In this we don't agree with Angell and Korshover (1983); however, one should note that their investigation is based on only a few selected radiosonde stations. At the subtropics (20° and 30°N) the warming induced by Mount Agung was larger at the 50-mbar level, although Mount Agung is situated at 8°S . This clearly hints to differences in the transport in the lower stratosphere after the two eruptions.

For a clarification of this question the horizontal distributions of the temperature deviations from the 10-year average 1964-1973 are given in Figure 5. Here we find in July 1963, Figure 5a, a maximum deviation of +4 degrees at 50 mbar over India. We assume that the transports involved in the Monsoon circulation may have attracted parts of the aerosol cloud to this region.

During the summer of 1982, a lower cloud of much lesser aerosol mass spread quickly polewards at the 20-km level, and the positive deviation of 2 degrees south of the Aleutian Islands very likely reflects this, Figure 5c.

At the 30-mbar level the temperature deviations are much more regular around the tropics in both cases, Figure 5b and 5d, probably because the aerosol was very regularly distributed around the globe over the tropics and subtropics. Our deviations agree well with those published for August 1982 by Parker and Brownscombe (1983).

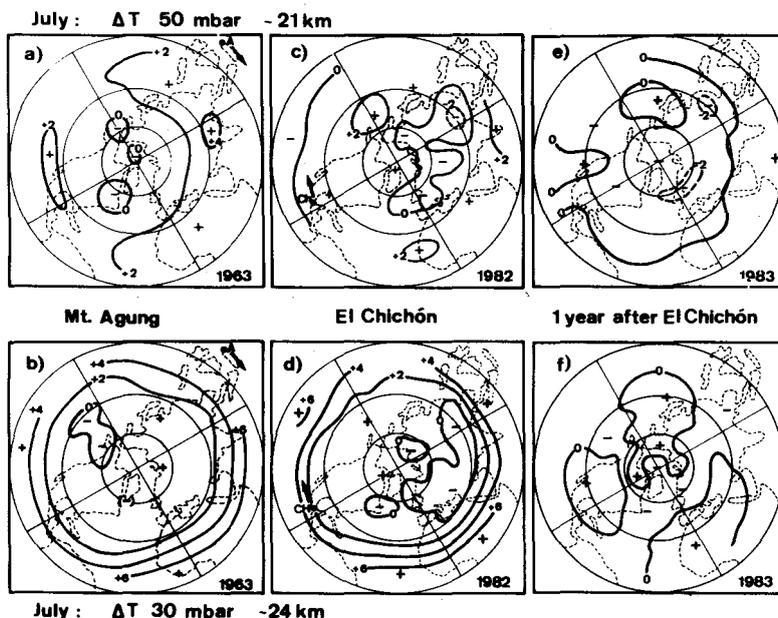


Fig. 5. a) Deviations ($^{\circ}\text{C}$) of the 50-mbar temperatures of July 1963 from the 10-year average 1964-1973. The position of Mount Agung and the direction of the mean zonal wind at the 50-mbar level during April 1963 are indicated.

b) Same as (a), but for the 30-mbar level.

c) Same as (a), but for July 1982, and with the position of El Chichón and the respective wind direction.

d) Same as (c), but for the 30-mbar level.

e) Same as (c), but for July 1983.

f) Same as (d), but for July 1983. (Update from Labitzke and Naujokat, 1983).

The weak temperature deviations of July, 1983, Figs. 5e and f, indicate that the stratosphere has recovered largely from the warming due to the increased aerosol. Larger positive deviations (almost 2°C) are still being observed over the tropics at the 50-mbar level, Fig. 5e. Here, the equatorial winds did not change from westerlies to easterlies during the summer of 1983, as would have been expected under

“normal” conditions. Instead, the westerlies continue (when this report was written, i.e., December, 1983) and modify the period of the QBO. This seems to be similar to the situation after the eruption of Mount Agung, as noted and explained by Dunkerton (1983). A note on this is under preparation (Labitzke and Naujokat, 1984).

CONCLUSION

It is shown that during the summers of 1963 and 1982 middle stratospheric temperatures over the tropics were exceptionally high; it is concluded that this was caused by the increased aerosol loads from the volcanic eruptions of Mount Agung and El Chichón. Further it is shown that until the summer of 1983 the stratosphere recovered largely from the warming, with the exception of the tropics at the 50-mbar level where positive anomalies continue, leading to a modification of the QBO.

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BIBLIOGRAPHY

- ANGELL, J. K. and J. KORSHOVER, 1983. Comparison of stratospheric warmings following Agung and Chichón. *Mon. Wea. Rev.*, *111*, 2129 - 2135.
- DUNKERTON, T. J., 1983. Modification of stratospheric circulation by trace constituent changes? *J. Geophys. Res.*, *88*, 10831 - 10836.
- HANSEN, J. E., W. WANG and A. A. LACIS, 1978. Mount Agung eruption provides test of a global climatic perturbation. *Science*, *199*, 1065-1068.
- LABITZKE, K., B. NAUJOKAT and M. P. McCORMICK, 1983. Temperature effects on the stratosphere of the April 4, 1982 eruption of El Chichón, Mexico. *Geophys. Res. Lett.* *10*, 24-26.
- LABITZKE, K. and B. NAUJOKAT, 1983. On the variability and on trends of the temperature in the middle stratosphere. *Contributions to Atmosph. Physics*, *56*, 495 - 507.
- LABITZKE, K. and B. NAUJOKAT, 1984. An update on the QBO (under preparation for submission to *J. Atm. Sci.*).
- McCORMICK, M. P. and T. J. SWISSLER, 1983. Stratospheric aerosol mass and latitudinal distribution of the El Chichón eruption cloud for October 1982. *Geophys. Res. Lett.* *10*, 877-880.

- McINTURFF, R. M., A. J. MILLER, J. K. ANGELL and J. KORSHOVER, 1971. Possible effects on the stratosphere of the 1983 Mount Agung volcanic eruption. *J. Atmos. Sci.*, 28, 1304-1307.
- NEWELL, R. E., 1970. Modification of stratospheric properties by trace constituents changes. *Nature*, 227, 697-699.
- PARKER, D. E. and J. L. BROWNSCOMBE, 1983. Stratospheric warming following the El Chichón volcanic eruption. *Nature*, 301, 406-408.
- QUIROZ, R. S., 1983. The isolation of stratospheric temperature change due to the El Chichón volcanic eruption from non-volcanic signals. *J. Geophys. Res.*, 88, 6773-6780.

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