The Abnormal Temperature Rises in the Lower Stratosphere After the 1982 Eruptions of the Volcano El Chichon, Mexico

by

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Abstract

Abnormal temperature rises were found in the lower stratosphere over the north subtropical Pacific after the 1982 eruptions of El Chichon. The significant temperature anomalies at 30 mb level moved westward with the El Chichon volcanic clouds.

The positive temperature anomalies from the normal were simultaneously observed with the large backscattering ratios from the lidar measurements in the southern parts of Japan.

The height-time cross section for the standardized temperature ($T' = (T - \bar{T})/\sigma_T$) showed warming in the lower stratosphere over the eastern and central parts of the north subtropical Pacific. In the above formula T is a monthly mean temperature, $\bar{T}$ is the normal and σ_T is a standard deviation. The magnitudes of the anomalies were in the range between σ_T and $2\sigma_T$ at most in this area. On the other hand, in the western part of the north subtropical Pacific, a stratospheric warming was spectacular.

In particular, over Chichijima (about 27°N, 140°E) the air layer between 30 mb and 20 mb levels was abnormally warmed, with a peak anomaly of more than $5\sigma_T$ at 50 mb level in July and over $8\sigma_T$ at 20 mb level in September.

In order to investigate northward diffusion of the volcanic clouds, the height-latitude cross sections of temperature anomalies along the 140°E Meridian were made every month from May to December 1982.

Until June a positive temperature anomaly was limited to the south area of 40°N lat. over Japan. But in July it diffused north of the 40°N circle and the time variations of the monthly maxima of the direct solar radiation in USSR showed that the volcanic clouds passed through 50°N latitude in October and 60°N in November.

Lastly it was found that the lower stratospheric temperature anomalies in the past three El Niño events did not show such remarkable warming as in 1982-83. They were all rather negative. Therefore it is not likely that the temperature rises in the lower stratosphere after the 1982 eruption of El Chichon was caused by the 1982-83 El Niño event.

1. Introduction

The volcano El Chichon (17.33°N, 93.20°W) in southern Mexico violently erupted in late March and early April, 1982. (SEAN BULLETIN, Vol. 7, No. 3, 1982) The April 4 eruption was particularly strong, throwing up large quantities of volcanic ashes and

sulfur-rich gases into the lower stratosphere.

They were observed by the geostationary GMS, GOES satellites and the polar-orbiting NOAA7 satellite. Some of the worldwide lidars detected the stratospheric dense aerosols from the El Chichon eruptions.

On April 9-10, a groundbased lidar at the Mauna Loa observatory (M.L.O.), Hawaii

(19.5°N, 155.6°W), first detected several dense aerosol layers with the strongest backscattering ratio (B.S.R.) at an altitude of 25.7 Km. (SEAN BULLETIN above)

Robock (1983) made a global location map of the volcanic clouds for the first three weeks after the El Chichon eruptions.

The map shows that the volcanic clouds rounded the latitude zones between 10°N and 30°N for three weeks.

Labitzke et al. (1983) showed by the 30 mb gridpoint data that the 30 mb zonal mean temperature at 10°N increased in July, August, September and October, 1982, to values well above those shown for the previous 18 years. They attributed the warmer temperatures to the aerosols produced from a series of 1982 eruptions of El Chichon.

Parker and Brownscombe (1983) also reported a warming of the equatorial lower stratosphere after the El Chichon eruptions and concluded that the warming was the combined effects of the El Chichon eruption and the tropical stratospheric quasi-biennial oscillation (Q.B.O.).

The above two reports have in common that the analyzed regions are restricted to relatively lower latitudes where Q.B.O. predominantly affects the stratospheric temperature anomalies.

Angell and Korshover (1983) showed that a warming of nearly 4°C was found at the 30 mb level in the north subtropics two seasons after the El Chichon eruption.

In this paper, first, the existence of the dense volcanic aerosols in the stratosphere will be confirmed from the lidar measurements, Robock's volcanic cloud map, the direct solar radiation intensities in Japan and India, and unusual evening glows in Japan.

Next, the relationship between stratospheric dense aerosols and warmer temperature anomalies will be investigated from the lidar measurements and aerological data in Japan.

Third, abnormal temperature rises and their northward diffusion in the lower stratosphere will be analyzed by the time-height and latitude-height cross sections of

the standardized temperature anomalies over the north subtropic Pacific and along 140°E.

Lastly, the relationship between the remarkable El Niño event and stratospheric temperature anomaly will be examined.

2. Stratospheric dense aerosols caused by the El Chichon eruption.

The lidar measurement at M.L.O., Hawaii, first detected, on April 9, an enhancement of B.S.R. at an altitude of about 26 Km (20 mb).

It is certain that the anomalous B.S.R. were caused by the aerosols produced from the El Chichon eruption on April 4, judging from the mean easterly wind velocity at the 30 mb level over 19°N latitude between Mexico and Hawaii at that time. (about 12.1 m/sec)

The global location map of the El Chichon clouds (Robock (1983)) showed that they moved westward through the stratospheric easterly winds. April 11 they appeared in the upper air over Wake Island (19°N, 167°E) and passed through the lower stratosphere over Guam Island (13°N, 145°E) on about 13 and reached the 130°E Meridian about next day.

In Japan, Hirono and Shibata (1983), Iwasaka et al. (1982) and Uchino et al. (1984) first observed large B.S.R. by lidar observations from late April to early May.

The turbidity coefficient at Naha (26°N),

Fig. 1. Forenoon direct solar radiation during April 1982 at Bhaunagar (21.75°N, 72.2°E), India. $\bar{X}$ and σ_X indicate the average and the standard deviation on the period of both April 1980 and 1981 respectively.

(a)

(c)

(b)

(d)

Fig. 2. Evening glows at Tsukuba and Tokyo, (a) 19:10, May 24 1982 (Tokyo, solar depression angle; -5.5°). (b) 16:55, Dec. 7 1982 (Tsukuba; -6.3°). (c) 17:25, Jan. 15 1983 (Tokyo; -7.0°). (d) 16:55, Nov. 18 1983 (Tsukuba; -5.4°).

Japan, increased in April over a standard deviation calculated from 1959 to 1983. (Yamauchi and Shimura (1984)) Also on April 20, the direct solar radiation intensity at Bhaunagar (21.75°N, 72.2°E), India, greatly decreased to below 3 times the standard deviation. (Fig. 1)

It seems that the remarkable reduction of the radiation intensity in western India corresponds to the coming of the El Chichon clouds on Robock's map.

Fiery red evening glows and unusual twilights which were reported by the inhabitants at many places in Japan after the middle of May 1982 also suggested the existence of dense volcanic aerosols at the lower stratosphere over Japan.

According to the SEAN BULLETIN (Vol. 7, No. 7, 1982), Lamb observed Bishop's Ring on 28 and 29 May 1982 at Norwich, England (52.5°N, 1°E).

Schaaf also observed a probable Bishop's Ring on 18 Feb., 1983, at Millville, New Jersey (39.4°N, 74.9°W). (SEAN BULLETIN, Vol. 8, No. 2, 1983). Some of the representative evening glow photographs at Tsukuba and Tokyo are shown in Fig. 2. Evening glows in December 1982 appeared more reddish than those in late May but by mid January 1983 the red glow colors were rapidly becoming lighter. When the sun had set and its depression angle was about $-6^{\circ} \sim -7^{\circ}$ (about 40 minutes after the sunset), evening glow appeared deep fiery red in the sky 2° – 3° above the western horizon.

It would be suggested from simple geometry about the evening glow that the volcanic aerosols exist in the layer of about 23–25 Km. (Meinel and Meinel (1983))

The photograph shown in Fig. 2(d) was taken on Nov. 18, 1983, the evening glow being still brilliant.

Lamb (1970) defined the dust veil index, D.V.I., in which the total time between the eruption and last observation of the dust veil was used as a parameter. Therefore it is important to record how long the unusual optical phenomena continue.

3. A relationship between volcanic debris and stratospheric temperature.

Fig. 3(a) shows the time variations of wind and temperature at the 30 mb level over Fukuoka (33.5°N, 130.4°E) in the first half of May 1982. Until 15 northerly winds prevailed and temperatures fluctuated around -54°C . On 16 the wind turned to the souther and temperature suddenly increased by about 5°C . The temperature rise can not be explained by warm air advection, because the meridional temperature gradient was from north to south.

Fig. 3(b) reveals the simultaneous relationship between lidar B.S.R. due to volcanic clouds and temperature rises in the stratosphere. On May 17 intense B.S.R. were simultaneously observed in the lower stratosphere at Fukuoka, Nagoya (35.2°N, 137°E) and Tsukuba (36.1°N, 140.1°E). The left side of the figure indicates a vertical profiles of the temperature anomalies from 17-year average (1964–1980), in which lateral bars mean their standard deviations.

The figures show significant temperature rises in the layer of about 3 Km under the peak height of the B.S.R..

The simultaneous correlations between dense volcanic clouds and abnormal temperature rises in the lower stratosphere were certainly caused by aerosol absorption of visible solar radiation and long wave radiation from the warmer ocean surface (Newell (1970a, b), Robinson (1966), Ogren et al. (1981) and Hansen (1978)).

According to Pollack and Ackerman (1983), a statistically significant warming of the lower stratosphere took place in the northern tropics with the peak ΔT occurring at the 30 mb level and having a magnitude of $3.5^{\circ} \pm 1.5^{\circ}\text{K}$. Therefore a daily warming over the ocean station may exceed 6°K .

In Fig. 4, daily temperature anomalies from the 17 years' average (1964–1980) at the 30 mb level are presented from Hilo to Ishigakijima (24.3°N, 124.2°E) on the north subtropical Pacific.

The dotted lines in the figure represent

the standard deviation for the anomaly series on April (hereafter denoted by the symbol σ) and one point chain lines, the movement of

(a)

12Z May 17 1982

12Z May 17 1982

(b)

the maximum temperature anomalies. Some peak positive anomalies over Hilo and Johnstone are of the order of σ at most. In the western Pacific, however, the peak values often exceed 2σ , in particular over Marcus Island (24.3°N , 154°E), on 18 remarkable warming occurred at the 30 mb level, the temperature anomaly by $+6.6^\circ\text{C}$ was observed, which was more than 5σ . Over Wake, Guam and Ishigakijima significant positive anomalies

Fig. 4. Daily temperature anomaly series from 17-year average (1964-1980) at the 30 mb level from Hilo to Ishigakijima. Dotted line indicates the standard deviation and one point chain line, the movement of a maximum anomaly.

Fig. 3. (a) A time variation of wind and temperature at the 30 mb level over Fukuoka during the first half of May 1982. An arrow with a flag indicates a wind speed of 5 m/sec and with a long line, 2 m/sec, with a short line, 1 m/sec respectively. (b) The vertical profiles of a temperature anomaly from the normal and backscattering ratio from lidar measurement which were observed May 17 at Fukuoka, Nagoya (Shionomisaki) and Tsukuba. Lateral bar means the standard deviation.

were also observed, which exceeded 2σ or 3σ respectively.

An average propagation velocity of a first peak anomaly from Hilo to Ishigakijima was about 14 m/sec and the second was about 10 m/sec.

These velocities agree relatively well with the velocity, 11.5 m/sec which was estimated from the movement of the El Chichon clouds in Robock's map between 9 and 15 April.

4. Time evolution of the abnormal temperature rise in the lower stratosphere.

4.1 Abnormal temperature rises in the lower stratosphere over the north subtropical Pacific.

Volcanic clouds that travel many times around the earth would undoubtedly influence the monthly mean temperature.

In this section, the standardized temperatures, $T' = (T - \bar{T})/\sigma_T$, are analyzed, where

T : monthly mean temperature

$\bar{T}$: normal of T

σ_T : standard deviation of T

The station normals and standard deviations were calculated from all available data up to 1980, that is, 30 years for Japanese stations and 17 years for the other stations. Fig. 5 shows height-time cross sections for standardized temperature anomalies at the stations in the north subtropical Pacific.

The cross sections at Hilo, Johnstone and Wake are similar to one another as shown in Fig. 5(a)–(c).

After the El Chichon eruptions, in the lower stratosphere (30 mb–50 mb), the temperature anomalies above σ_T appeared in the period May 1982 to January 1983. The maximum anomaly had a magnitude over $2\sigma_T$.

On the other hand, near the tropopause, a large negative anomaly was often found from July 1982 to April 1983.

In the midtroposphere the warmer anomalies with maxima ($2\sigma_T$ to $4\sigma_T$) were found from the end of 1982 to the beginning of 1983.

The significant statistical relation between SST in the north temperate Pacific and tropospheric temperature with four seasons lag in the summer season was found by Angell (1981). Accordingly, the warmer temperature anomalies in the midtroposphere may due to the remarkable El Niño-like event of 1982–1983.

In Fig. 5(d)–(f) the cross sections at Marcus, Chichijima (27.1°N, 142.2°E) and Minamidaitojima (25.8°N, 131.2°E) are shown.

They have the common characteristics of remarkable stratospheric warming, a tropospheric cooling, with some scattered sections of warming.

They have a common feature that the maximum anomalies near the 70 mb level in April were elevated up to the 20 mb level from August to September and monotonously declined toward the 100 mb level in March 1983.

Maximum anomalies had magnitudes between $2\sigma_T$ and $4\sigma_T$ at Marcus and Minamidaitojima; in particular at Chichijima the air layer between the 30 mb and the 20 mb levels was abnormally warmed up and the anomaly came up to more than $5\sigma_T$ in July at the 50 mb level, then was over $8\sigma_T$ at the 20 mb level in September.

The positive temperature anomalies near the 70 mb level January to March 1982 may be due to what the popular press call "Mystery Clouds". The clouds were observed by the lidar measurements at Fukuoka, Hawaii and Virginia (SEAN BULLETIN, Vol. 7, No. 3).

However the B.S.R. were about 4–5, which were less than that after El Chichon eruptions.

The origin of the clouds was not definitely identified but the best candidate appears to be Pagan volcano (18.1°N, 145.8E), where moderate explosive activity was reported in early January (SEAN BULLETIN, Vol. 7, No. 3).

The height changes of the densest volcanic cloud are shown for every latitude from 19.5°N to 37°N in Fig. 6.

At the M.L.O. (19.5°N), in early June, a

Fig. 5. (a) The height-time cross section for the standardized temperature anomaly at Hilo. (b) the same as (a) except for at Johnstone. (c) the same as (a) except for at Wake. (d) the same as (a) except for at Marcus. (e) the same as (a) except for at Chichijima. (f) the same as (a) except for at Minamidaitojima.

Fig. 6. The height changes of the densest volcanic clouds due to latitude from April to December 1982.

maximum B. S. R. was observed at the highest altitude (28.2 Km) and then gradually declined until early September, after which more slowly.

At Fukuoka (33°N), the aerosol-rich layer was highest in August and then linearly declined.

On the other hand, at Tsukuba (36°N) and Langley (37°N), a primary maximum height appeared at the end of June, declined gradually until the end of September. In early November the volcanic clouds reached a secondary maximum height.

Consequently, it is certain that the altitudes of the maximum temperature anomalies in Fig. 5(d)-(f) change in accordance with the height of the densest volcanic cloud at Fukuoka.

4.2 Northward diffusion of stratospheric aerosols and reduction of solar radiation.

Until August 1982 the volcanic clouds were confined to a relatively narrow range of latitudes from 0° to 30°N (Barth et al. (1983)), while after September it seems that they abruptly began to diffuse northward as the following studies show.

According to Uchino et al. (1984), the integrated backscattering coefficients measured at Tsukuba had a large scatter till July but the scatter becomes smaller and the intensities further increased in the autumn. And then they reached the maximum value in December and declined linearly with a narrow scatter from January to September 1983.

Yamauchi and Shimura (1984) made a deviation series from the 25-year (1959-1983) average of monthly turbidity factor at 14 meteorological observatories in Japan. At Naha (26.2°N, 126.5°E) it increased as early as in April over a standard deviation and reached a maximum with about twice the standard deviation in June.

At Yonago (35.5°N, 133.5°E), a maximum value exceeding twice the standard deviation was observed in June, temporarily declined in September, and reached a secondary maximum in December.

On the other hand, at stations north of Matsumoto (36.3°N, 137.5°E), first maxima were not so obvious and were observed in late August to September, secondary peaks being also late.

Thus the results of turbidity observation in Japan well correspond to the increasing tendency of the stratospheric aerosols detected by the groundbased lidar measurements in Japan.

In order to investigate how far the north influence of stratospheric aerosols extends, the radiation data in USSR were compiled.

Fig. 7 shows a time change of direct solar radiation which is represented by a ratio to the normal (hereafter referred to simply as the ratio). The normal was calculated from the radiation data observed every 10 degrees of the latitude zone for 1969-1979.

During this period large volcanic eruptions were relatively infrequent. 8-12 observation stations are included in every latitude zone located over the whole USSR.

Monthly maximum values of direct solar radiations were used as the radiation data. They are suitable for expressing direct solar radiation with less lower tropospheric

Fig. 7. Time change of the monthly maximum direct solar radiation ratio to the normal (1969-1979) in the latitude zones of 50°N-60°N and 60°N-70°N in USSR. N is the number of the measurement station included in each zone.

aerosols.

It may be permitted to adopt a reduction of the ratio under 90% as a threshold in the abnormal reduction of solar radiation.

For, according to Kimball (1918), the three great depressions under 90% in the ratio's curve followed the great eruptions of Krakatoa in August of 1883, of Pelee, Santa Maria and Colima in 1902-1903, and of Katomai in June in 1912.

Now, as Fig. 7 shows, in the latitude zone between 50°N and 60°N (Bottom), until September the ratio kept the level of about 95% but in October it decreased under 90% and in December went down to about 74%. At Vancouver, Canada (49.25°N), a monthly mean aerosol optical depth began to increase sharply in October 1982 (Hay and Darby (1984)).

In the higher latitude zone between 60°N and 70°N (Top), it suddenly declined under 80% in November.

Wendler (1984) showed a figure of direct solar radiation, sky radiation and global radiation for Fairbanks, Alaska (64.8°N, 147.9°W). After November 15, 1982, direct solar radiation suddenly decreased by about $200 \text{ W} \cdot \text{m}^{-2}$ (24.8%), while the percentage of diffuse radiation to the global radiation

abruptly increased by about 76%.

He stated that the substantial disturbances of solar radiation due to the El Chichon clouds began at that time.

Therefore, it may be estimated that the El Chichon clouds passed through 50°N latitude circle in October and through 60°N in November, and extended to the polar region at the end of 1982.

4.3 Height-latitude cross section of temperature anomaly.

In order to investigate a northward movement of a warmer temperature anomaly which may be caused from the volcanic clouds, the height-latitude cross sections of temperature anomalies along the 140°E Meridian were made for every month.

Fig. 8(a)-(d) show them every other month from May to November 1982. The monthly mean temperatures were transformed to the standard form as mentioned earlier.

The cross section covers from 10°N to 45°N latitudes and 1000 mb to 20 mb levels. In May 1982, a maximum anomaly was seen at the 30 mb level over Chichijima whose magnitude was more than $3\sigma_T$ and under the maximum layer (50 mb-70 mb), a slightly warm layer ($1.5\sigma_T > \Delta T > \sigma_T$) extended northward over the 35°N latitude and above the 30 mb level (about 24 Km), the anomalies were small positive or rather negative. The vertical distribution of the anomalies is well consistent with the relationship in Fig. 3(b).

A peak anomaly in May over Chichijima split into two altitudes; a warmer anomaly went down and the magnitude was more than $5\sigma_T$ at the 50 mb level, the other presented itself at the 20 mb level whose intensity was about $4\sigma_T$ in July.

On the other hand, another maximum anomaly appeared near the 30 mb level over the 40°N latitude and that some warmer anomalies covered a wide section.

It is likely that the anomalies were due to the volcanic clouds, because according to Yamauchi and Shimura (1984), a monthly mean turbidity factor observed at Miyako (39.6°N, 142°E) exceeded the standard devi-

Fig. 8. (a) The height-latitude cross section for the standardized temperature anomaly along the 140°E Meridian in May. (b) the same as (a) except for in July. (c) the same as (a) except for in September. (d) the same as (a) except for in November.

ation. However, nothing further is known owing to a lack of lidar observation.

It is interesting to note that the descent of an anomaly height coincides well with a height change of aerosol concentration at Fukuoka in July. (Fig. 6)

A maximum anomaly over Chichijima in July descended to the 70 mb level in September and decreased in magnitude and the secondary maximum over 40°N lat. almost disappeared.

A spectacular new anomaly (over $8\sigma_T$) was found at the 20 mb level and some warm anomalies extended northward. This may mean that a primary maximum anomaly before August might be mainly due to fine

volcanic ashes but they had settled down faster because of their large radius. After September, sulfuric acid gases from El Chichon were chemically converted to sulfate aerosols, which caused spectacular temperature anomalies by absorbing mainly terrestrial radiation from the warm ocean surface.

The northward extension of a warmer temperature anomaly at the 30 mb level in September still remained in November. Judging from declining tendencies of the direct solar radiation intensities in USSR (Fig. 7) and radiation measurements at Fairbanks, the El Chichon clouds in the lower stratosphere would pass through 60°N latitude in the middle of November.

The core of the warm temperature, however, still remained over the latitude zone between 25°N and 30°N in November. It went down from the 20 mb level to 70 mb. It appears that the dense volcanic clouds were diffusing north and southward but the main part of them stayed at that time over the subtropical region and were actively converted into sulfate aerosols and slowly settled down (Shah and Evans (1984)).

5. Stratospheric temperature anomalies in the El Niño events and Q. B. O. phases

A major warm SST occurred in the

Fig. 9. (a) The height-time cross section of the standardized temperature anomaly in the lower stratosphere in 1965-66. (b) the same as (a) except for 1972-73. (c) the same as (a) except for 1976-77.

eastern and central tropical Pacific during 1982-1983. It was said that the El Niño was perhaps the strongest in this century.

The positive SST anomalies, however, developed during the northern summer rather than the winter which has usually been the season for this process (Parker (1983)). In addition, the 1982-1983 episode was characterized by an unusually abrupt swing of the Southern Oscillations (Rasmusson et al (1983)).

Simpson (1983) also pointed out in connection with the warming in the California Current that equatorial El Niño events have appeared many times in the past, only few of them seeming to have affected the California Current System strongly. And the initial collapse of the equatorial easterlies occurred in May-June rather than in October-November (Simpson (1983)).

On the other hand, the past sensitivity studies for GCM with warm SST's over different parts of the equatorial Pacific consistently indicated the negative temperature anomalies in the lower stratosphere (Chervin et al. (1980), Keshavamurthy (1982) and Blackmon et al. (1983)).

In this study the annual variations of the stratospheric temperature anomaly from 17 years average (1964–1980) at Wake and Hilo were examined in the three considerable El Niño events.

Fig. 9(a) shows height-time cross section of standardized temperature anomaly in the lower stratosphere, 1965–1966.

The top is a case at Wake and the bottom, at Hilo. In both figures the anomalies reveal a small value or rather a negative one. The second and the third event appeared in 1972–1973 and 1976–1977, respectively. Fig. 9(b) as well as Fig. 9(c) shows the same tendency as Fig. 9(a). In the three remarkable El Niño events, large positive anomalies like those in 1982–83 could not be found and in the lower stratosphere rather cool anomalies were presented in the El Niño event. It agrees with the results simulated from the GCM mentioned above.

The El Niño episode during 1982–83 is probably different from the past typical El Niño episodes in the various aspects above.

Accordingly this episode should be called an El Niño-like event.

Holton and Tan (1980) composited monthly mean Northern Hemisphere 50 mb geopotential heights for a 16-year period (1962–1977) with respect to the phase of the equatorial Q.B.O. Following their Fig. 2 and Fig. 4, the difference of 50 mb heights due to westerly and easterly categories was hardly found in the subtropical zone lower than 30°N lat. It means that the Q.B.O. does not affect the temperature anomalies in the lower stratosphere over the northsubtropical Pacific Ocean.

6. Summary

(1) It is certain from the lidar observations, direct solar radiation intensity, the global location map of the El Chichon clouds and the unusual evening glows, that large amounts of volcanic aerosols from the El Chichon eruptions existed in the lower stratosphere over Japan after May 1982.

(2) Significant temperature rises were

found in the lower stratospheric layer of about 3 Km below the height of maximum B.S.R., which were observed at Fukuoka, Nagoya and Tsukuba in the southern part of Japan. It is considered that the significant warming in the lower stratosphere resulted from absorption of solar and terrestrial radiation by the dense volcanic clouds.

(3) The results of turbidity observation in Japan correspond well to the increase of stratospheric aerosols detected from the groundbased lidar measurements. In the southern part of Japan a maximum turbidity appeared in April to May, in the central part in June to July, and in the northern part in August to September.

According to the radiation data in USSR, in the latitude zone between 50°N and 60°N, the zonal mean ratio of direct solar radiation to the normal decreased to below 90% in October and in December went down to about 74%. In a higher latitude zone (60°N–70°N) it suddenly decreased to below 80% in November.

(4) The height-time cross section for standardized temperatures after El Chichon eruptions showed a warming in the lower stratosphere over the eastern and central parts of the north subtropical Pacific. The magnitude of anomaly was in the range between σ_T and $2\sigma_T$ at most, where σ_T indicates the standard deviation.

On the contrary, the maximum anomalies had magnitudes between $2\sigma_T$ and $4\sigma_T$ at Marcus Island and Minamidaitojima. In particular, over Chichijima the air layer between the 30 mb and the 20 mb level was abnormally warmed and the anomaly came up to more than $5\sigma_T$ in July at the 50 mb level. It was over $8\sigma_T$ at the 20 mb level in September. The altitudes of maximum warming over the western subtropical Pacific change in accordance with the height of the densest volcanic clouds at Fukuoka. (See Fig. 5(d)–(f) and Fig. 6)

In the eastern Pacific, due to major warm SST, there were so much convective clouds that volcanic clouds absorbed less terrestrial radiation.

(5) The height-latitude cross sections of temperature anomalies along 140°E Meridian were prepared for each month from May to November 1982. They showed that the core of warm temperature still remained over the latitude zone between 25°N and 30°N in November. The northern boundary of the warming was 35°N in May and then extended northward over 40°N in July. Judging from the declining tendency of direct solar radiation intensities in USSR, at Vancouver and at Fairbanks, the El Chichon clouds in the lower stratosphere probably reached the 50°N lat. in October and passed through the 60°N lat. in the middle of November.

(6) In the three remarkable El Niño events in the past (1965-66, 1972-73, 1976-77), no warming could be found in the lower stratosphere over the north subtropical Pacific, where rather the cooler anomalies were prevailing. These anomalies coincide with the results simulated from GCM. Therefore it is likely that the stratospheric warming after the 1982 El Chichon eruptions is not due to the 1982-83 El Niño-like episode. However, a significant midtropospheric warming at the beginning of 1983 over the eastern north subtropical Pacific may be due to the remarkable El Niño-like episode in 1982-83.

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1982年エル・チチヨン火山の爆発後の下部成層圏異常昇温

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1982年のエル・チチヨン火山の爆発のあとで北太平洋の亜熱帯の下部成層圏で異常昇温がみられた。30 mb 面の高温偏差はエル・チチヨンの火山雲とともに西方に流された。平年値からの有意な高温偏差がライダー観測による強い後方散乱比と同時に日本南部の各地で観測された。基準化された温度偏差 ($T' = (T - \bar{T}) / \sigma_T$) の高度-時間断面図には北太平洋の亜熱帯の東部および中部上空で $\sigma_T \sim 2\sigma_T$ の範囲の昇温が示された。一方、西部亜熱帯上空での昇温は驚くべきものであった。とくに、父島上空の 30 mb ~ 20 mb の間の気層は異常に暖められ、その最大値は7月の 50 mb 面で $5\sigma_T$ 以上、9月には 20 mb 面で $8\sigma_T$ にも達した。火山雲の北方への移動を調べるために、140°E 子后面に沿って平年値 (1964-1982年) からの気温偏差の高度緯度断面が5月から12月まで毎月作られた。

6月までは、高温偏差域は日本の上では 40°N 以南の地域に限られていたが、7月には 40°N 圏をこえて北へ拡がり、ソ連邦の直達日射量の月最大値の時間変化によると火山雲は10月には 50°N をこえ、さらに11月には 60°N を通過したことが分った。

最後に、過去3回の顕著なエル・ニーニョ現象のときの下部成層圏気温の偏差はいずれも 1982-1983年のような著しい昇温を示さず、むしろ負の偏差であった。従って 1982年のエル・チチヨン爆発後の下部成層圏の昇温は 1982-1983年のエル・ニーニョ現象が原因ではなかったと思われる。