NOTES AND CORRESPONDENCE

Change of the Surface Air Temperature Averaged over the Northern Hemisphere and Large Volcanic Eruptions during the Year 1951-1972

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1. Introduction

Effects of volcanic eruption on the climate have been argued by many scientists. Surface air temperature decrease due to volcanic eruption has been shown by studying the temperature records from a number of stations, together with some radiation computation (*e.g.* Humphreys (1940) and Lamb (1970)). While some scientists (Gentilli (1948), Deirmendjian (1973) and Landsberg and Albert (1974)) claim that no convincing evidence for climatic effect of volcanic eruption had been found. As Wexler (1951) had mentioned, thermal effect of the past volcanic dust is still not known quantitatively, because the world-wide data to determine the true surface temperature change averaged over the world were not available until the first half of this century. Some attempts of such spatial averaging have been made by Willett (1950), Mitchell (1961), Callender (1961) and Budyko (1969). Their results indicate the tendency of temperature lowering due to the volcanic eruption, although accuracy of such spatial mean is not sufficient for quantitative discussion of the effect, because of sparse network and/or spatial mean technique. Recent establishment of dense meteorological network and development of objective analysis technique of sparse network data make it possible to compute the spatial mean of temperature change more elaborately.

In the present paper, a preliminary result on change of northern hemispheric mean temperature

during the last two decades will be described with the aid of analysis technique of cubic spline under tension (Cline (1973)).

2. Method of analysis and data network

Hamming (1973) has recommended the spline technique for interpolation of sparse data, and the "objective analysis" by such a technique has been performed by several investigators (*e.g.* Fritsch (1971)). In the present paper a technique of cubic spline under tension for interpolation that Cline (1973) has developed for one-dimensional or two-dimensional data analysis are used. Application of the two-dimensional interpolation technique to the data of irregularly distributed station network, as is shown in Figs. 1a and 1b, gives a two-dimensional pattern at the interpolated grid points. To the grid points located within a specified latitudinal zone of small width (2°), one-dimensional interpolation is applied, and the values at points of each 5 degree longitude along the latitudinal circle are easily obtained.

The monthly mean surface air temperature at 343 stations illustrated in Figs. 1a and 1b are used during the period from 1951 to 1972. The temperature deviation from the 22 year-mean values are computed so that the analysis of the temperature anomaly reasonably eliminates the influence of station altitude. The zonal mean anomaly is furthermore computed at each 5 degree latitude from 10°S to 85°N , and the integration from the equator to 90°N gives the hemispheric mean anomaly.

Fig. 1 a: Maps of the location of stations (the black dots)

Fig. 1 b: the same as Fig. 1 a, except for the polar region.

3. Change of Northern Hemisphere mean temperature anomaly

Fig. 2 illustrates the monthly and hemispheric mean surface air temperature anomaly, where the short period fluctuations are smoothed out by 3-month moving average. Several apparent lowering of temperature are found out. Such a volcanic eruption since 1951 that the magnitude of ejection is greater than 0.07 km^3 and that the dust column clearly penetrated the tropopause are picked out. These are listed in Table 1,

Fig. 2: Monthly mean surface air temperature anomaly averaged over the Northern Hemisphere. 3-month moving averaged values are presented. The arrows indicate the time of volcanic eruption and maximum level of the dust column.

and illustrated in Fig. 2 together with the height of dust column. Associating with each eruption, negative anomaly of temperature with duration of 6 months or longer is noticed. Significant minimum appeared after each eruption with lag time 0.5 to 1 year. It may be permissible to interpret that this result shows the direct effect of large volcanic eruption.

4. Discussion

A meridional-time section of the zonal mean temperature anomaly is illustrated in Fig. 3, where the negative or positive anomaly greater than 0.5°C is shown. It is noted that the variability of temperature is clearly large at higher latitudes, that the temperature decreases are associated with large volcanic eruption, and that the magnitude of these temperature decreases are larger

Table 1 Large Volcanic Eruptions since 1953.

Date	Name	Latitude	Longitude	Height of Dust Column	Severity Class*	Authority
1953 July	Spurr (Alaska)	61°N	153°W	22 km	2	Lamb (1970) Mitchell (1970) Cronin (1971)
1956 March	Bezymianny (Kamchatka)	56°N	160.5°E	40~45 km	2	Lamb (1970) Mitchell (1970) Cronin (1971)
1963 March	Agung (Bali)	8.5°S	115.5°E	≥ 22 km	1~1/2	Meinel and Meinel (1963, 1964) Mitchell (1970) Deirmendjian (1973)
1965 Sept.	Taal (Luzon)	14°N	121°E	16~20 km	3	Moore et al. (1966)
1968 June	Fernandina (Galapagos)	0.5°S	92°W	22~24 km	2	Mitchell (1970) Simkin and Howard (1970)
1970 May	Hekla (Iceland)	64°N	19.5°W	16 km	3	Cronin (1971) Bull. Vol. Erup. 11 (1973)
1970 Sept.	Beerenberg (Jan Mayen)	71°N	80°W	15 km	3	Bull. Vol. Erup. 11 (1973)

* Severity Class defined by Sapper (1927) represents the order of magnitude of the total mass of material ejected.
Class 1: 10~1 km³ (10¹⁰ metric tons)
Class 2: 1~0.1 km³ (10⁹ metric tons)
Class 3: 0.1~0.01 km³ (10⁸ metric tons)

Fig. 3: Meridional-time section of monthly and zonal mean surface air temperatures, where the 7-month moving average is used in order to smooth out the short-period fluctuations. The negative (shaded) or positive anomaly greater than 0.5°C is only illustrated. Unit in °C.

at higher latitudes. The maximum value of lowering exceeds 1.5°C, *e.g.* in 1958 and 1965. However, the magnitude and time of temperature decrease are different from case to case. It may be natural to presume that the temperature decrease may depend on the magnitude and intensity of volcanic eruption, the geographic location of volcano, and the atmospheric circulation.

Rather detailed investigation of the global dust

spread is only the case of the Agung eruption in March 1963 by Dyer and Hicks (1968). Their result shows appearance of two peaks of the index at each latitude, which is assumed to indicate the spread of dust. Comparison with our result in Fig. 3 gives the following conclusions:

- (i) The first peak of the Dyer-Hicks index at higher latitude is nearly simultaneously associated with a remarkable negative anomaly of temperature in the summer 1964.
- (ii) While the second peak in the spring 1965 has negative anomaly not simultaneously, but with delay of about 10 months.

The latter negative anomaly may be perhaps caused by Taal eruption in September 1965. However, taking account of two negative anomalies associated with Bezymianny eruption in March 1956, we cannot reject the effect of Agung eruption to its anomaly in 1966. These two eruptions should be noted for their severity of the magnitude of ejection or the height of dust column respectively, in comparison with the remaining case, as is shown in Table 1.

5. Concluding remarks

The trend of monthly and zonal mean surface air temperature in the present work agree well with the corresponding result by Starr and Oort (1973), although the latter is for the period from 1958 to 1963.

In the present paper, it is concluded that a lowering of temperature appears after a large volcanic eruption with more lowering at higher latitude. For the exceptionally severe eruption, another temperature decrease occurs about 18 months later from the first temperature minimum. The fact that the time interval between the eruption and temperature decrease is different from case to case may be probably related to difference of season of eruption, geographical location of volcano, height of dust column and optical property of dust. As future problems to be solved, we are interested in detailed analysis of the atmospheric general circulation, and how much the surface air temperature over the Southern Hemisphere changed in comparison with that of the Northern Hemisphere, although the computation is not so easy because of quite sparse network of the Southern Hemisphere.

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1951-1972 年における北半球地上平均気温の変化と火山大噴火

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