Climatology

EL CHICHON PROVIDES TEST OF VOLCANOES' INFLUENCE ON CLIMATE

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1. INTRODUCTION

The 4 April 1982 eruption of El Chichon volcano in Mexico reminds us of the potential for relatively small volcanic eruptions which are rich in sulfur gases to have a large impact on climate. While El Chichon was not as powerful as the Mount St. Helens' eruption of 18 May 1980, it produced the highest and probably most massive stratospheric dust cloud of any volcano this century, and climate model simulations show that it will therefore have a large cooling effect at the earth's surface. Most of the energy of the Mount St. Helens' eruption was used to blast away the north side of the mountain, and while this produced a lot of tropospheric dust with large short-term effects on surface air temperature, not to mention on the people and landscape of the surrounding area, it had an inconsequential effect on climate. By studying these and other volcanic eruptions, we are beginning to understand how they, and past and future volcanic eruptions, can cause the climate to change.

In this paper the El Chichon dust cloud will be described first, showing the many ways it is being observed. Then the Mount St. Helens' eruption will be discussed, showing its large effects on surface temperature. Next the influence of volcanoes on climate for the past 400 years will be described using a numerical climate model simulation to show how large these effects have been, especially compared to possible sunspot effects. Finally, the El Chichon effect on climate, simulated by a numerical model will be presented. If we wait a few years we will then see how accurate these predictions are.

2. THE EL CHICHON DUST CLOUD

Following three smaller eruptions on 29 March and 3 April 1982, El Chichon produced its biggest bang on 4 April, sendng massive amounts of dust and sulfur gases into the stratosphere. The resulting cloud, which was densest at a height of 26 km, traveled westward, circling the globe in 21 days at a mean speed of 22 m/s (2). The daily location of the dust cloud is shown in Figure 1 for this period. The cloud quickly spread to occupy the latitude band between the equator and 30°N, and then slowly spread further, so that by the end of 1982 it was located at about 10°S to 35°N. Numerous satellite, balloon, airplane and surface observations were made of the cloud, as shown in Figure 2. Vertically pointing lidar was particularly useful in locating the cloud, giving the height and concentration. The U-2 and WB-57 NASA research airplanes were only able to reach the lower 20 km portion of the cloud, probably caused by the 29 March eruption, which was much less dense than the main 26 km cloud. Only balloons were able to sample the main cloud.

It is interesting that several of the most useful measurements of the volcanic cloud were inadvertent -- the result of the cloud interfering with measurements that the instruments were supposed to be taking. NOAA started a program to measure sea surface temperatures (SST) with the NOAA-7 satellite just a few months before the eruption, but the dust cloud blocked some of the outgoing radiation, resulting in negative anomalies of satellite measured SST as compared to ship and buoy measurements at the surface. The pattern of anomalies allowed the dust cloud to be tracked. An instrument on Nimbus-7 designed to measure total ozone amount by looking at the ultraviolet albedo got anomalous readings from the sulfur dioxide gas in the eruption cloud, allowing a calculation of the total sulfur dioxide content. The Solar Mesosphere Explorer (SME) satellite also picked up readings from the El Chichon dust in short and long waves as it attempted to measure other gases in the stratosphere.

Large particles put into the atmosphere by a volcanic eruption fall out very rapidly, within a month, and so do not have long-term effects, but if the volcano puts massive quantities of sulfur rich gases into the stratosphere, these gases slowly convert to sulfuric acid particles. The sulfuric acid particles are small and very bright, so they last a long time, on the order of several years, and reflect and scatter large amounts of sunlight. They, therefore, can produce long-lasting effects, some of which have already been observed. Measurements of stratospheric temperatures taken after the eruption show a warming of several degrees Celsius. This is due to another effect of the particles -- absorption of long and short wave radiation. Brilliantly colored sunsets have been observed in many locations in the Northern Hemisphere during 1982 as a result of the scattering by the dust. Measurements of radiation received at the surface show large decreases due to the dust, of more than 7% of the total clear sky radiation in June at Hawaii. And these effects are projected to cause significant cooling at the surface, as discussed later. More details on the observations of the El Chichon cloud can be found in Robock (3).

3. MOUNT ST. HELENS' EFFECTS ON TEMPERATURE

Volcanoes can have large short-term effects on surface temperature as shown in a study of Mount St. Helens (4 and 5). In this study, the location of the dust cloud from Mount St. Helens, as seen in GOES satellite pictures, was compared to surface temperatures in the Northwest United States. We compared surface temperature on the day of the eruption with the previous day's temperatures, since the area was dominated by high pressure and the changes could be attributed to the dust. We also looked at errors of the Model Output Statistics (MOS) forecasts, as these were the best guess of what the temperature would have been without the eruption. It was found that during the daytime, surface air temperatures were as much as 8°C cooler under the dust cloud, and at night as much as 8°C warmer under the cloud (Figures 3-5). These effects were caused by dust filling the troposphere during the day after the eruption. Very little sulfur gas got into the stratosphere, however, preventing large climate effects.

4. VOLCANO INFLUENCE ON CLIMATE OVER THE PAST 400 YEARS

During the past 400 years, volcanoes have been the major cause of changes in Northern Hemisphere surface temperature. Figure 6 gives estimates of the stratospheric loading of volcanic dust for this period. Figure 7, from Robock (6), shows a climate model simulation using these data as forcing compared to observations and other model runs for the period. The climate model used in these experiments is an energy-balance numerical model with 15-day time steps on an 18 by 2 grid, that is 10 degree latitude bands with separate boxes for land and ocean. Incoming and outgoing radiation are considered in detail and horizontal energy transports by the atmosphere and ocean are parameterized. The model is described in detail by Robock (7). The volcano simulations were found to be highly correlated with the actual climate change, but forcing with sunspots gave an uncorrelated curve. The bottom curve gives an idea of how much climate change could be expected from purely random unpredictable atmospheric behavior.

Robock (8) simulated the eruption of El Chichon with the same climate model and looked at the latitudinal and seasonal distribution of the climate response. Figure 8 gives the annual average results, showing that the Northern Hemisphere has a faster and larger response, due to more dust in this hemisphere combined with less ocean surface to delay the response. Other climate model simulations have given similar results. El Chichon means "lump on the head" in Spanish, and we can now wait several years to see if we deserve chichones for this prediction.

ACKNOWLEDGMENTS

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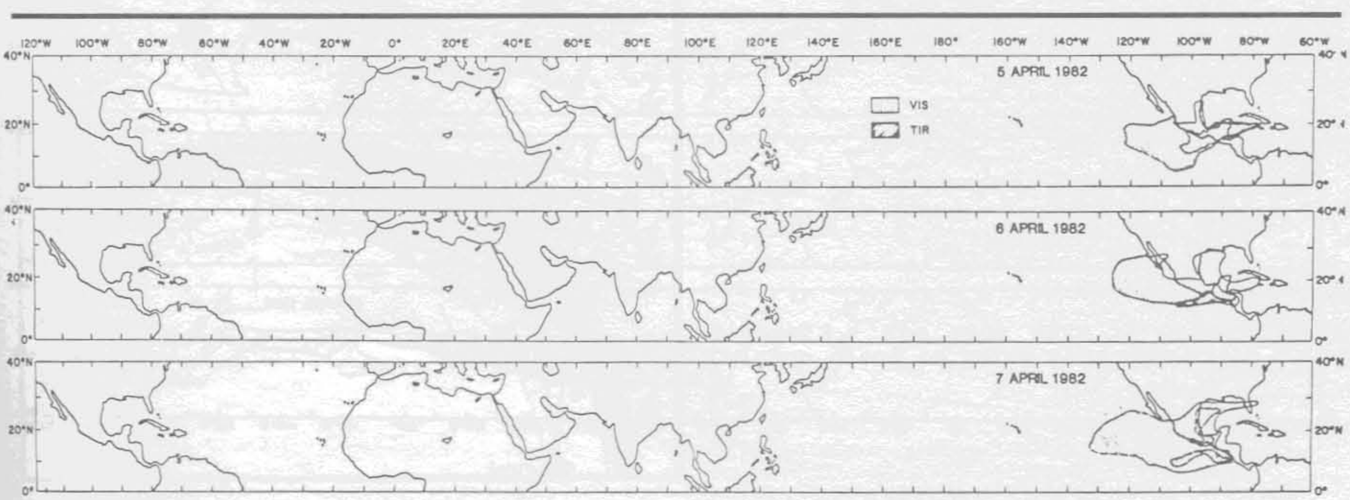

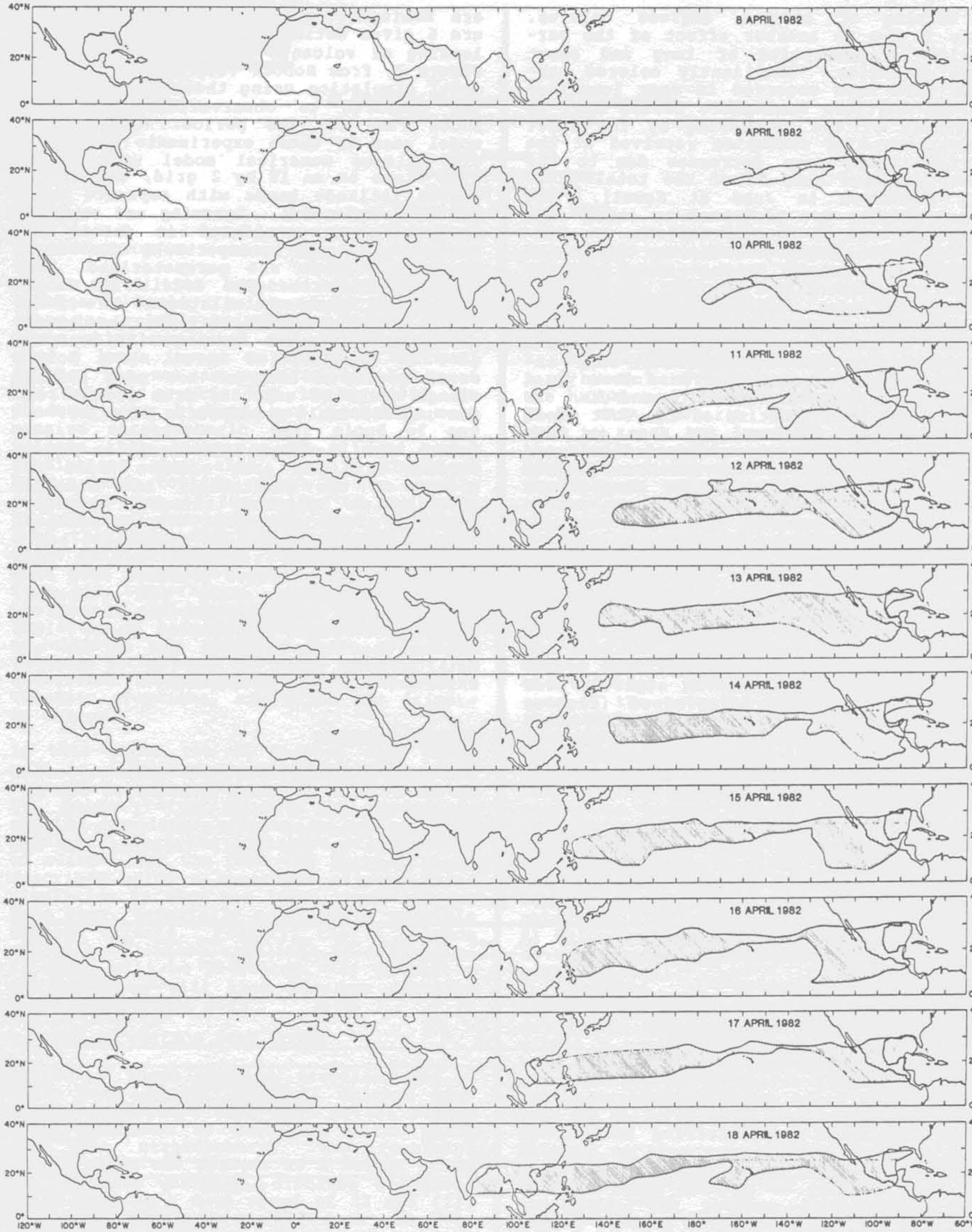
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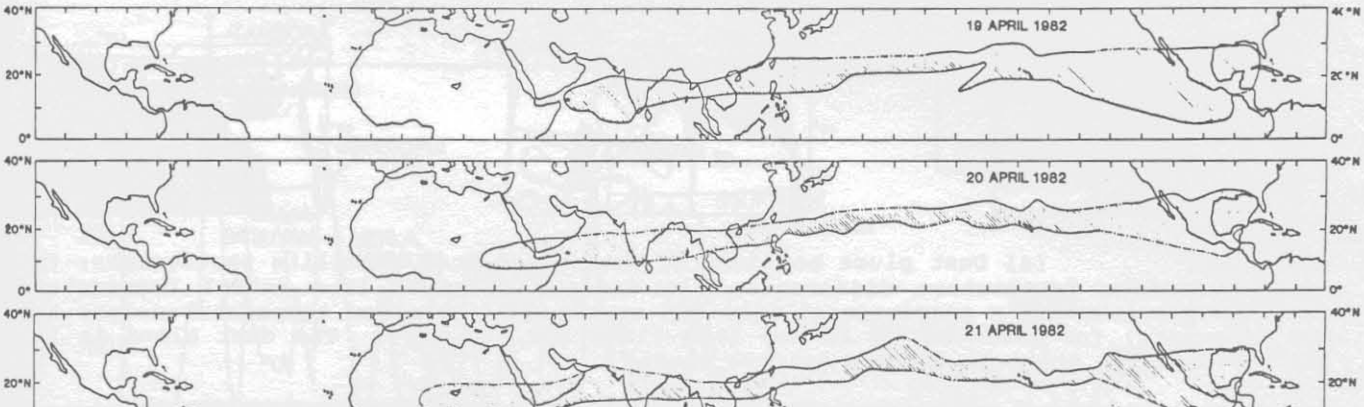


Figure 1. The location of the dust cloud from the El Chichon eruption as observed with visible (VIS) and thermal infrared (TIR) imagery. Portions of the cloud to the right of 180° are plotted at 00 G.M.T. Portions to the left of 180° are plotted at 3 p.m. local time. Dash-dot lines indicate difficulties in observing the exact location of the edge of the cloud.

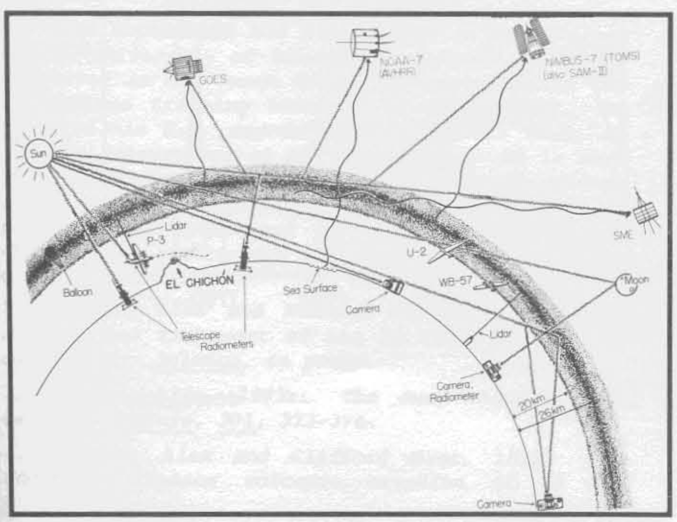


Figure 2. The many ways in which the El Chichon cloud is being observed.

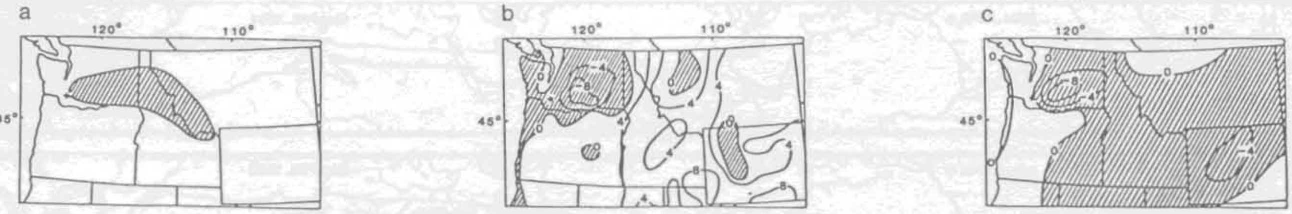


Figure 3. (a) Dust plume boundary as determined from satellite photographs; (b) 24-hour surface temperature differences (in degrees Celsius) (the actual temperature less the previous day's temperature); (c) MOS errors (the observed temperatures less the MOS forecasts) for 0000 GMT on 19 May 1980 (1600 PST, 18 May). The dust cloud in (a) and the negative areas in (b) and (c) are shaded.

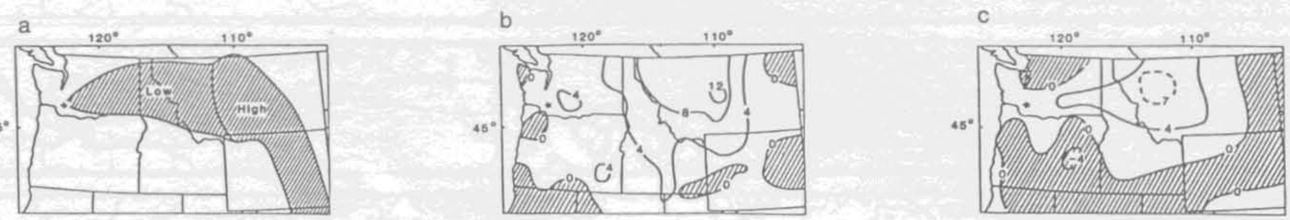


Figure 4. Same as Figure 3, but for 1200 GMT (0400 PST) on 19 May 1980. "Low" and "High" in (a) refer to cloud heights.

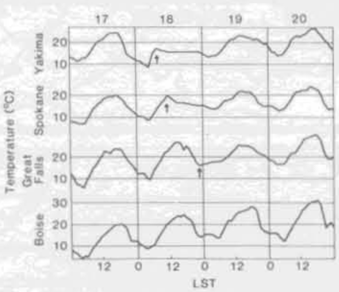
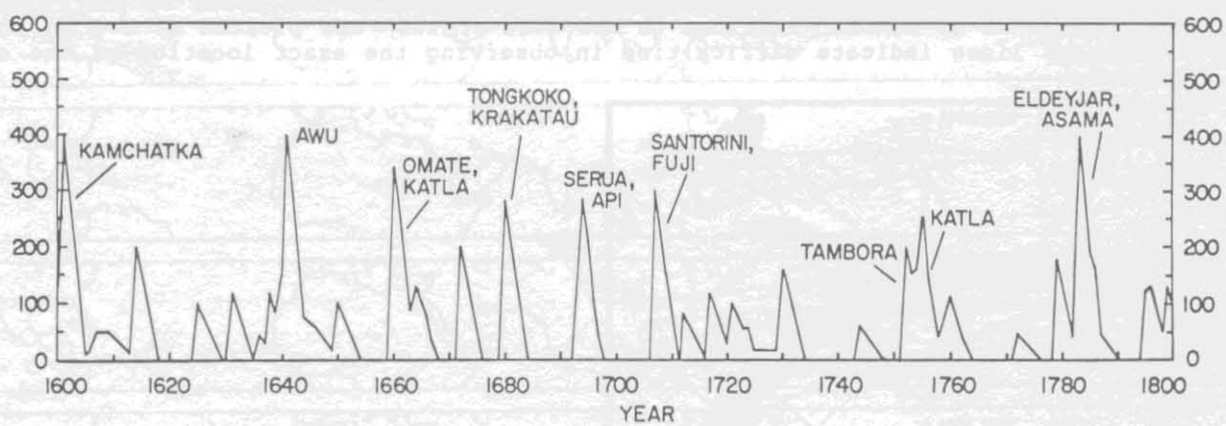


Figure 5. Surface temperature variation from 17 through 20 May 1980 at Yakima and Spokane, Washington; Great Falls, Montana; and Boise, Idaho. The arrows indicate the times of arrival of the Mount St. Helens' plume. (LST, local standard time).



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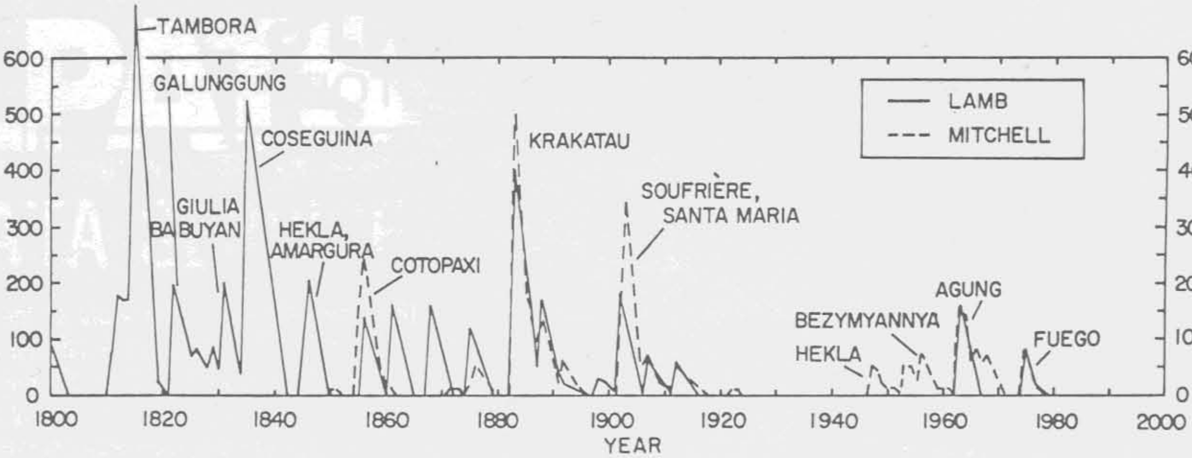

Figure 6. Northern Hemisphere annual average volcanic dust loading, from Robock (1978).

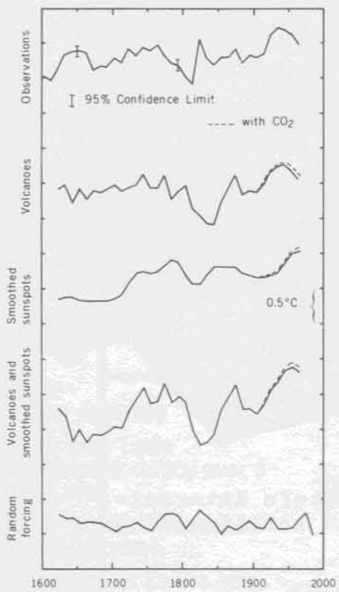

Figure 7. Northern Hemisphere average surface temperature observations and climate model calculations, shown as 10-year averages.

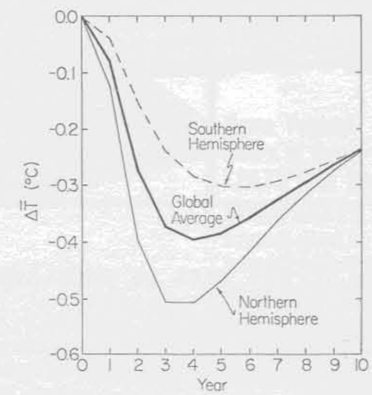

Figure 8. Annual average response to El Chichon eruption. Year 1 is the year of the eruption, 1982.

REFERENCES AND FOOTNOTES

1. Alan Robock got his B.A. degree in Meteorology at the University of Wisconsin, Madison, in 1970. He served in the Peace Corps for two years in the Philippines training teachers of meteorology. He received his S.M. degree in 1974 and his Ph.D. in 1977 in Meteorology at MIT, Cambridge. He is currently involved in research in climate change using numerical modeling and data analysis. He is particularly interested in surface temperature changes and interaction of snow and ice with the climate system.

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