El Chichón eruption

The dust cloud of the century

from Alan Robock

THE 4 April 1982 eruption of the El Chichón volcano in Chiapas state, Mexico, produced a stratospheric dust veil that is higher and probably more massive than any this century. Local temperature increases in the stratosphere of more than 5°C have already occurred and a cooling of about 0.5 °C is expected at the Earth's surface. The high sulphur content of the volcanic gases, and subsequent conversion to small, bright, long-lasting sulphuric acid particles, ensures that the effects will be large and continue for several years.

The vast array of observations being taken from the ground, aeroplanes, balloons and satellites (see the figure) will ensure that it is the best observed and monitored volcanic cloud ever. The eruption has provided meteorologists with an unprecedented opportunity to test theories of gas-to-particle conversion, stratospheric transport and settling of dust particles, radiative interactions of dust particles and resulting changes of stratospheric and surface air temperatures. At two recent meetings* scientists discussed the continuing evolution of the dust cloud and its climatic significance. Attention focused on the following topics: the three-dimensional location of the cloud, the changing gaseous and particulate composition of the cloud, observations of possible weather and climate effects, and theoretical models of the above processes.

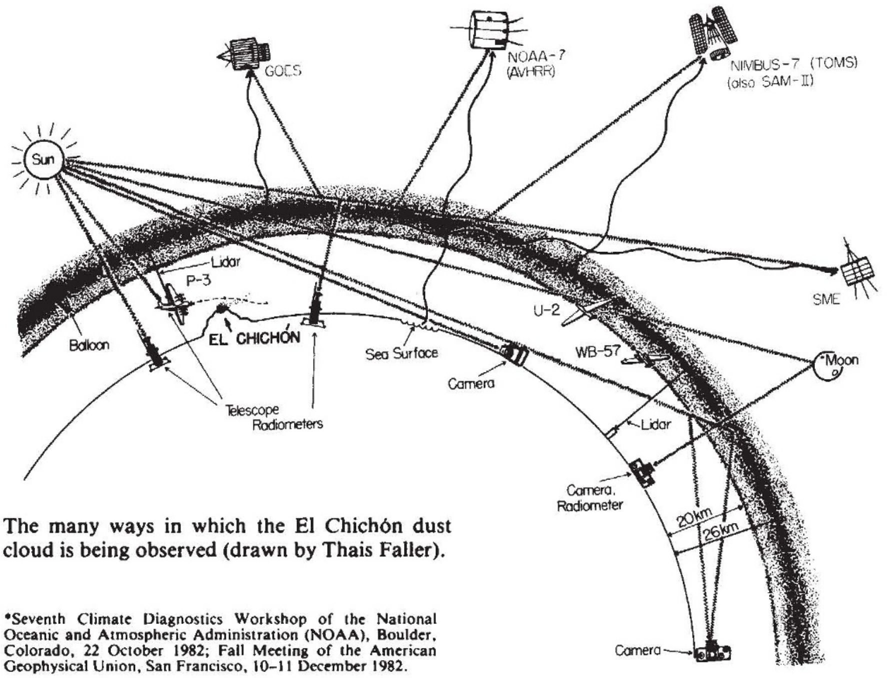
Using images from the GOES and NOAA-7 weather satellites, M. Matson (NOAA) described the sequence of the eruptions. The first occurred on 29 March (GMT) and probably produced a small stratospheric cloud at a height of about 20 km. Measurements of the thermal IR emissions from the cloud allowed estimates to be made of temperature and comparisons with nearby radiosonde measurements of the atmospheric temperature profile then allowed estimates of height. Comparisons of the direction of motion of the cloud with winds at different levels confirmed a stratospheric component moving towards the south-west. Two smaller non-stratospheric eruptions on 3 April were followed by the large eruption on 4 April which produced the massive stratospheric cloud later shown to be densest at about 26 km. A. Krueger (NASA) also observed the initial eruption sequence, using the Total Ozone Mapping Spectrometer (TOMS) on the Nimbus-7 satellite. Anomalous ozone measurements turned out to be the UV signature of sulphur dioxide gas in the eruption cloud and allowed him to track and measure the total sulphur dioxide.

Matson and A. Robock (University of Maryland) used the weather satellites to track the visible image of the dust cloud as it travelled due westwards, completely circling the globe in 21 days at a mean speed of 22 m s^{-1}. That it could be seen for this long on satellite photographs indicates just how massive the cloud was. The Mount St Helens cloud, in contrast, could only be followed for 3 or 4 days after the eruption. R. West (University of Colorado) found identical results from observations of scattered sunlight taken with the limb-scanning visible spectrometer on the Solar Mesosphere Explorer (SME) satellite.

Fortunately, the densest part of the 4 April cloud went right over Hawaii, arriving on 9 April, allowing many different surface measurements of the cloud. Hawaii is one of a few places in the world with vertically pointing lidar facilities. Lidar (acronym for LIght Detection And Ranging) works similarly to radar, but sends up a laser light pulse and uses a telescope to measure the timing and intensity of the light scattered back from particles in the atmosphere. K. Coulson (Mauna Loa Observatory) reported that the Hawaii lidar measured the highest and largest cloud ever seen, with backscatter ratios (total to gaseous) of over 200. The 'mystery cloud' which came from an as yet unidentified eruption early in 1982 had, by contrast, backscatter ratios of about 3 at the most. The lidar saw finely structured layers of particles with a small peak at about 20 km and the large peak at 26 km, but with some dust over 30 km. Later measurements showed reduced backscatter ratios at the peak, but larger values above the peak and less structure to the layers, indicating continuing particle formation and horizontal diffusion. Other lidar measurements, made around the world, allowed the latitudinal spread and total amount of the cloud to be monitored over time.

It also became possible to locate the El Chichón cloud becaused it blocked some of the outgoing long-wave radiation being measured in a new programme designed to investigate global sea-surface temperatures (A. Strong, NOAA). The differences between the satellite sea-surface temperature measurements and ship and buoy measurements at the surface gave maps of the volcanic cloud's location and relative thickness. Other measurements from the SME satellite in longer-wavelength bands (G. Thomas and R. Sanders, University of Colorado) also showed the vertical and horizontal extent of the cloud. In addition, McCormick reported measurements of the cloud over the polar regions with the SAM II instrument on the Nimbus-7 satellite, and R. Keen (University of Colorado) used observations of lunar brightness during an eclipse to infer the latitudinal distribution of the dust. *In situ* balloon measurements of particle density in the cloud, discussed by D. Hofmann (University of Wyoming), also located the cloud.

Except for the SME results in visible wavelengths, all the above measurements showed that the upper cloud quickly spread, occupying the latitude band between the equator and 30°N after 2 months, and then spread very slowly to the north and the south so that it now occupies a band from about 10°S to 35°N. The lower 20 km cloud has probably spread to completely cover the globe. The SME visible results showed particles to above 40 km in the Northern Hemisphere and large concentrations in the Southern



The many ways in which the El Chichón dust cloud is being observed (drawn by Thais Faller).

*Seventh Climate Diagnostics Workshop of the National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado, 22 October 1982; Fall Meeting of the American Geophysical Union, San Francisco, 10–11 December 1982.

Hemisphere that were not observed by any other means. The reasons for these discrepancies are not yet understood.

It has become accepted, as pointed out by S. Self (Arizona State University) and B. Toon (NASA), that sulphur gas content is the important factor determining the long-term climatic effects of eruptions that place material in the stratosphere. Silicate particles are large, fall out rapidly and have only a short-term effect. Sulphur gases, on the other hand, are converted to sulphuric acid particles which are very small and thus have a long mean residence time in the stratosphere — around 2 or 3 years. The particles are very bright and have a large effect on the amount of solar radiation received at the Earth's surface by scattering several per cent of the radiation back to space. It is therefore important to measure the silicate to sulphur ratio of the particles and the concentrations of the sulphur gases that are precursors to the particles, as functions of time and space.

Several NASA research aeroplane flights reached heights of about 20 km and were able to sample the lower cloud, and samples were also taken of gases currently being emitted by the volcano. Only balloon flights were able to take samples from the main 26 km cloud. High-altitude aeroplane collections have been examined by scanning electron microscopy and show silicate particles with distinct sulphuric acid pitting. Energy-dispersive X-ray spectrometer analysis of the particles showed sulphur was a significant component. Particles collected by balloon from within the main cloud were at least 95 per cent sulphuric acid. Krueger measured only 3.3 million tons of sulphur dioxide with the TOMS instrument in the eruption cloud on 6 April, but calculations of the total mass based on later observations of the dust particles suggest that more sulphur gas should have been put in by the volcano. Carbon sulphide was not found by the high aeroplanes, but recent samples made at the volcano showed emissions rich in hydrogen sulphide. If the actual eruption cloud had the same composition, then it would take some time for the hydrogen sulphide to convert to sulphur dioxide and then to sulphuric acid particles.

Radiative effects of the dust cloud were seen in ground measurements of incoming solar radiation and optical effects in the sky as well as satellite measurements of the Earth's radiation budget. B. Mendonca (NOAA) and E. Yasukawa (Mauna Loa Solar Observatory) reported that the direct solar radiation at Hawaii was reduced by more than 20 per cent and the total by more than 7 per cent. These are the largest reductions of direct solar radiation ever observed there. J. DeLuisi (NOAA), W. Lockwood (Lowell Observatory) and B. Herman (University of Arizona) all used radiation measurements to estimate the particle size distributions of the cloud. DeLuisi calculated optical depths of the cloud and estimated that its total was about 15 million tons.

The radiative effects of the dust cloud and resulting surface air temperature changes were modelled by R. Turco (R&D Associates), J. Pollack (NASA), F. Luther (Lawrence Livermore National Laboratory) and Robock, each using different types of climate models. All showed cooling, in fair agreement with each other. Robock's model gave time-dependent latitude-dependent results, predicting Northern Hemisphere average cooling of about 0.5 °C during 1984 and 1985 with the effect becoming less after that. Local stratospheric warming of more than 5°C has already been observed (J. Angell and R. Quiroz, NOAA; McCormick). It is difficult, however, to separate the signal from the normal quasi-biennial temperature variations in the stratosphere that are of about this amplitude. Strong made a controversial suggestion that the warming was responsible for a weakening of the Hadley cell circulation, resulting in anomalously warm equatorial Pacific sea-surface temperatures and hence affecting the winter climate of North America. His idea is intriguing, but remains to be proved. A model proposed by L. Capone (San José State University) suggested that large anomalies in the stratospheric circulation induced by the warming would explain the high altitude of the cloud as well as its slow spread northwards. El Chichon in Spanish means 'lump on the head', and I am sure the modellers, myself included, will be prepared to accept our chichones should our results prove faulty. □

Alan Robock is an Associate Professor in the Department of Meteorology, University of Maryland, College Park, Maryland 20742.

Immunological diversity

How the elephant got its trunk

from Elizabeth Simpson and Michael Pope

A PAPER in this issue of *Nature*[1] (p.388) presents some of the first evidence that gene conversion or homologous recombination may be used to generate a part of the striking polymorphism of transplantation antigens.

Multicellular organisms must distinguish between self and non-self in order to deal with viruses and other harmful foreign invaders. In mammals the immune system has evolved complex defence mechanisms which centre round the activities of B and T lymphocytes. B lymphocytes produce antibodies which bind specifically to foreign determinants (antigens) whereas T lymphocytes recognize antigens only when they are presented together with self, class I or II molecules of the major histocompatibility complex (MHC). Almost all cells of the body have on their surfaces class I MHC molecules; these tissue antigens are also the most important in triggering graft rejection when tissues of one individual are transplanted into a non-identical individual of the same species.

A striking feature of class I MHC molecules is their extraordinary polymorphism — in the mouse there are at least 100 alleles at the principal class I loci. Such polymorphism almost certainly has selective advantage for the species. It has been a matter of speculation, though, as to how this polymorphism arises at the gene level. One hypothesis was that each individual possessed copies of genes for all possible 'alleles' found in the species but that expression was selective. This possibility has been rendered unlikely by the finding that there are too few genes at the principal class I loci (*H–2K*, *D* and *L* in the mouse).

Another possibility is that of gene conversion, by which exons of adjacent homologous genes are recruited into the expressed gene. Analogies exist in bacterial[2], lower eukaryotic[3] and viral systems[4].

Evidence consistent with such a mechanism comes from recent findings of Mellor *et al.*[5] who have cloned and sequenced $H\text{–}2K^{b}$ and mutant $H\text{–}2K^{bm\text{-}1}$ molecules and found fairly extensive DNA sequence alteration in the mutant sequence, suggestive of gene conversion rather than point mutation at the DNA level. The work reported in this issue[1] shows that isolated partial class I DNA sequences can be inserted and expressed by cellular DNA. DNA clones containing only the first three exons of either a K^d or L^d gene (the complete gene includes eight exons), were inserted into L cells which then expressed complete K^d or L^d molecules on their surfaces, presumably by utilizing their own homologous exons 4–8.

Perhaps class I MHC genes commonly use such gene rearrangements to guarantee their remarkable genetic diversity and possibly this reflects a general strategy by which other polymorphic gene clusters may produce their variability. □

Elizabeth Simpson is in the Transplantation Biology Section and Michael Pope in the Clinical Sciences Division of the Clinical Research Centre, Watford Road, Harrow, Middlesex HA1 3UJ.

1. Goodenow, R.S. *et al. Nature* **301**, (1983).
2. Radding, C.M. *Rev. Biochem.* **47**, 847 (1978).
3. Stahl, F.W. *Genetic Recombination* (Freeman, San Francisco, 1979).
4. Winocour, E. & Keshet, I. *Proc. natn. Acad. Sci. U.S.A.* **75**, 1929 (1980).
5. Varmus, H.E., Quintrell, N. & Ortiz, S. *Cell* **25**, 23 (1981).
6. Mellor, A. *et al. Nature* (in the press).