Red Sky at Night

As the dust cloud from El Chichón envelops the globe, scientists are delighted by what they see as a natural experiment in atmospheric chemistry

*"One marvelous effect is often a sudden appearance of thick luminous haze where a minute before all was pellucid, unsullied blue. Meantime the glow especially gathers and deepens above the western horizon along a line of 60 degrees until the whole occident is a uniform sheet of flaming crimson, shading up into lilac and orange. Down upon that creeps the dark earth-shadow, sharply cutting off the edge of the blazing sheet, often serrated with the shadow of remote cumuli. As the shadow descends, the glow deepens, until night has closed down upon it. At once on the darkened sky arises a secondary or 'after-glow,' repeating the same phenomenon as the stars come out with almost equal brilliancy of effect."**

S. E. Bishop, 1884

Aden and Marjorie Meinel

A "secondary" or after-glow illuminates the sky over Tucson as light after sunset is reflected by stratospheric particles injected by El Chichón.

By CHERYL SIMON

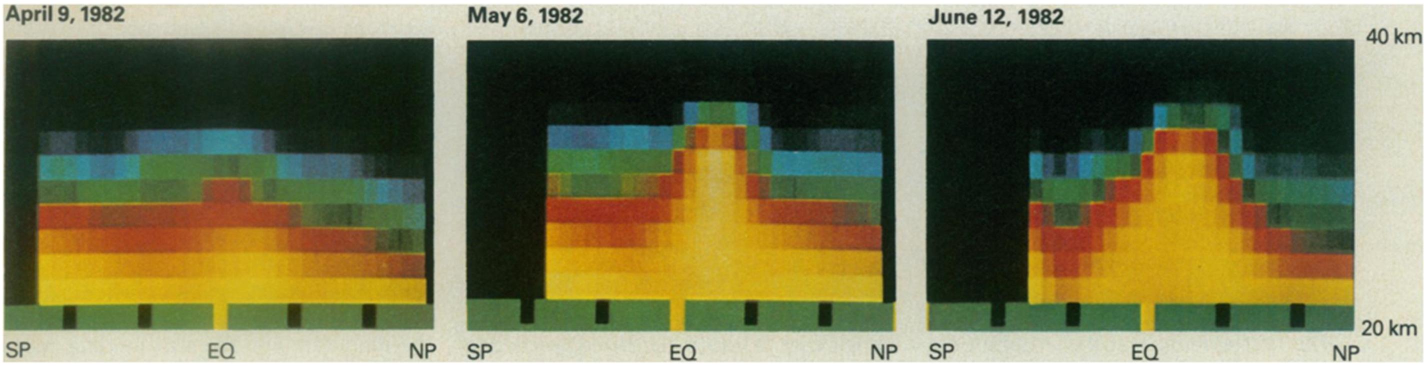
The sparkling blue skies typical of summer days in Tucson instead are "mushy white, what you in the East would call haze," observes Marjorie Meinel of the University of Arizona's Optical Sciences Center. But at intervals, she says, residents are treated to brilliant twilight minuets of cloud and color, such as those that followed the eruption of Krakatoa in 1883. The recent sky-show is a legacy of a little-known volcano called El Chichón on Mexico's Yucatán peninsula. In its first eruptions in recorded history, the volcano burst into action March 28, building quickly to an explosive crescendo April 4 when a great stream of sulfur-rich ash and gas was launched high into the earth's stratosphere (SN: 5/15/82, p. 326). Eventually, the cloud's gaseous tendrils will cover the entire Northern Hemisphere.

Except for some astronomers who grumble that stellar observations are obscured, scientists seem delighted that nature has provided the volcanic cloud — essentially a colossal experiment in atmospheric chemistry. They don't know how much material the volcano injected into the stratosphere, or what its effects will be on ozone, sea surface temperature, global air temperature or climate. They do know that at last they have a chance to test and refine some of their theoretical models, and to learn, in at least one instance, how the atmosphere responds when a huge quantity of particles is introduced.

Though it is far too soon to evaluate the ultimate effect of the volcanic cloud, scientists agree that the infusion of particles, or aerosols, almost certainly will affect climate and the earth's radiation budget. Researchers hypothesize that such events as changes in solar luminosity, substantially heightened levels of atmospheric carbon dioxide, or thermonuclear explosions also could be powerful vehicles for climatic change.

"There are hundreds of papers written theoretically about what these things

*"The Eruption of Krakatoa, and Subsequent Phenomena; Report of the Krakatoa Committee of the Royal Society," Ed. by G.J. Symons, London, Trübner & Co., 1888.



might do to the climate, but there are no opportunities for us to find out experimentally what really happens," says Brian Toon of NASA Ames Research Center in Moffett Field, Calif. "This is really the first time in modern meteorology that something has happened that has the potential to affect the climate. If all those models do work, it will give us a lot more confidence working on all those other problems."

Toon predicts that over the Northern Hemisphere the cloud will induce gradual cooling of between 0.3°C and 0.5°C over the next few years. Such a change would be large enough to be distinguishable from normal temperature fluctuations but probably too small to have much effect on life-styles.

Some other scientists are more conservative in their estimates but most anticipate a discernible lowering of temperatures. The reason is that the volcano pumped particles high into the atmosphere, far above the reach of efficient cleansing mechanisms such as normal cloud formation. Clouds usually form between altitudes of about 2 kilometers to 14 km. In the El Chichón cloud, the tiniest ash particles — those less than 1 micrometer — have no way of getting back out of the atmosphere other than slow gravitational settling, explains Murray Mitchell, a climatologist with the National Oceanic and Atmospheric Administration in Rockville, Md. (The largest bits of ash probably have fallen out by now.) Abundant sulfur dioxide remains, he says, to combine in the presence of sunlight with water vapor to form sulfuric acid particles. This process is limited by the scant water vapor available at high altitudes, and may take several years.

In the meantime, the aerosols in the cloud act as a thick veil that meddles with the earth's radiation budget. The particles absorb a little of the infrared radiation — heat in the invisible part of the spectrum — that the earth sends out to space. They also absorb and scatter back to space incoming visible light that ordinarily would warm the earth's surface. The net effect may be a slightly warmer stratosphere ... but a cooler earth.

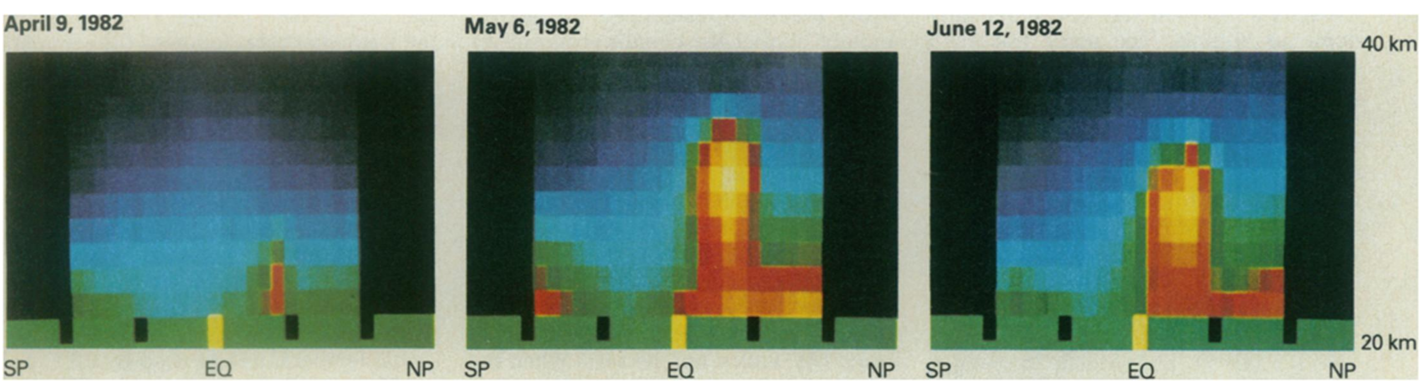
A growing contingent of scientists is joining an informal, international effort to track the effects and movements of the El Chichón cloud. Their tools are satellites and instruments designed for quite different purposes. In many cases it is data collected inadvertently while measuring other phenomena that enable them to observe the cloud as it changes and disperses on its journey around the globe.

Like many of the cloud-watchers, when the volcano erupted, Charles Barth and colleagues at the University of Colorado in Boulder were studying another problem — what causes changes in the earth's ozone. Using a National Aeronautics and Space Administration satellite, the Solar Mesosphere Explorer (SME), they measure the effects of solar ultraviolet radiation on photochemistry in the mesosphere, that part of the earth's atmosphere between 55 km and 80 km above the earth. This is the region where ozone is most susceptible to changes, Barth says.

The researchers find they also have collected measurements of the cloud over a number of wavelengths, providing information about the ability of aerosols to scatter light and absorb radiation.

Key: SP South pole
EQ Equator
NP North pole

Laboratory for Atmospheric and Space Physics/Univ. of Colo.



False color images taken over Western Europe by the polar-orbiting NASA satellite, the Solar Mesosphere Explorer, show that the injection of particles by El Chichón has radically affected the atmosphere's normal scattering properties between 20 and 40 kilometers above the earth's surface. Above: SME measurements of scattering in the blue region of the visible spectrum (incoming solar radiation). By April 9 the first of the volcanic aerosols are indicated by the emergent yellow north of the equator. The May 6 image shows the clear asymmetry of the cloud, with sharper concentrations of particles on the northern edge. By June 12, the cloud was at an altitude of 37 km, and starting to move north of the 35° "barrier." Below: Measurements of infrared radiation (transmitted from earth back to space) at 6.3 microns. SME first recorded evidence of the cloud over Europe on April 9, five days after the major eruption. By May 6 the cloud had spread south to the equator and to 32°N. The June 12 image shows a slightly diminished cloud, still constrained mostly south of 30°N, where the bulk remained until at least mid-August.

Principal volcanic eruptions since A.D. 1880 and their transient effect on mean annual temperature of the Northern Hemisphere (usual duration of effect about 5 years)

Year	Volcano	Location	Latitude	Longitude	Cooling Effect
1883	Krakatoa	Indonesia	6°S	105.5°E	−0.3°C
1902	Santa Maria	Guatemala	14.5°N	92°W	−0.3
1902	Mt. Pelée	Martinique	15°N	61°W	−0.3
1902	Soufrière	St. Vincent	13.5°N	61°W	−0.3
1912	Katmai	Alaska	58°N	155°W	−0.1
1963	Mt. Agung	Indonesia	8.5°S	115.5°E	−0.3
1982	El Chichón	Mexico	17.3°N	93.2°W	?

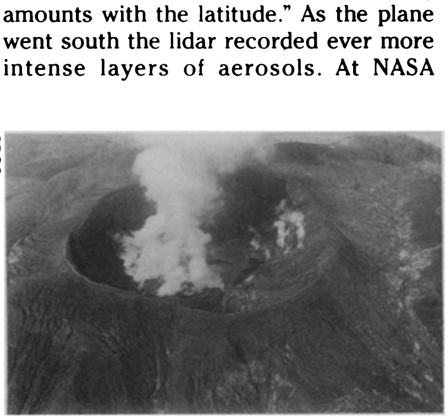
Note: Effect of Mount St. Helens' eruption of 1980 was less than −0.1°C

Mitchell, NOAA

The first evidence of the eruption appeared on April 9. After the cloud circled the earth once or twice, Barth says, SME images of visible light show that the tail caught up with the head, so to speak, forming a continuous, doughnut-like belt around the earth, centered at 19°N latitude. Wind patterns characteristic of spring held the cloud rigidly south of 32°N. By May 26, the cloud had filled in the region between the equator and 32°N, and was beginning to spread south. By June 12, not only had the cloud spread as far as 10°S, but it also had broken through in the North: By June 12, it was observed at 45°N, and moving. Barth says, however, that recent SME images show that four full months after the eruption, the great bulk of the cloud still is locked south of 30°N—a surprising finding given present assumptions about atmospheric circulation. As the cloud moves north, "We'll all know it because we'll start seeing brilliant and delayed sunsets," Mitchell says.

On July 8 Patrick McCormick of NASA Langley Research Center in Hampton, Va., boarded a NASA plane equipped with a lidar, a special laser system designed to shoot a pulse of radiation upward and measure the light scattered back by atmospheric particles. From Wallops Island, Va., he flew to Puerto Rico, down the coast of Venezuela, and back up to Puerto Rico. A pause for rest and refueling, then back to the skies ... up to Albany, N.Y., and finally home to Virginia. The plane traversed latitudes from 42°N to 12°N, and never approached the southern reaches of the cloud, McCormick says. "We saw a layer from El Chichón anywhere we looked," he says. "It has probably spread over the entire Northern Hemisphere, in varying amounts with the latitude." As the plane went south the lidar recorded ever more intense layers of aerosols. At NASA

USGS



El Chichón's new crater.

Langley, for instance, the cloud reached to only 22.5 km; in the south, it stretched up to 32 km. Above 21 km or 22 km, the cloud was 10 km to 12 km thick.

While the lower layers of the cloud are just as large as those observed three months after Mt. St. Helens erupted in May 1980, the upper layers are so dense that they make Mt. St. Helens's ash-laden plume seem like smoke from a campfire.

The fate of the cloud will be explored at a flurry of scientific meetings beginning with a session at the end of August at NASA Ames. In addition to questions regarding the cloud's effect on climate and the earth's radiation budget, scientists will describe their efforts to distinguish *real* effects of the aerosols from *perceived* effects. For instance, Alan Strong, with NOAA's National Earth Satellite Service, says that measurements from the polar-orbiting satellite, NOAA 7, show that since the eruption sea surface temperature at low latitudes has cooled by as much as 3°C. Comparisons with direct readings taken from ships at various locations around the world show that, in fact, temperatures have not changed. What is observed is the contamination of the thermal infrared signal as the satellite measures the sea surface temperature through the screen of the El Chichón cloud. The positive aspect of the "error" is that by logging the extent and pattern of the temperature signal, the NOAA researchers provide yet another map of the cloud's progress. Alternatively, Strong says, "It's messing up our ability to measure the temperature of the ocean."

The cloud's gyrations also are playing havoc with studies of the earth's ozone layer. John de Luisi of the NOAA Environmental Research Laboratory in Boulder, Colo., explains that it is not known whether the stratospheric aerosols will affect ozone concentrations. Surface measurements of the vertical distribution of ozone are "fouled up," he says. When the instrument sees the extra haze, it records it as a decrease in ozone at upper levels, albeit a fictitious one. Other researchers, such as Arlin Krueger of NASA's Goddard Space Flight Center in Greenbelt, Md., expect some reaction between the particles and ozone, as well as local decreases in ozone due to displacement by volcanic gas. He expects the cloud to do little to hinder his ozone observations. Because sulfur dioxide absorbs light at different wavelengths than ozone does, it is possible to separate the cloud's signal from ozone measurements. With colleagues, Krueger is measuring the rate at which the sulfur dioxide is converted to sulfuric acid, and ultimately hopes to determine for the first time the amount of sulfur dioxide injected by a volcanic eruption.

By now, heavy rains in southern Mexico have eroded much of the ash deposited in April. But two weeks after the major eruptions, when Johan Varekamp, a geologist at Arizona State in Tempe, visited El Chichón, the mountain and the surrounding countryside were cloaked by a thick layer of ash. Analysis of the ash showed "reasonable" amounts of chlorine and fluorine and "incredible" amounts of sulfur, he says. Varekamp calculates that there were 2 million metric tons of sulfur on the ground. While he figures that 0.4 or 0.5 cubic km of compacted ash was piled on the region, a far greater volume of material—roughly 3 or 4 cubic km — may have been injected into the atmosphere. Other researchers still are collecting data that can be used to make more specific estimates of the quantity and composition of material in the cloud.

American researchers and scientists with the Universidad Nacional Autónoma de Mexico in Mexico City are cooperating on studies of the volcano. Lindsay McClelland, staff geologist with the Smithsonian's Scientific Event Alert Network, says that one fact they hope to establish is how long it has been since El Chichón last erupted. Varekamp says that because of the extensive erosion, little evidence of *this* eruption will be cemented into the stratigraphic record. But the scars from pyroclastic flows — cascades of hot, gaseous volcanic debris that cut a searing path through valleys in the region — attest to the volcano's deadly power.

The historical record provides ample circumstantial evidence that volcanoes can force climate change. The "year without a summer" that followed the eruption of Mt. Tambora in 1815 is only the most notable cool period linked to eruptions. Mitchell is comparing records of temperature changes over the Northern Hemisphere in the last 100 years with the known chronology of eruptions. (Many eruptions probably go unreported because they occur in sparsely populated locations.) About 30 of the events could have affected global temperatures, with most changes less than 0.1°C, he says. Krakatoa caused global temperatures to drop by 0.3°C. So did Mt. Agung, a volcano in Indonesia that in 1963 also injected copious sulfur dioxide into the stratosphere.

"El Chichón is the biggest eruption since Agung, and it may be bigger in terms of the amount of stuff put into the atmosphere," Mitchell says. He cautions that he is not yet convinced that the El Chichón eruptions were as rich in sulfur. If not, he says, the climatic effects of El Chichón may be "very pronounced but not long lasting." □