Antarctic Ozone Hole Is Still Deepening

The Antarctic ozone hole "is a challenge to atmospheric scientists to explain an observed ozone phenomenon on the basis of our current understanding," says Richard Stolarski of the Goddard Space Flight Center in Greenbelt, Maryland. "It is a test." There is no shortage of proposed answers to the test, but it is still unclear why the total amount of stratospheric ozone over Antarctica drops every September and then recovers every November just after the long winter night ends. Equally unclear is whether this temporary thinning or "hole" in the earth's protective ozone layer is an early warning of an imminent global decline in ozone (and an accompanying increase in skin cancer-inducing ultraviolet rays reaching the ground) or just an academic though intriguing peculiarity.

At the recent meeting of the American Geophysical Union, in Baltimore, Stolarski and his colleagues reported satellite observations that confirm the increasing severity of the October ozone thinning since 1979. More ominously, they show that the deepening of the ozone low extended through last October's episode, reaching a new minimum in 1985 about 30% below the values of 5 years earlier. Last year Joe C. Farman and his colleagues at the British Antarctic Survey first announced the discovery of the October low, noting that October values had been more or less steady from 1957 until the early 1970's. Only then did total ozone begin dropping sharply. The overall drop in October values is now almost 50%.

Although worsening, the annual episodes are still only a possible threat to the global ozone layer. No empty hole has appeared, only a thinning, and it lasts for little more than a month. Covering only a third of one hemisphere, the loss of ozone centered on the South Pole affects the total ozone of the Southern Hemisphere only marginally, says Stolarski, because it is largely swamped by the variations closer to the equator. On a global scale, the temporary loss is undetectable in month-to-month records, he says. The global decrease due to pollutant chlorofluorocarbons sought by atmospheric chemists remains undetected.

What does bother researchers is that no chemical model of the stratosphere predicted the precipitous October decreases. What is driving down that October minimum from year to year over a dozen years is proving to be the most difficult part for any model to explain. Theorists are offering explanations, almost as many as there are workers in the field. Whatever the explanation, it will likely involve the unique meteorological isolation and extreme cold of the Antarctic stratosphere. There is no analogous phenomenon in the warmer stratosphere of the North Pole.

Chlorine from man-made chlorofluorocarbons, most familiar as the aerosol propellants now banned in the United States, is the leading suspect. Its abundance, like the severity of the ozone low, has been increasing. The trick to using chlorine to explain the lows seems to be to get it converted during the long winter night from a harmless form into a form that, once struck by the first rays of the sun, will yield enough of a sufficiently reactive chlorine species to destroy ozone as rapidly as is observed. If chlorine is behind the deepening ozone lows, they could be a sign of what will happen to the rest of the stratosphere as chlorine builds further.

Other explanations involve normal chemical and meteorological processes interacting in unforeseen but innocuous ways. They include, among others, heating and lifting of volcanic aerosols along with ozone-poor air, interaction of normal atmospheric chemistry with the nitrogen oxides enhanced during the solar cycle, and strengthening of the atmospheric vortex that tends to isolate Antarctica. Aside from collating all the data in hand, the next crucial step will be to observe next October's episode. A continued decline of the minimum would eliminate a number of possible causes, as could analyses of chemical species planned for the minimum.

Nevado del Ruiz Repeats Itself

Volcanologists are finding that the behavior of volcanoes, especially those around the rim of the Pacific, can be predictable. Predictions made of last November's eruption of the Colombian volcano Nevado del Ruiz, the second-worst volcano disaster of the century, proved "tragically accurate," according to Darrell Herd of the U.S. Geological Survey in Reston, Virginia. He and his Colombian colleagues of the Ruiz Volcanological Studies Committee reported their findings at the recent meeting of the American Geophysical Union.

A long-term forecast of future activity at Ruiz had been a possibility since Herd completed his dissertation on the geology of Ruiz in 1974. Taken with the recent work of Jean Claude Thouret and his colleagues at the University of Grenoble, the geological study of eruption deposits revealed that Ruiz had at least ten major eruptions during the past 2000 years and had erupted every 160 to 400 years. The most recent major eruption had been in 1595, 390 years ago. Thus, Ruiz could be expected to erupt again in the geological near future. Considering its lengthy repose, its next eruption could well be a large one, it seemed. A similar long-term forecast had been made in 1975 for Mount St. Helens.

Predicting the specific hazards of the next eruption seemed practicable as well. After almost a year of intermittent precursory activity, including earthquakes, increased fumarolic activity, and explosions of steam and ash, the geological survey of Colombia released a preliminary hazards map on 7 October 1985. Based on the geologic and historical record of past behavior, the map predicted with 100% certainty that the next major eruption would melt part of the permanent ice cover of Ruiz and send the resulting high-speed mudflows down some or all of the seven principal rivers around the mountain. A small 11 September debris flow that traveled 27 kilometers provided a neat example of the mudflow hazard. History held larger examples. A mudflow down the Rio Lagunillas after a steam eruption or large earthquake in 1845 killed 1000 persons at the site of the modern town of Armero. One accompanying the 1595 eruption went down the same valley.

The cataclysmic eruption of 13 November 1985 began abruptly with a strong steam explosion shortly after 3 p.m. This episode had given no warning detectable by any of the monitoring instruments, so that a short-term prediction before the fact proved impossible. But by 7:30 p.m. a consensus among most scientists developed that this ongoing episode, unlike earlier ones, warranted immediate evacuation. Authorities sent out the first of several warnings to evacuate Armero at about that time. At 9:08 p.m. the paroxysmal eruption began with two explosions heard 30 kilometers away. Within 30 minutes a column of ash rose over 11 kilometers.

Herd and the Volcanological Studies Committee conclude that "it is unclear if the general populace of Armero received an order to evacuate." If the message got through, few in Armero chose to or were able to take action. Twenty-one thousand persons, 90% of the town's residents, perished at about 11:30 p.m. as mudflows following the path laid out on the hazard map repeatedly surged over the town 50 kilometers from the summit of Ruiz.

Given sufficient resources, many other potentially hazardous volcanoes might be understood as well as Ruiz was. A prime candidate lies just 20 kilometers northeast of Ruiz. Cerro Bravo has no cap of ice, but it has produced two to three times as much ash as Ruiz and has erupted within the past 1000 years.

Thin-Skin Tectonics Is Getting Thinner

The realization that a continental collision had thrust a sheet of rock more than 100 kilometers wide but less than 10 kilometers thick onto eastern North America came as a shock to geologists. Now that sheet, probed by ever more sophisticated seismic reflection profiling techniques, appears to be several kilometers thinner, in some places as thin as 3 kilometers. At the proposed drill site of the ultradeep hole in the southern Appalachians, the lower boundary of the thrust sheet, which was originally the ultimate objective of the 10-kilometer hole, is now thought to be only 7 kilometers from the surface.

The sharper view of continental crust in the southern Appalachians comes from seismic reflection profiling, the same technique that discovered thin-skin thrusting shortly after geophysicists borrowed the method from the oil industry. Modifications to the method were required in order to send the mechanically generated waves to greater depths through crystalline rocks rather than the sedimentary rocks of oil formations and to receive the reflected waves at the surface. The Consortium for Continental Reflection Profiling (COCORP) has pioneered the imaging of crystalline rock using reflection profiling and has surveyed a variety of geologic structures coast to coast.

The need to understand thoroughly the rock beneath a single costly drill-hole site has prompted the development of further refinements to increase the resolution of reflection profiling of the upper crystalline crust. Within the Appalachian Ultradeep Core Hole (ADCOH) project headed by Robert Hatcher of the University of South Carolina, seismic profiling lines have been run across the Appalachians near the junction of the Georgia, South Carolina, and North Carolina borders with special attention paid to techniques that increase the sharpness of the two-dimensional image formed by the reflections.

The resolution of the profiles acquired by ADCOH "is unequaled by any previously acquired in the crystalline terranes in the eastern United States, possibly the world," the group claims. The sharper picture makes it clear that the reflection once taken to be the fault on which the thrust sheet slid over the underlying sediments actually lies within a thicker sediment layer. In fact, the thrust fault lies at a depth of 7 kilometers at the drill site and as little as 3 kilometers in the Blue Ridge Mountains to the west. The ADCOH group can also see how compression sliced up the sediment layer and laid one slice upon another to thicken it. Dome features seen previously in the crystalline thrust sheet and thought limited to that rock are apparently related to structures below them in the sedimentary rock. The crust above the Precambrian basement rock underlying the sediment is full of reflections, although few had been found before.

Larry Brown of Cornell University and COCORP attributes the success of the ADCOH lines to the targeting of shallower rocks. Not having to penetrate to the bottom of the crust 30 to 40 kilometers down, ADCOH researchers could use shorter wavelength seismic waves, which are rapidly absorbed, to image smaller details of crustal structure. They could also space their seismic receivers closer together, which also decreases penetration but increases resolution.

ADCOH researchers Robert Phinney and Kabir Roy-Chowdhury of Princeton University carried these changes even further when they ran short, additional lines in the drill site area. They also refined the collection and processing of the data. Their resulting resolution seems to be even better. It splits faults such as the Brevard zone into two reflectors separated by a zone of few reflections. The thickness and small-scale structure of crustal features seem to change over distances as small as a few kilometers. Obviously, fine-tuning the seismic reflection technique holds promise for those exploring the continental crust for something other than oil.

The Most Complex Magnetic Field

The Voyager 2 spacecraft has discovered that the magnetic field of Uranus is not only tilted at a crazy 60° angle and offset from the center of the planet, but the part above the surface of Uranus is more complexly structured than the field of any other planet. In effect, Uranus puts on display the complex inner parts of its magnetic field that other planets keep buried deep below their surfaces.

The complexity of the Uranian magnetic field became evident when John Connerney, Mario Acuña, and Norman Ness of the Goddard Space Flight Center in Greenbelt, Maryland, tried to describe mathematically the field through which Voyager passed. Obviously, it needed to be tilted 60° from the planet's axis of rotation, versus the usual inclinations of the solar system of 0° or about 10°. The mathematical model fit the observations still better when the field was offset from the center of the planet by one-third of its radius, an unheard of amount.

But the observations required even greater complexity, so the Goddard group added quadrupole and octupole components to the dipole type of field familiar from iron bar magnets and Earth's field. Unlike a dipole field, whose sign changes once moving from one pole to the other, the sign of a quadrupole field changes twice as the magnetic field lines from a pole dive back below the surface before reaching the equator. Dipole field lines would extend across the equator into the other hemisphere. If the dipole component of the Uranian field is given a relative strength of 1, then the quadrupole component would have a relative strength of 0.7. The Goddard workers see a need for octupole components as well, but such components are difficult to determine from the available observations. The next most complex field in the solar system is Jupiter's, which has dipole:quadrupole:octupole components of 1:0.25:0.2.

The blending of nearly equal dipole and quadrupole components makes for an odd-looking model of the Uranian field. The field intensity at the surface of the planet ranges from 0.1 to 0.9 gauss. Within one region on the sunward hemisphere, the same field lines both leave and reenter the surface, forming a magnetic bottle—a magnetosphere within a magnetosphere. Any charged particles formed within the bottle, which extends 5000 to 8000 kilometers above the surface, will be trapped there.

Undoubtedly, this unusual magnetic field is generated by the motions of the water mantle lying between the rocky core and the atmosphere and not by the core itself. If the magnetic dynamo were that far from the surface, the higher-order components, which weaken more rapidly with distance than the dipole, would fade away at the distance of Voyager. Earth's field has a significant quadrupole component within its mantle, but it fades to 13% of the dipole at the surface. The next step for theorists is to come up with a reasonable dynamo to generate a Uranian field that is tilted, offset, and remarkably complex.