Stratospheric Ozone Is Decreasing

A massive reanalysis of measurements confirms that protective stratospheric ozone has decreased during the past 17 years; some decreases greatly exceed predictions

THE announcement by the authoritative Ozone Trends Panel* that stratospheric ozone has indeed decreased, at some times and places several times faster than predicted, has pushed the scientific side of the ozone debate close to resolution. Only 2 years ago, the official conclusion was that no decrease could be detected anywhere. That left the magnitude and even the reality of ozone destruction by man-made chlorofluorocarbons (CFCs) in doubt. That doubt is rapidly fading.

"I am more concerned," said Robert Watson of the National Aeronautics and Space Administration (NASA), chairman of the panel, "and I am more convinced that CFCs have a role. The indicators are bad. Everything points more and more to their being involved."

The discovery of the global ozone decrease comes on the heels of last fall's recognition that CFCs create the Antarctic ozone hole every October through reactions mediated by ice particles formed at the lowest temperatures of the stratosphere. No model of stratospheric chemistry predicted the hole because standard models did not, and still do not, include the ice in their reaction schemes. The panel's discovery of unexpectedly large ozone decreases during winter, especially at higher, colder latitudes, hints that such ice-mediated chemistry may play a role in the global decrease as well. Watson says that one could speculate, "Are we seeing in the Northern Hemisphere the equivalent of the Southern Hemisphere [Antarctic]? It is certainly one of the possibilities."

In any case, researchers' faith in their models of ozone is now not quite what it was. The models were predicting only small changes in ozone if the global production rate of CFCs were frozen at today's rate, as called for by the 31-nation Montreal Protocol ratified by the Senate the day before the panel's announcement. "However," noted Watson, "those same models do not predict that ozone decreased the way it did over the Northern Hemisphere during the past 17 years. Our models are not doing a good job, so we would have to say that they are underestimating decreases in the future."

This sobering news results from the first comprehensive analysis, including data quality control, calibration, error analysis, and modeling, of nearly all ground-based and satellite ozone observations. More than 100 scientists from the United States and a half dozen other countries spent the past 16 months dissecting the record, almost data point by data point. This fever pitch of activity was brought on by the ominously deepening Antarctic ozone hole and by Donald Heath, the NASA scientist at the Goddard Space Flight Center analyzing ozone data from the Solar Backscatter Ultraviolet (SBUV) satellite instrument.

Heath had been arguing since 1981 that earlier satellite instruments and then the

*The Ozone Trends Panel is the creation of NASA in collaboration with the National Oceanic and Atmospheric Administration, the Federal Aviation Administration, the World Meteorological Organization, and the United Nations Environment Program. Copies of the executive summary of the panel's report are now available from Robert Watson at NASA Headquarters, Washington, DC 20546.

The Latest on the Antarctic Hole

NASA's Ozone Trends Panel also reported the most recent consensus on what is happening in and around the ozone hole, the annual October thinning of stratospheric ozone over the Antarctic continent.

- Extreme losses. The October 1987 loss reached 50% of total ozone within the hole, but the loss within the hardest hit layer of the lower stratosphere, between 15 and 20 kilometers, soared to 95%.
- Record losses outside the hole. Poleward of 60°S, the latitude of the southern tip of South America, total ozone fell to the lowest levels ever recorded during the austral spring.
- A longer lived hole. In 1987 the hole lingered until late November–early December, the latest disappearance since it was first detected.
- A colder hole. The hole is about 8°C colder near an altitude of 15 kilometers than it was in 1979. Polar stratospheric clouds, whose ice particles allow the creation of the high abundance of ozone-destroying chlorine monoxide, are now more pervasive and more persistent. Apparently, the ozone hole feeds on itself. The initial loss of ozone decreases the absorption of solar energy, which cools the atmosphere, increases ice cloud production, and amplifies the ozone loss.
- A year-round effect. Since 1979 total ozone has decreased by 5% or more at all latitudes south of 60°S at all times of the year, not just within the hole or during the austral spring. "At this time it is premature to judge if this is caused by a dilution of the air from the region of very low ozone, a changed meteorology, or some other unidentified phenomenon. However, at least some of the decrease is likely due to dilution," the report said.
- Some theories discarded. Studies have found extremely low abundances of nitrogen oxides, eliminating the sunspot cycle theory for the hole, and a low abundance of bromine oxide, which limits its present role to causing less than 10% of the loss. There is also strong evidence against an upwelling of the atmosphere as a cause of the hole.
- Chlorofluorocarbons indicted. "The weight of evidence strongly indicates that man-made chlorine species are primarily responsible for the observed decrease in ozone within the polar vortex [hole]," according to the report. ■ **R.A.K.**

SBUV were detecting surprisingly rapid decreases in ozone. He regularly made his argument in scientific gatherings, congressional hearings, and, inevitably, the press. But the data and his interpretation never made it into the refereed literature, that is, until the week of the panel's announcement (*Nature*, 17 March).

Critics argued as well that SBUV data were fundamentally unreliable because the instrument's calibration system was degrading. A plate that scatters sunlight directly into the instrument during periodic calibrations has become progressively duller as the sunlight itself damages its surface, until it reflects about 50% of the amount it did when launched. Heath claimed that he could account for the diffuser plate degradation with sufficient accuracy. Others doubted it. Most recently, Heath claimed that stratospheric ozone between 65°N and 65°S had decreased about 5% between 1978 and 1986, or 0.57 ± 0.05% per year. He could find nothing like this drop in any ozone record since 1959.

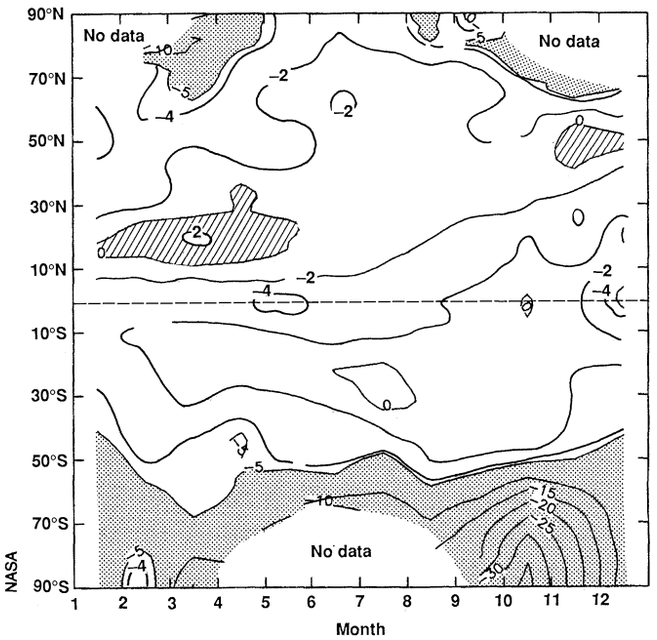
The Ozone Trends Panel found that Heath was better than half right. It rejected Heath's diffuser plate correction as nonunique and inconsistent with trends in ozone measured by ground-based, so-called Dobson instruments. After comparing SBUV and Dobson observations over individual Dobson sites, the panel concluded that more of the changes in SBUV ozone could be attributed to diffuser plate degradation than Heath had assumed. Once normalized to the Dobson data in the way preferred by the panel, SBUV indicates a decrease from October 1978 to October 1985 of about 2.5% between 53°N and 53°S, or about 0.35% per year. That is more than half of Heath's estimate of recent years and still larger than the decrease that might be attributed to the influence of the sunspot cycle.

Because of the shortness of this record, the panel declined to compare satellite observations with model predictions. The 17-year-long Dobson record was another matter, at least in the mid-latitudes of the Northern Hemisphere where coverage is good. Between 30°N, the latitude of New Orleans, and 64°N, the latitude of Fairbanks, Alaska, ozone decreased 1.7% to 3.0% between 1969 and 1986, depending on the latitude. That is "broadly consistent" with model calculations, according to the report. It was also foreshadowed in analyses of Dobson and Dobson-derived data published last year before the intensive reanalysis (*Science*, 10 July 1987, p. 131).

What is not consistent with the models is the wintertime losses. Between 30°N and 39°N, wintertime ozone decreased 2.3%,

The decrease

This is a plot of the percent change in total ozone from 1979–80 to 1986–87 as determined by the satellite-borne Total Ozone Mapper Spectrometer. The tendency toward larger losses at higher, colder latitudes and colder seasons is apparent. The Antarctic ozone hole is in the lower right.



A Cautionary Note

The Ozone Trends Panel's conclusion that ozone has at some times and places decreased faster than predicted has raised questions about the sufficiency of proposed production controls on chlorofluorocarbons (CFCs), the ultimate cause of ozone destruction. The 31-nation Montreal Protocol ratified by the U.S. Senate on 14 March calls for a 50% reduction from 1986 production levels by 1999. According to Robert Watson of NASA, chairman of the panel, current models would predict ozone losses of only a few percent at most latitudes if the signatories adhere to the Protocol.

The newly recognized ozone decline casts doubt on these modestly comforting results. But scientists will be closely considering such problems next year as they begin their reassessment of the scientific underpinnings of the Protocol's control measures, as required by the Protocol itself. Then in 1990 the parties to the Protocol must reconsider their control measures in light of the latest understanding of ozone depletion.

The panel did not consider the implications of its findings for the proposed control measures, but it did have a warning—do not be lulled into a false sense of security by the trend of global ozone during the next few years. The panel predicted that ozone creation by increasing solar ultraviolet radiation during the current upswing in the sunspot cycle should at least halt the decline in ozone for the time being. The distinct downward trend between 1979 and 1986, when the declining solar cycle reinforced CFC destruction of ozone, could even be reversed. In the Northern Hemisphere, far from the influence of the Antarctic Ozone Hole, the recent downward trend has already disappeared, according to the Ozone Trends Panel.

The trap that the panel is pointing out to those about to reassess the Protocol provisions is that ozone will resume its fall after the reassessment and during the 4 years before the next reassessment. "We would predict that the decrease in ozone would slow down or even reverse," noted Watson, "However, once we pass 1991, we would again expect a decrease in ozone."

The warning given, Watson then noted that "the Montreal Protocol is an essential first step. Scientists should get the appropriate information to the policymakers. The policy community should then look long and hard at whether the Montreal Protocol is appropriate." That appropriate information will have to include the significance of the Antarctic ozone hole. If the potency of CFCs in ozone destruction is widely enhanced by ice particles, as it is over the Antarctic, proposed CFC control measures may be insufficient. ■ **R.A.K.**

between 40°N and 52°N 4.7%, and between 53°N and 64°N 6.2%. Although Dobson stations farther north are too sparse to yield an accurate trend, "the limited data suggest that there has been a decrease comparable in magnitude to that observed between 53° and 64°N." When the ozone trend between two consecutive 11-year solar cycles was determined, the pattern was the same—a smaller than average decrease in summer than in winter and within winter a larger decrease at higher, colder latitudes. Model predictions of wintertime losses are about one-third of these observed losses.

Reactions to the newly recognized losses run the gamut from heightened concern to outright consternation, Watson's near-concession of CFC involvement falling in the middle ground. Ralph Cicerone of the National Center for Atmospheric Research (NCAR) in Boulder, a panel working group member, says "I'm struck by the whole thing, but instead of being able to say clearly that CFCs are involved because the losses are so large, the changes are at the level of natural variability."

Panel member Sherwood Rowland of the University of California at Irvine, a co-originator of the CFC hypothesis, is more confident about the possible conclusions. "My own view is that we're seeing appreciable losses in Antarctica and losses in the Northern Hemisphere," he said. "It seems quite likely that heterogeneous [ice-mediated] reactions could happen in the Arctic. I would be surprised if we don't find heterogeneous reactions of some significance in the Northern Hemisphere, especially in the Arctic."

A consensus must in all likelihood await direct chemical evidence that CFCs lie behind the loss of ozone. John Gille of NCAR, another panel member, noted that in the case of the Antarctic hole, there is now a smoking gun—high levels of chlorine monoxide, the ozone-destroying form of the CFCs' chlorine, as well as a wealth of other observations directly implicate CFCs. "This report says for the first time," in the case of the rest of the globe, "here is the corpse," observed Gille. Many researchers will be waiting to see if the same weapon was used in both crimes. A ground-based international expedition to the Arctic this spring may soon shed some light on the question. And a NASA-sponsored airborne study may be launched next year.

The panel had some suggestions. First, it complained that no validated data were yet available from the SBUV-2 instrument launched in 1984. Second, it noted that data interpretation must "be given higher priority and involve a broader cross section of the scientific community than in previous years."

The implications of the ozone decrease for the health of humans as well as flora and fauna were beyond the purview of the panel's report. It has been estimated that a decrease of 2.5% in ozone, such as that seen over Northern Hemisphere mid-latitudes, would lead to about a 10% increase in the rate of human skin cancer. That presumes decades of exposure that are required for the induction of skin cancer. It also presumes that the ozone reduction is spread evenly throughout the year, which it was not. Humans as well as the flora and fauna fortuitously tend to minimize their exposure in the season of greatest loss. What the future holds may be a bit clearer next month when NASA makes its periodic full report to Congress on the state of the upper atmosphere. ■ RICHARD A. KERR

Calculus: Crisis Looms in Mathematics' Future

Researchers and educators are debating how calculus should best be taught to increasingly recalcitrant students

MATHEMATICS, a discipline not normally known for its heated debates, is warming up to the subject of calculus reform. The teaching of calculus—when to do it, and even why to do it—has become a major issue in mathematics. The National Science Foundation has earmarked more than $1 million for an initiative in calculus reform. And at colleges across the country, experimental teaching programs are springing up.

"The more computer power we have, the less the students know what they're doing."

Calculus reform is considered urgent because of the course's commanding position in the early undergraduate experience of students hoping to go on in science, engineering, business, and other fields. Robert White, president of the National Academy of Engineering, calls calculus "a critical waystation for the technical manpower that this country needs." Yet at some institutions as many as 50% of the students enrolling calculus either fail or withdraw from the course.

Many students today enter college with a weak background in the prerequisites to calculus: algebra, geometry, and trigonometry. Worse, in the opinion of college professors, many of these students have already had a watered-down taste of calculus in high school. The upshot is that many of these students retake calculus in college and do poorly; they think they know more than they really do, and the course does not "grab" them because they have already seen the highlights. The shortage of teachers capable of teaching calculus in high school adds another dimension to the problem.

In response, the Mathematics Association of America and the National Council of Teachers of Mathematics have sent a joint letter to high schools nationwide recommending that calculus be taught only to students who have a full 4 years of preparation in mathematics, and that it be taught with the expectation that students will not repeat the course in college.

While there is widespread agreement as to the problems that beset calculus instruction at the college level—unwieldy textbooks that have stuck to an outmoded emphasis on rote and repetition, unmanageable class sizes in many institutions, and unmotivated faculty who see teaching as a distraction from research—there is a correspondingly widespread disagreement as to the solutions.

Many argue that computers and the new generation of sophisticated hand-held calculators will force a change in calculus instructions, whether change is wanted or not. The Hewlett-Packard HP 28S, a programmable calculator that incorporates symbolic manipulations, equation-solving algorithms, and graphing capabilities—in short, much of what students are currently taught to do—represents a threat to some and an opportunity to others.

"This identifies a new wave," says John Kenelly of Clemson University, who has worked with several of the pocket calculators. Kenelly and five colleagues are using the HP 28S this year in calculus and other courses at Clemson. Engineers do not work with paper and pencil anymore, Kenelly points out, adding "We have a colleague or