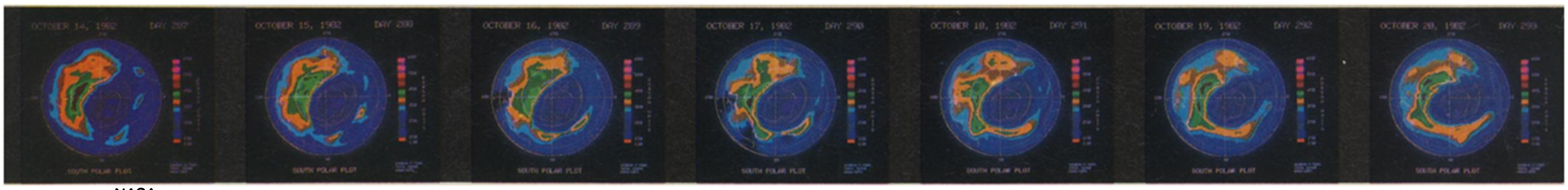

NASA

The Ozone Hole, Dynamically Speaking

By STEFI WEISBURD

In spite of tremendous static on the satellite link to Washington, D.C., the message from the National Ozone Expedition (NOZE) in Antarctica seemed clear enough: The dynamic theory proposed to explain the mysterious ozone hole was dead. In their Oct. 20 statement to reporters and researchers, NOZE atmospheric chemists concluded that chemical processes – not atmospheric winds – are fundamentally responsible for the thinning of stratospheric ozone that has occurred and worsened each Antarctic spring for the past few years (SN: 10/25/86, p.261).

Back in the Northern Hemisphere, dynamists have cried "foul." Without seeing the NOZE data firsthand, they have been unable to comment directly on the results. But they do question whether the NOZE team has enough information to eliminate dynamics as a contender. Moreover, a number of atmospheric observations are emerging that bode well for dynamics, but not for chemical theories, according to Mark R. Schoeberl at NASA Goddard Space Flight Center in Greenbelt, Md. Schoeberl is an editor of the November special issue of GEOPHYSICAL RESEARCH LETTERS (GRL) describing many of these observations.

At this stage, neither the chemical nor dynamic theories can explain the ozone hole in all its details. In fact, most scientists think the hole is probably caused by a combination of dynamics and chemistry; the question is which kind of process dominates. And contrary to the general impression left by the press conference, say some, the dynamic theories are still very much in the running.

Photo series above: NASA scientists made a movie out of the daily ozone maps they compiled with the Total Ozone Mapping Spectrometer aboard the Nimbus 7 satellite. The oscillations and movement of both the zones of highest ozone values (in yellow and green) and the ozone hole (in gray and purple) suggest to some that dynamic motions of the atmosphere are creating the hole.

The public may be more familiar with chemistry as a culprit for the ozone hole than it is with dynamics. One class of chemicals – the chlorofluorocarbons (CFCs) – has been the focus of a long, heated debate about the predicted *long-term* decline of the *global* ozone layer. CFCs, which have a variety of commercial uses such as refrigeration, release chlorine that catalytically destroys ozone. Stratospheric ozone is important to earth life because it absorbs biologically harmful ultraviolet light from the sun.

While atmospheric chemists have grown more confident in their models of the slow depletion of global ozone due to CFCs, the discovery of the more dramatic drop in Antarctic ozone each spring took them completely by surprise. Some scientists believe that the polar regions are a kind of Achilles' heel of the atmosphere – the places where chemicals like CFCs have their best shot at attacking ozone – and they worry that the polar ozone holes are only the first signs of a planetary-scale depletion of ozone due to CFCs. If they are right, regulation of CFCs might help control the hole and stave off future ozone depletion. A dynamic explanation, on the other hand, takes the onus off humans for creating the present ozone hole, but it also complicates the detection of long-term ozone depeletion due to chemistry.

In spite of their suspicions that the ozone hole is due to chemicals, atmospheric chemists have not had a lot of success in directly applying their theories to explain the hole. There is some question, for example, whether chemicals can react fast enough to destroy ozone at the observed Antarctic springtime rate of 0.5 percent per day. Moreover, theories involving CFCs "pale quantitatively" when it comes to replicating the year-to-year decrease in Antarctic ozone that has been observed, according to Jerry D. Mahlman at Princeton (N.J.) University's Geophysical Dynamics Laboratory.

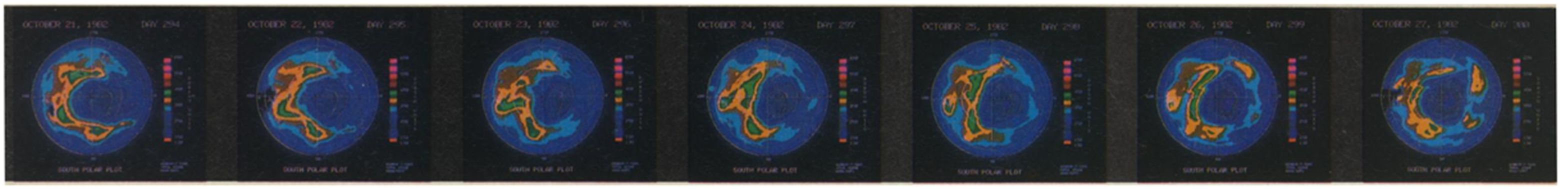
CFC theories predict that the ozone hole should deepen each year because CFC levels in the atmosphere have been growing. In the November GRL, Dagmar Cronn and her co-workers at Washington State University in Pullman report that the concentrations of some CFCs near the South Pole have been increasing at 5 percent per year. But according to GRL special issue editor Arlin J. Krueger at NASA Goddard, ozone levels in the hole this October have been comparable to 1984 concentrations, which were greater than what was observed during October of 1985.

Chemists would also be hard pressed to explain the findings of Schoeberl and NASA Goddard's Richard S. Stolarski. Using satellite data, they report in the November GRL that the decrease in ozone levels over Antarctica each spring is directly compensated for by an increase of ozone levels at lower latitudes – so that the total amount of ozone, from the pole to about 44° S, remains approximately constant from August through November.

"This is consistent with dynamics, which moves ozone from Antarctica and dumps it at other latitudes," says Ka-Kit Tung, a fluid dynamist at Clarkson University in Potsdam, N.Y. "Chemistry, as far as we know, has no way of explaining that," he adds, because chemical effects are much too localized.

Another factor that possibly favors dynamics is that atmospheric winds have created an ozone minimum in another part of the world. In his November GRL paper, Tung notes that an equatorial ring of low ozone values exists throughout the year in the tropics, where the abundant supply of sunlight readily *creates* ozone by photochemical processes. Scientists think that large-scale circulation cells constantly lift ozone-rich air in the equatorial stratosphere and move it away from the equator toward the poles, while at the same time replacing it at the equator with ozone-poor air from the troposphere below.

Tung and Schoeberl propose that a type of upwelling may also be responsible for the seasonal formation of the Antarctic ozone hole. When the sun begins to shine on the stratosphere after it has been cooled during the dark polar winter, the air is rapidly heated. Because the suddenly warmed air is unable to dissipate all



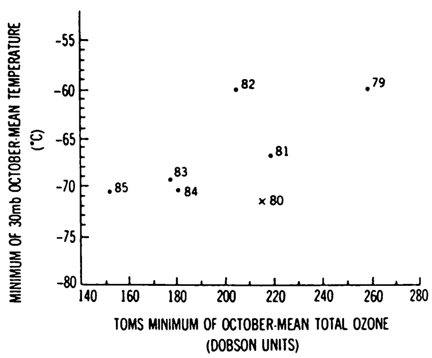
Atmospheric chemists, sent to Antarctica to uncover the cause of the ozone hole, recently dismissed dynamic theories in favor of a fundamentally chemical explanation. What are these dynamic theories and why are there scientists who still believe in them?

of its heat through radiation, it rises. And as in the tropical case, the upwelling air moves ozone out of the lower stratosphere above Antarctica and brings it to midlatitudes.

In two GRL papers, researchers estimate that the heating of the air from the absorption of solar radiation by ozone, volcanic aerosols and polar stratospheric clouds is great enough — about 0.5° K per day — to create the springtime upwelling. One supporting bit of evidence for these ideas is that the most dramatic seasonal decrease in Antarctic ozone levels occurred in 1983 when the volcanic aerosol cloud from El Chichón reached the stratosphere. Scientists say that polar stratospheric clouds should also form more readily when the stratosphere is cold and/or aerosol levels are high.

The NOZE team's conclusion that the "proposed dynamical mechanism of hole formation is not valid" was based on measurements of nitrous oxide and aerosol particles. If upwelling is bringing ozone-poor air from the troposphere into the lower stratosphere, reasoned the NOZE researchers, then the levels of nitrous oxide and aerosols in the hole should reflect what is usually found in the troposphere as well. But this was apparently not the case.

Dynamists say that had the NOZE team made these observations from many stations located well within the hole, where there is more vertical air motion, then this evidence could have been a deathblow for dynamics. But because McMurdo Station is located at the edge of the hole, where there is little vertical air motion, the question of the hole's cause, they argue, is still very much up in the air.



Mahlman and Fels/GRL

The strongest evidence supporting dynamics is a link between ozone and temperature. As Antarctic ozone levels have fallen each year, so have stratospheric temperatures over the pole. The x in 1980 means the temperature is uncertain.

The upwelling theory may explain why ozone levels have dropped each spring. But how does dynamics account for the year-to-year decrease in ozone? Princeton's Mahlman hypothesizes that changes in the weather patterns, specifically in the activity of tropospheric waves, have altered the winds, temperatures and ozone levels in the stratosphere. Ironically, in 1980 Mahlman had published the results of an atmospheric model that predicted ozone levels remarkably similar to what is seen today.

"I did a lot of self-flagellation in the paper about what a failed experiment that was because the ozone was much too low over Antarctica," he says. "That previous failure got me thinking about the problem today. What would happen if the atmosphere were to flip into the regime of that model?"

Mahlman's model holds that under normal conditions, stratosphere cooling during the Antarctic winter is limited by atmospheric waves. These waves rise from the troposphere at low latitudes and force air down at the poles. This downward motion warms the polar air and also brings ozone-rich air into the lower stratosphere. If for some reason, however, these waves were to become weaker, their effect on the Antarctic atmosphere would diminish.

One result would be that less ozone is pushed down into the lower stratosphere — this effect would account not only for declining ozone levels at the South Pole from year to year but also for lower stratospheric ozone levels over the whole Southern Hemisphere, according to Mahlman.

"If in 1979 the plug was suddenly pulled on the forcing from the troposphere, then ozone should continue to drop for as much as three to four years," says Mahlman. "And if it was pulled gradually, ozone should drop over a much longer time."

The other result of weaker waves from the troposphere is that during the polar night, stratospheric temperatures would get colder than normal. And this is exactly what has been observed. In the November GRL, Schoeberl and Paul A.

Newman at Applied Research Corporation in Landover, Md., report that as the Antarctic ozone levels have decreased in the hole over the last seven years, stratospheric temperatures in the polar region have also fallen, by as much as 18° C.

"The most important piece of evidence supporting dynamics — and one that the [NOZE team members] down in Antarctica don't have — is this very strong correlation between total ozone and temperature that we've seen," says Schoeberl. "We believe that the only thing that could produce that strong a correlation is a dynamic process."

Schoeberl thinks that the colder stratospheric temperatures also explain why the hole first began to appear in 1979. Since the strength of the upwelling cell that develops each spring depends on the contrast between the cold winter temperature of the stratosphere and the amount of rapid heating by the sun, colder winter temperatures would result in more pronounced upwelling, and hence, an ozone hole.

Mahlman is a little less enthusiastic about using this dynamic theory to explain the magnitude of the seasonal drop in ozone. But as for the year-to-year changes, he is encouraged by the findings of Ronald M. Nagatoni and Alvin J. Miller at the National Oceanic and Atmospheric Administration's Climate Analysis Center in Camp Springs, Md. These researchers have noticed that vertical meteorological wave activity out of the troposphere has dropped markedly in September and October over the past five years.

"Their paper is an independent calculation of wave activity that is very compatible with our dynamic theory," says Mahlman. "But why activity has dropped, we don't have the faintest idea."

NSF/Jim Herpolsheimer

NOZE scientists prepare a balloon for atmospheric measurements in Antarctica.

One possibility might be changes in the sea surface temperatures (SSTs). Timothy Palmer at the European Center for Medium Range Weather Forecasting in Reading, England, has found a strong connection between warm SSTs of the southern oceans and the decline in polar ozone. This is consistent with dynamic theories because warm polar waters would reduce the temperature contrast between the cold poles and the warm equator that is needed to drive tropospheric wave activity. A few dynamists are kicking around the idea that the 1982-83 El Niño — a warming of the Pacific waters that altered climate worldwide — might be involved, but so far the SST-ozone correlation has not been explained.

Tung says that ocean temperatures naturally oscillate every few decades; the last warm period before the present one was in the 1940s. The tie between this natural cycle of the oceans and ozone is still very speculative, he says, "but it's intriguing."

A dynamic explanation for the ozone hole suggests that there have been Antarctic ozone holes in the past and that they will develop again in the future — although dynamists have little idea about how frequently they may recur. Both Mahlman and Schoeberl note that if dynamics is the root cause of the present ozone hole, then it will be much harder for scientists to model and detect the future changes in global ozone levels caused by CFCs. "How will we know, when we see changes in ozone, that they're due not to climate shifts but to chemistry and man's pollution?" asks Schoeberl. "That's an important issue because right now we're not very well geared up [for telling the difference]."

Mahlman stresses that while he and other dynamists think that dynamics is important to the ozone hole, they still believe that CFCs are going to have a "monstrously large effect" on stratospheric ozone in the future. The ozone hole dilemma, Mahlman says, "is not an ideological question of pro-CFC versus anti-CFC."

And dynamists *do* think that chemistry is involved, to some degree, in the formation of the ozone hole. One possible combination of dynamics and chemistry is described in the November GRL by Owen B. Toon at NASA Ames Research Center in Moffett Field, Calif., and his colleagues. Toon's group proposes that polar stratospheric clouds are formed out of nitric acid, a compound involved in the reactions that tie up chlorine into "reservoir" species so that it can't attack ozone. With the nitric acid out of the way, chlorine is free to destroy ozone.

"This is by far the more plausible mechanism of any that I've heard," says Mahlman. "My best guess at the moment is that dynamic events set up unusual chemistry, but I wouldn't bet on it."

The message from dynamists, and especially scientists like Mahlman, who has been studying ozone and the stratosphere for years, is that there is still much to learn. "The wave motion is just an obsession in about three or four of our heads at the moment," he says. "We're describing a wave phenomenon in September and October in the Southern Hemisphere that really has not been studied before. So this story isn't over yet." □