SCIENCE NEWS of the week

Northern Ozone Hole Deemed Likely

An ozone hole will likely form over populated regions of the northern hemisphere sometime within the next 10 years, according to a team of scientists involved in a six-month study of Earth's protective ozone layer. The new data, reported this week in Washington, D.C., also reveal that experts have overestimated the atmosphere's ability to defend itself against ozone-destroying chlorine pollution.

The researchers judged these findings so important that they released their results early, before the end of the experiment in March.

"We don't like what we see. This isn't good news," concludes project scientist James G. Anderson of Harvard University.

Involving 40 scientists, the NASA-run experiment began in October, with the aim of assessing the chances of a northern ozone hole and explaining a disturbing erosion — detected everywhere except the tropics — of Earth's stratospheric-ozone layer. In flights over northern New England and Canada on Jan. 20, instruments aboard NASA's high-altitude ER-2 aircraft detected record-setting levels of chlorine monoxide (ClO), the key molecule that destroys ozone. Concentrations ranged as high as 1.5 parts per billion (ppb), a value never before seen, even during flights into the Antarctic ozone hole, Anderson says.

The ER-2 instruments measured the high ClO concentrations at a time when the Arctic Vortex — a region of extremely cold air — had shifted from its polar position toward the United States. Ozone destruction occurs most readily inside the vortex because air there is cold enough to form cloud particles that help harmless chlorine-containing compounds convert into dangerous ClO.

At levels above 1.5 ppb, ClO can destroy ozone at a rate of 1 to 2 percent per day — if sunlight is present. For an ozone hole to develop over the Arctic, weather in the stratosphere must remain stable, allowing the vortex to persist into March, when sunlight reaches the polar region.

NASA aircraft will continue to monitor the fate of Arctic ozone through March. Although they do not know if it will happen this year, project scientists say that during some year in the near future, the vortex will remain intact. As levels of chlorine climb each year, the chances of severe Arctic ozone depletions rise. "The probability for forming an ozone hole — that is, for significant ozone erosion in this vortex region — is very high for the decade to come," Anderson says.

An Arctic ozone hole would most directly affect regions underneath the vortex, allowing increased levels of biologically dangerous ultraviolet radiation to reach much of Canada and parts of the United States, Europe and Asia. But the aircraft mission also uncovered disturbing findings about the global ozone layer outside the vortex region. ER-2 flights as far south as the Caribbean detected ClO in the range of 0.1 ppb — five times the amount scientists expected.

NASA

During January, NASA's Upper Atmosphere Research Satellite measured chlorine monoxide (ClO) at levels of 2 ppb. Image from Jan. 11 shows northern Europe and Asia covered by high ClO concentrations (orange) above 1.5 ppb.

The stratosphere also holds far less hydrochloric acid — a safe form of chlorine — than expected, ER-2 observations indicate. This suggests the atmosphere is more efficient than scientists had thought at converting stable chlorine to destructive forms, Anderson says. Other ER-2 measurements reveal lower-than-expected levels of nitrogen oxides, chemicals that bind to ClO and thereby slow ozone destruction.

"The immune system of the atmosphere — its ability to suppress chlorine — is weaker than we expected," explains Anderson.

The data indicate that safe forms of chlorine pollution have been converting into ClO on the surfaces of sulfur particles, present in the stratosphere all around the world. While the eruption of Mt. Pinatubo last June spewed additional sulfur into the stratosphere and has enhanced ozone deterioration, this process went on before the eruption, according to ER-2 measurements made outside the volcanic debris. The mission scientists conclude that ClO, created on sulfur droplets, and a similar bromine chemical have caused the ozone erosion observed above midlatitude regions.

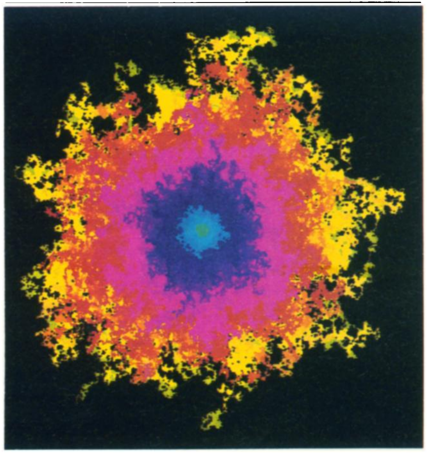
The ER-2 flights also passed through thin horizontal sheets of enhanced ClO, which appeared over the temperate latitudes as far south as the Caribbean. Anderson says the discovery of these unexplained sheets has concerned mission scientists, who plan to investigate them further. They suspect volcanic sulfur may have stimulated the growth of the layers, giving scientists a look at processes that could occur in the future as chlorine levels rise.

"This is really the tip of the iceberg. I think this is an early warning," says Anderson. — *R. Monastersky*

Bringing random walkers into new territory

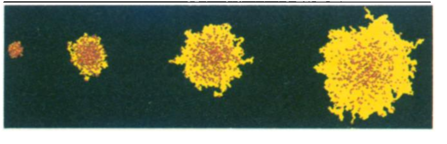
The introduction of muskrats into central Europe in 1905 afforded ecologists a unique opportunity to study the spread of a population. Five surveys taken during the succeeding 23 years revealed an intriguing pattern of expansion. As the territory occupied by the increasing population of muskrats grew larger, its initially smooth boundary became increasingly convoluted.

A team of researchers has now developed a mathematical model that provides a new avenue for studying the spread of populations. This model suggests that the roughening of a territorial boundary, as demonstrated by the rambling muskrats, occurs naturally in any situation in which groups of diffusing



Stanley et al.

Below: Snapshots of the territory (yellow) covered by 1,000 random walkers (red squares) for a sequence of times increasing from left to right. Left: Successive colors show the progress of 1,000 random walkers starting at the center as they claim additional territory over several, consecutive time periods.



"particles," whether muskrats or molecules, move at random from position to position.

The model's importance stems from the fact that researchers can express many different physical processes as random-walk problems. "The random motion of particles is at the root of much physics, chemistry and biology," says physicist and team member H. Eugene Stanley of Boston University.

The novel random-walk variation developed at Boston University arose out of a curriculum project designed to introduce concepts of randomness to high-school students. Going beyond the familiar, well-studied problem of depicting the territory covered by a single "walker" randomly wandering from square to square on a grid, project manager Paul Trunfio decided to look at the patterns formed by a swarm of random walkers, all starting simultaneously on the same square, as they independently explored the grid.

Trunfio's computer-generated patterns were sufficiently interesting to prompt further investigation. "We realized ... that this might be an unsolved problem in random walks," Stanley says. "We spent two or three months looking at computer images trying to discover the laws that seemed to govern the behavior we saw."

The computer experiments revealed that the set of visited sites initially has a relatively smooth boundary. But after the territory reaches a certain size, this edge grows increasingly jagged.

Graduate student Hernan Larralde, aided by Shlomo Havlin and George H. Weiss of the National Institutes of Health in Bethesda, Md., then worked out a precise, mathematical solution of the problem in one, two and three dimensions. "At first sight, it looks like a trivial problem to solve," Stanley says. "It was in fact a very difficult mathematical problem."

The analysis unexpectedly revealed that this random-walk process goes through three distinct time regimes representing characteristic but different rates and patterns of growth. "We were surprised by the fact that a relatively simple question about random walks could be so rich," Stanley says. A paper detailing the findings appears in the Jan. 30 NATURE.

"The work of Larralde [and his coworkers] opens up a host of further possibilities — of using interacting walkers, of working in fractal spaces ... and so on," Michael F. Shlesinger of the Office of Naval Research in Arlington, Va., comments in the same issue of NATURE. "These would find applications in fields as diverse as physics and ecology."

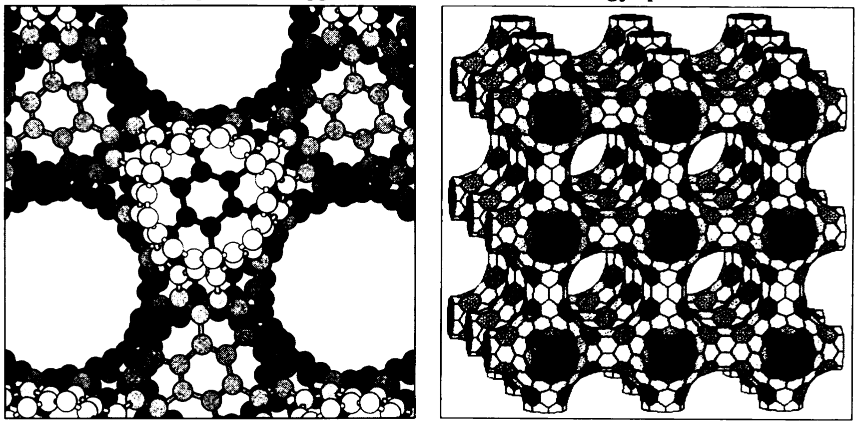
"What's nice about this particular problem is that it's sufficiently simple that you can get some feeling for the collective behavior of large numbers of particles," Weiss notes. *— I. Peterson*

Theorists design new-look fullerenes

Add some five-sided rings of carbon to a graphite sheet—with its honeycomb arrangement of carbon atoms— and the sheet curves around to form a buckyball or one of its rounded fullerene cousins.

But if that sheet contained seven-sided carbon rings instead of five-sided ones, an entirely different sort of fullerene would result, two independent groups of theoretical physicists report. These new theoretical molecules would be more stable than a buckyball, and they seem quite light and strong, David Vanderbilt at Rutgers University in Piscataway, N.J., and a colleague conclude in the Jan. 27 PHYSICAL REVIEW LETTERS.

Such useful properties suggest that



Vanderbilt and Tersoff/Phys. Rev. Lett.

Steve Townsend and Thomas Lenosky/Cornell

These computer images show how seven-sided rings (yellow) give this fullerene its saddle shape (right), and in this sliced open molecule, how atoms are arranged (left).

scientists should start looking for fragments of these molecules in the soot generated during fullerene production, says Veit Elser, whose group at Cornell University studied a theoretical molecule containing 216 carbon atoms.

Vanderbilt and Jerry Tersoff at the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y., call their new 168-carbon molecule buckygym because of its repeating, jungle-gym-like structure. Using a computer program, they constructed the buckygym by substituting seven-sided rings of carbon where fullerenes typically have five-sided rings: Six-sided rings surround each seven-sided ring, and each six-sided ring is surrounded by alternating six- and seven-sided rings.

"If you use this [substitution] pattern, [the molecule] does close in on itself, but in a complex way," Tersoff says. A fullerene's 12 pentagons make the carbon sheet bend inward. But septagons cause the sheet to curl in along one axis and outward along the perpendicular axis, so parts of these sheets resemble saddles. Instead of joining to form a ball, the saddle-like segments form a network of short tubes. Molecules join and become repeating units in a lattice arrangement. The arrangement is tetrahedral, like the structure of diamond, and leads to a structure that looks nothing like a buckyball's, he adds.

"It's sort of a lacy network, with all this empty space," says Tersoff. "Yet even though it is mostly vacuum, it's still macroscopically rigid." Thus, the teams expect a material made with these molecules to be quite strong, but lightweight. Also, these molecules seem more stable than buckyballs. The seven-sided rings allow carbons to bond with one another with less strain than do pentagons, note both research groups. Vanderbilt and Tersoff calculate that the buckygym needs about one-sixth the energy per atom that the buckyball needs to form.

Working with Michael Teter at Corning Inc., in Corning, N.Y., Elser and his group decided to add extra hexagons as well as replace the pentagons with septagons, thereby making it easier for repeating molecules to link up with less strain. In their report in the Jan. 23 NATURE, they call the substance schwarzite. They also studied theoretical molecules with eight-carbon rings.

"The big question is the feasibility of synthesizing these things," says Elser. "We're in the same position that the buckyball people were in five or six years ago." Both groups suspect, however, that parts of these molecules may form during the production of fullerenes. Slow-growing sheets curl inward to make buckyballs, while the fastest-growing sheets of carbon may take on these saddle curves, Elser adds.

To help chemists recognize these new molecules when they see them, Vanderbilt and Tersoff plan to calculate buckygym's electronic structure and vibration modes, characteristics that would signal the existence of saddle-shaped carbon sheets. *— E. Pennisi*