

of each haltere, and they in turn send a revised message to the wing's steering muscles, one that might translate into "turn left," as well as "rotate the body 5 degrees." "It's a different way to think about halteres," comments Cole Gilbert, a neuroethologist at Cornell University in Ithaca, New York.

Gilbert's team has additional results supporting this new view. The position of the head relative to the rest of the body also influences the flight path, and his group recently found that sensors in the neck that monitor head position relative to the thorax in the fly relay that information not just to the wings but also to the halteres.

A dual role for the halteres makes sense from a functional standpoint, Dickinson says. Instead of having to override the stabilizer system in the halteres, which tends to keep a fly flying straight, signals from the brain telling the fly to change course may work through the stabilizer system. As a result, the fly can change course in less than 30 milliseconds, without disabling its gyroscope.

This setup would also be consistent with evolution's penchant for tinkering with preexisting circuitry, Robertson adds. Most researchers think that the fly's ancestors had two pairs of wings and that during evolution the rear pair degenerated into halteres. This improved the fly's maneuverability by helping it keep from tumbling out of control as it zips about. But the neural connections that originally allowed the two pairs of wings to coordinate their activities may have been retained and refined as this new function evolved. "You can really see how evolution has exploited circuitry in the brain that was there in a much more primitive system to create a system that looks very, very different," says neurobiologist Heinrich Reichert at the University of Basel in Switzerland.

Still, Dickinson has yet to prove that the haltere is relaying flight commands to the wing. For one, despite Dickinson's failure to detect input from the fly visual system to the wing steering muscle, neurobiologist Nicholas Strausfeld at the University of Arizona in Tucson has described a physical connection between the visual parts of the brain and the wing steering muscle. The role of that connection is unclear, but its existence means that direct input to the wing muscles can't be ruled out.

To try to confirm his new ideas, Dickinson hopes to show that the haltere steering muscles do influence the wing steering muscles. And he may not be alone in his efforts. "It's such an interesting idea," Robertson says, "that now people will go out and try to find evidence for or against it."

—Elizabeth Pennisi

ATMOSPHERIC CHEMISTRY

Ozone Loss, Greenhouse Gases Linked

Buffeted by scores of news accounts, the public has sometimes mixed up global warming, which is fueled by heat-trapping gases in the lower atmosphere, and stratospheric ozone destruction, spurred by voracious chlorine compounds like chlorofluorocarbons. Now a computer model suggests there may be a real connection between the two processes. For the first time, a single model has combined greenhouse warming and ozone depletion in a long-term simulation, and the results are sobering: Greenhouse gases and chlorofluorocarbons together may be ganging up to destroy ozone.

In the wake of global controls on ozone-destroying compounds, most observers expected that the annual Antarctic ozone hole would fade, and the more modest Arctic ozone losses diminish, as atmospheric chlorine declines. But in this week's issue of *Nature*, a group from NASA's Goddard Institute for Space Studies (GISS) in New York City reports that their model indicates that during the next few decades, greenhouse gases will trigger a springtime ozone hole over the Arctic, much like the one now over the Antarctic.

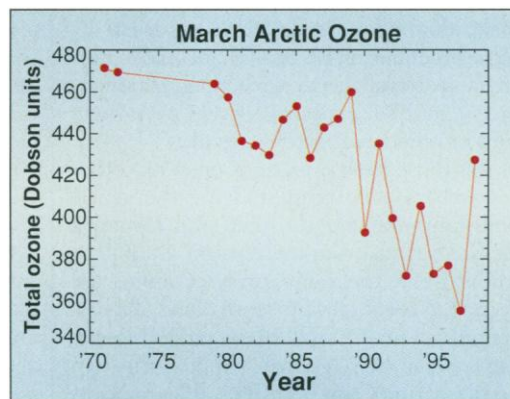
Atmospheric researchers are taking these results seriously, although they caution that the model is rather crude. "It's a bold calculation and an important result," says atmospheric physicist Paul Newman of NASA's Goddard Space Flight Center in Greenbelt, Maryland. "But it's a really soft result," because the model is relatively simple. Still, the recent behavior of Arctic ozone tends to support the result. Says ozone researcher Ross Salawitch of the Jet Propulsion Laboratory in Pasadena, California: "I think they may be on to something."

The link between ozone destruction and greenhouse gases involves temperature, but cooling rather than warming. Stratospheric chlorine-ozone reactions in polar regions are catalyzed by icy cloud crystals that form only in the most extreme cold. The colder it gets and the longer that cold persists into the spring—when the other key ingredient, sunshine, appears—the more ozone will be destroyed. Greenhouse gases warm the lower atmosphere, but they can also cool the polar stratosphere by radiating heat to space and by changing atmospheric heat transport.

When GISS modelers Drew Shindell, David Rind, and Patrick Lonergan ran their global ocean-atmosphere climate model with ozone chemistry included, they found that projected increases in greenhouse gases progressively chilled the model's wintertime

stratospheric temperatures over the poles by 8° to 10°C. Arctic ozone losses, rather than declining in step with decreasing chlorine, worsened until the 2010s and then slowly recovered. During the worst years, up to 65% of Arctic ozone was destroyed, a larger proportion than in the current Antarctic ozone hole. The same process would delay healing of the Antarctic ozone hole, but it would cause minimal additional ozone loss because the hole there is already so severe.

Researchers are intrigued by the model



SOURCE: P. A. NEWMAN/NASA/GSFC

A hole in the making? Although it bounced back this year, ozone has been declining over the Arctic.

results but note that the only way a modeler can find enough computer time to project this far into the future "is to use a rather crude model," as Newman puts it. One concern, for example, is that some other models wouldn't produce as much greenhouse-induced reduction in the heat delivered to the polar stratosphere. Still, even though the GISS model "is fudged up and has a lot of patches," says stratospheric modeler Jerry D. Mahlman of the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, "their punch lines are all plausible."

What's more, the GISS model simulation of the 1990s resembles what actually happened—the wintertime Arctic stratosphere has gotten progressively colder and more depleted in ozone. In the spring of 1997, ozone loss was already half as severe as the gloomiest model projection, for around 2015. But as if to show how hard it will be to sort out the effect of greenhouse gases in the real world, Arctic ozone losses this spring dropped to near zero, presumably because of natural climate variability. Given all these uncertainties, the best result of the GISS study, says Newman, may be the enhanced awareness that two great human alterations of the atmosphere—greenhouse warming and ozone depletion—are indeed interdependent.

—Richard A. Kerr