CLIMATE CHANGE

Possibly Vast Greenhouse Gas Sponge Ignites Controversy

As greenhouse warming experts try to predict how much the world's climate may heat up in the next century, they keep bumping up against a mystery: Where does much of the carbon dioxide (CO_2) pumped into the air actually end up? Answering this question could have huge ramifications for nations that ratify the climate change treaty signed in Kyoto, Japan, last December: Countries shown to harbor substantial carbon "sinks" could argue that an ability to soak up excess CO_2 should offset their emissions.

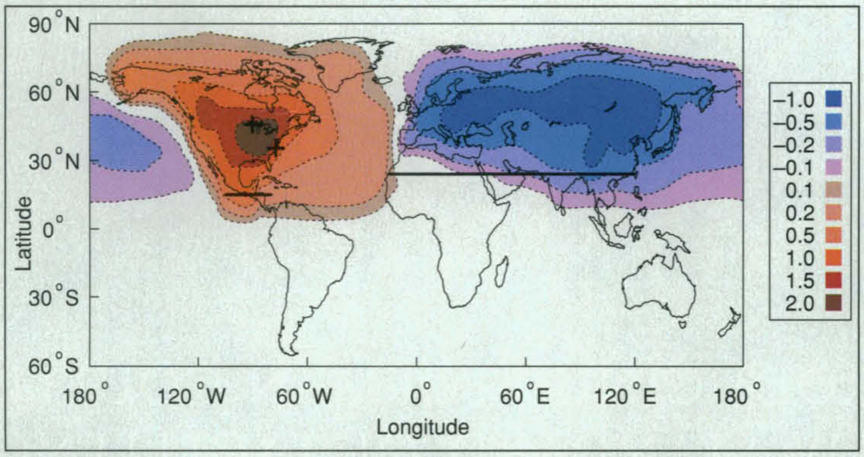
If those arguments prevail, it appears that North America may have drawn the winning ticket in the carbon sink sweepstakes. In what is shaping up as one of the most controversial findings yet to emerge in the greenhouse gas debate, a team of researchers on page 442 of this issue of *Science* presents evidence that North America sops up a whopping 1.7 petagrams of carbon a year—enough to suck up every ton of carbon discharged annually by fossil fuel burning in Canada and the United States. The magnitude of the apparent sink, says team member Jorge Sarmiento of Princeton University, "is going to be a lightning rod for all sorts of criticism."

Indeed, critics have already thrown up a fistful of red flags, attacking the study for everything from its methodology to its implications. "There's a huge amount of skepticism about the result," says ecologist David Schimel of the National Center for Atmospheric Research in Boulder, Colorado, who notes that at least one other group has calculated a much smaller North American sink. Moreover, a second paper in this issue—by a group led by Oliver Phillips of the University of Leeds in the United Kingdom (p. 439)—adds to the uncertainty. It points to a carbon sink in tropical South America so large that it is hard to reconcile with the Sarmiento group's results.

Especially worrisome, Schimel and others say, is that groups opposed to the Kyoto treaty will seize on the estimate to argue that the United States doesn't need to reduce its emissions to comply with the accord. "We're all really concerned that many people will find it convenient to accept the result," Schimel says. At the same time, scientists say this sort of calculation is a key step toward honing our understanding of the global carbon cycle. "The authors deserve a lot of credit for sticking their necks out," says climate modeler Inez Fung of the University of California, Berkeley.

At the heart of the debate is a simple math problem, resembling a chronic inability to balance one's checkbook, that has bedeviled scientists for nearly 2 decades. The balance sheet looks like this: Less than half of the 7.1 petagrams of carbon produced by human activity each year stays in the atmosphere. Although about 2 petagrams go into the oceans, another 1.1 to 2.2 petagrams appear to vanish into the land, likely taken up by plants during photosynthesis. Figuring out what's going on—whether the extra CO_2 is spurring faster tree growth, for example, or carbon is disappearing into soils—is crucial to learning whether reforestation and other actions might help stave off warming (*Science*, 24 July, p. 504). "If you understood the mechanism, you'd be in a much better position to say whether the sink will continue," says biogeochemist Richard Houghton of Woods Hole Research Center in Massachusetts.

To get at how much carbon the different land masses are absorbing, Sarmiento and his colleagues with the Carbon Modeling Consortium (CMC), based at Princeton, used an approach called inversion modeling. They first gathered data on atmospheric CO_2 levels taken from 1988 to 1992 at 63 ocean-sampling stations. Next, they divided the world into three regions—Eurasia, North America, and the rest—then fed the CO_2 data into two mathematical models: one that estimates how much carbon the oceans absorb and release, and another that gauges how CO_2 is spread across the globe by wind currents. When they fitted their models to the data, they found that, surprisingly, CO_2 levels dropped off slightly from west to east across North America—even though fossil fuel emissions should boost levels in the east. That meant there must be a big carbon sink in North America.



Disappearing act. Contours show how predicted CO_2 levels (in parts per million) would change if there were no terrestrial uptake in North America. Measured levels decline, rather than increase, from west to east North America, however, implying a large carbon sink.

Straining belief among other experts is the sink's estimated magnitude—1.7 petagrams of carbon per year, plus or minus 0.5 petagrams—roughly equaling the continent's fossil fuel carbon emissions of 1.6 petagrams. "It's hard for me to know where that much carbon could be accumulating in North America," says Houghton. Data from forest inventories suggest the U.S. sink absorbs only 0.2 to 0.3 petagrams of carbon a year. Sarmiento's team suggests that the inventories have missed a lot of forest regrowth on abandoned farmland and formerly logged forests in the east fertilized by CO_2 or nitrogen pollution, and that they fail to account for carbon stored in soils and wetlands. But the result also suggests that Eurasia's immense forests are taking up only a fifth as much carbon as U.S. forests. "Ecologically, it seems al-

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most incomprehensible," Schimel says.

Several modelers contend that the study is riddled with uncertainties. For one thing, the two models used to gauge carbon flux "could easily be off by just a little bit, and you get a very different conclusion," says Fung. The results could also be skewed by a dearth of data from the North Atlantic, as the authors note in their paper. For example, the group threw out readings off Sable Island, Nova Scotia, because the data were unreliable, says team member Pieter Tans of the National Oceanic and Atmospheric Administration. Factoring in Sable Island, the sink shrinks by 30%.

Even if the results do hold up, observers note, the CMC study's time period includes the 1991 Mount Pinatubo eruption, which led to cooler, wetter conditions and a much higher global carbon uptake than usual. "Some of this sink must clearly be … transient," says Martin Heimann, a modeler at the Max Planck Institute for Biogeochemistry in Jena, Germany. And the findings clash with those from a team led by Peter Rayner of Monash University in Australia, which calculates a North American sink of only 0.6 petagrams of carbon from 1988 to 1992—about one-third the CMC group's estimate. The Australian group's results will be published next year in *Tellus*.

The CMC team acknowledges that its results strain credibility. "I have trouble quite believing" the size of the sink, says Tans, adding that "We're pushing the data pretty far." But, says Sarmiento, "we've really carefully analyzed the data in a lot of different ways." U.S. Geological Survey geochemist Eric Sundquist agrees: "The paper is a credible and rigorous interpretation of the available data."

More and better data, including direct measurements of carbon storage and flux over land, will be needed to narrow the gap between the two studies. Already, this approach has turned up a big surprise: According to the U.K. group's results, undisturbed tropical forests in South America are getting thicker and may account for about 40% of the missing sink, a figure seemingly at odds with the CMC group's inversion results. The study is the first to pool data from measuring carbon storage, or biomass, over 2 decades at over 150 tropical forest plots worldwide. "This illustrates the types of studies that really need to be integrated," says Sundquist.

Before this research has time to mature, however, the possibly vast North American carbon sink could be the subject of heated debate in climate treaty implementation talks next month in Buenos Aires, Argentina. If the CMC team's findings are accurate, "the most obvious conclusion" would be that "there's no need for the U.S. and Canada to curb emissions," says Heimann. Indeed, Steven Crookshank of the American Petroleum Institute says the study "calls into question the scientific basis on which we're making these decisions, when we still don't know if the United States is even emitting any carbon in the net."

But some observers argue that a large North American sink should not be an excuse to go easy on emission controls. Maturing forests eventually stop storing carbon, so "this part of the missing sink [won't] be with us forever or even much longer," says atmospheric physicist Michael Oppenheimer of the Environmental Defense Fund in New York City. "The existence of the sink isn't important. What's important is the changes in the sink."

–JOCELYN KAISER

SCIENCE EDUCATION

California Adopts Controversial Standards

Third-graders in California will be taught about the periodic table, and sixth-graders will learn about Earth's "lithospheric plates" under a new set of standards* approved last week by the state Board of Education. The standards—which will be used to revise the state curriculum, set guidelines for textbooks, and develop statewide tests—have been sharply attacked by many science education reformers, who contend that they focus too much on detailed knowledge and too little on concepts. Although the board's action appears to put an end to the controversy, critics are hoping that the winner of next month's gubernatorial race will revive the debate.

The standards reflect California's first attempt to spell out what students in kindergarten through 12th grade should learn about science. They follow on the heels of mathematics standards that were even more hotly contested before their adoption last December (*Science*, 29 August 1997, p. 1194). New tests for the state's 5.5 million students are scheduled to be ready in 2000—the same year public school textbooks will have to meet new guidelines. Those are expected to influence science teaching across the country, as California represents more than 10% of the national textbook market.

Last Friday's unanimous vote by the board came after a final flurry of lobbying and letter-writing by more than a dozen scientific societies (including the American Association for the Advancement of Science, which publishes *Science*). Some of these groups offered to help rewrite the final draft to bring it into line with National Science Education Standards issued in 1996 by the National Academy of Sciences (NAS). "It doesn't match the [national] standards in any way," says NAS President Bruce Alberts. He and others believe that the state standards contain so much factual material that teachers will be forced to skip more in-depth learning activities that would give students a better understanding of the scientific process.

But others praise the California standards as a challenging but realistic set of ex-

* See http://www.ca.gov/goldstandards; revisions are at http://www.cde.ca.gov/board/board.html

WHAT THE BATTLE'S ABOUT

NAS STANDARDS (Physical Science, grades K-4)

"Materials can exist in different states—solid, liquid, and gas. Some common materials, such as water, can be changed from one state to another by heating or cooling."

[Elements are introduced in grades 5-8; atoms are covered in grades 9-12.]

CALIFORNIA STANDARDS (Physical Science, grade 3)

"Matter has three forms: solid, liquid, and gas. … Evaporation and melting are changes that occur when the objects are heated. … All matter is made of small particles called atoms, too small to see with our eyes. … There are over 100 different types of atoms which are displayed on the periodic table of elements."

Standard deviation. California's new science standards introduce the periodic table in grade 3, while those developed by the National Academy of Sciences discourage use of the terms "atom" and "molecule" with students younger than high school.

SOURCES: NATIONAL SCIENCE EDUCATION STANDARDS; CALIFORNIA ACADEMIC STANDARDS COMMISSION; PHOTO: VISUALS UNLIMITED