METHANE, Plants and

CLIMATE CHANGE

The surprising recent finding that living plants produce methane does not throw doubt on the cause of global warming. Human activities—not plants—are the source of the surge in this and other greenhouse gases

By Frank Keppler and Thomas Röckmann

What do you do as a scientist when you discover something that clearly contradicts the textbooks? The two of us faced this problem head-on when experiments we were running in 2005 showed that living vegetation produces the greenhouse gas methane. The established view held that only microbes that thrive without oxygen (anaerobic bacteria) can manufacture this gas. But our tests unexpectedly revealed that green plants also make methane—and quite a lot of it.

The first thing we did was look for errors in our experimental design and for every conceivable scenario that could have led us astray. Once we satisfied ourselves that our results were valid, though, we realized we had come across something very special, and we began to think about the consequences of our findings and how to present them to other researchers. Difficult as this discovery had been for us to accept, trying to convince our scientific peers and the public was almost impossible—in large part because we had to explain how such an important source of methane could have been overlooked for decades by the many able investigators studying methane and puzzling over climate change.

Natural Gas

MOST PEOPLE KNOW methane (often written as the chemical formula CH_4) as natural gas. Found in oil fields and coal beds as well as in natural gas fields, it has become an important source of energy and will most likely remain so given the limited reserves of oil on the planet. Approximately 600 million metric tons of it—both anthropogenic (from human activities) and natural—rise into the atmosphere every year. Most of these emissions have been thought to come from the decay of nonfossil organic material as a result of activity by anaerobic bacteria. Wetlands such as swamps, marshes and rice paddies provide the greatest share. Cattle, sheep and termites also make methane, as a by-product of anaerobic microbial digestion in their gut. Forest and savanna fires release methane, as does the combustion of fossil fuels [*see box on page 57*]. Over the years, researchers have gained considerable knowledge about the global methane cycle, and the consensus of the Intergovernmental Panel on Climate Change (IPCC) in 2001 was that the major sources had probably been identified (although the proportion each source contributes was still uncertain).

Nevertheless, some observations were difficult to explain. For instance, large fluctuations of atmospheric methane during the ice ages and warm ages, which have been reconstructed from air bubbles trapped in ice cores, remained a mystery. But no scientist in 2001 would have factored in direct emis-

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sions of methane by plants, because no one suspected that biological production of methane by anything other than microbial anaerobic processes was possible.

Knowing the sources of methane and how much they emit is important because methane is an extremely efficient greenhouse gas. Much more carbon dioxide is spewed into the atmosphere every year, but one kilogram of methane warms the earth 23 times more than a kilogram of carbon dioxide does. As a result of human activities, the concentration of methane in the atmosphere has almost tripled over the past 150 years. Will it continue to increase into the 21st century? Can emissions be reduced? Climate scientists need to answer such questions, and to do so we must know the origin and fate of this important gas.

Startling Findings

THE IDEA OF INVESTIGATING plants as methane emitters grew out of research we had been conducting on chloromethane, a chlorinated gas that destroys ozone and was thought to come mainly from the oceans and forest fires. A few years ago, while working at the Department of Agriculture and Food Science in Northern Ireland, we discovered that aging plants provide most of the chloromethane found in the atmosphere. Because methane, like chloromethane, is released during the burning of biomass, we wondered whether intact plants might also release methane.

To satisfy our curiosity, we collected 30 different kinds of tree leaves and grasses from tropical and temperate regions and placed them in small chambers with typical concentrations of atmospheric oxygen. To our amazement, all of the various kinds of leaves and plant litter produced methane. Usually a gram of dried plant material releases between 0.2 and three nanograms (one billionth of a gram) of methane an hour. These relatively tiny amounts were difficult to monitor, even using our highly sensitive state-of-the-art equipment.

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The task was made still more challenging because we had to differentiate between methane produced by plant tissue and the high background levels normally present in ambient air. We believe this difficulty is what prevented biologists from observing the phenomenon earlier. The secret to our discovery was that we removed the interfering effect of the natural methane background by flushing the chambers with methane-free air before the start of each experiment. We were then able to measure the methane released by plant tissue.

Our curiosity fueled, we undertook similar experiments with living plants [*see box on page 58*], and we found that the rates of methane production increased dramatically, jumping to 10 to 100 times those of leaves detached from plants. By running a series of experiments, we excluded the possibility that bacteria that thrive without oxygen produced the methane. Finally, we were absolutely convinced that living plants release methane in significant quantities. We could provide no immediate answers about the mechanism of how they did this, although we suspect that pectin, a substance in the walls of the plant cells, is involved. We decided that this question would have to await further research, which is currently under way. Because of methane's role in climate change, however, we realized it was crucial to begin to take into account the quantity of gas released into the atmosphere by this newly discovered source.

How much might plants be contributing to the planet's methane totals? It was immediately obvious to us that even though a single leaf or plant made only tiny amounts of methane, these small bits would add up quickly because plants cover a substantial part of the globe. We were nonetheless astounded by the figure generated by our calculations: between 60 million and 240 million metric tons of methane come from plants every year—this constitutes 10 to 40 percent of annual global emissions. Most of it, about two thirds, originates in the vegetation-rich tropics. We knew, of course, that extrapolating global estimates from a limited sample of laboratory measurements was open to error. Still, the final number seemed extremely large—and if it surprised us, it would be heresy to many of our scientific peers.

Fortunately for us, support for our work soon came from an unexpected source. A group of environmental physicists in Heidelberg, Germany, was observing the earth's atmosphere from space. In 2005 the scientists' satellite measurements revealed "clouds" of methane over tropical forests [*see illustration on page 59*]. They reported that their observa-

Overview/*Nature's Surprise*

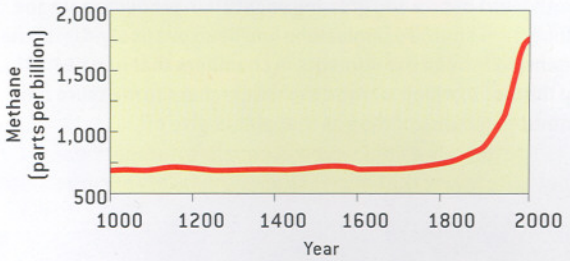
- The established view has been that methane (natural gas) is produced by microbes that thrive without oxygen, but experiments by the authors' team unexpectedly revealed that living plants also manufacture this potent greenhouse gas.
- Although this startling finding can explain many previously puzzling observations, a number of scientists are still skeptical, in particular about the amount of methane that plants generate. Knowing the sources of methane and how much they emit is important because of methane's role in trapping heat.
- An early misinterpretation of the finding suggested that forests might actually be contributing to global warming, but the authors emphasize that plants do not contribute to the recent increase in methane and global warming.

THE TEXTBOOK VIEW

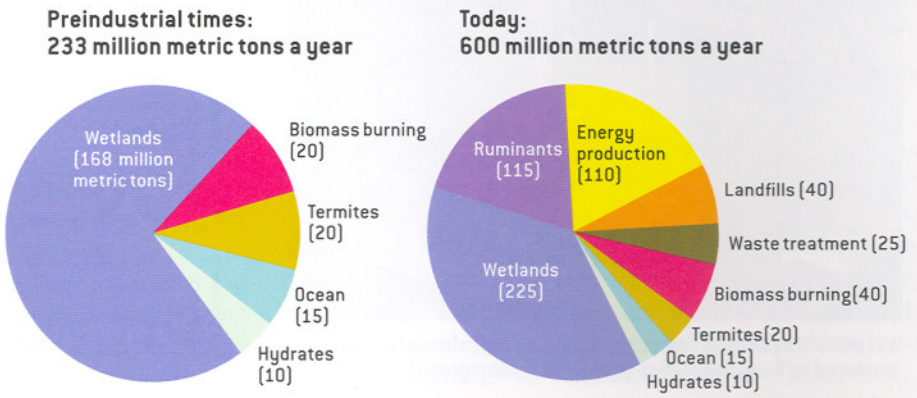
In the past 150 years, methane emissions into the atmosphere have roughly tripled (*graph*), and today some 600 million metric tons are sent into the air annually. That rise is a concern because methane, like carbon dioxide, traps heat in the earth's atmosphere and therefore contributes to global warming.

Until the authors and their colleagues published their recent discoveries, traditional thinking held that all natural releases of methane resulted from the activity of bacteria that thrive in wet, oxygen-poor environments. Such environments include swamps and rice paddies as well as the digestive systems of termites and ruminants. And analyses of the sources of the gas in the environment (*pie charts*) indicated that the dramatic rise in methane concentrations since the mid-1800s has stemmed from human industrial activities (such as the use of fossil fuels for energy) and increased rice cultivation and breeding of ruminants (because of population growth). The authors' work casts no doubt on the explanation for why methane concentrations in the atmosphere have increased, but estimates of the relative contributions to methane levels from natural sources will have to be revised.

Methane Concentration in the Atmosphere



Methane Emissions



tions could not be explained by simply using the current understanding of the global methane budget. In light of our findings, however, their work made sense: green vegetation was the source of the methane clouds.

Recently further support has come from Paul J. Crutzen, a 1995 Nobel Prize winner, and his colleagues. After our findings were published in January 2006, they reanalyzed measurements made in 1988 of air samples from the Venezuelan savanna and concluded that 30 million to 60 million metric tons of methane could be released from vegetation in these regions. Crutzen said that "looking back to 1988, we could have made the discovery, but accepting the general wisdom that methane can only be produced under anaerobic conditions, we missed the boat."

Despite this support for our work, many scientists are still skeptical about methane emissions from plants, especially about our estimate of how much methane comes from vegetation. A number of our scientific colleagues are therefore recalculating the budget for the plant source, using different methods from ours but applying our emission rates. Of course, we keenly await an independent verification of our laboratory findings.

Solving an Old Puzzle

OUR FINDINGS WOULD EXPLAIN a trend that has puzzled climate scientists for years: fluctuations in methane levels in parallel with changes in global temperatures. Ice cores serve as natural archives that store information about atmospheric composition and climate variability going back almost a million years. Tiny bubbles of air trapped in the ice reveal the relative concentrations of atmospheric gases in the past [*see box on next page*]. We see in the ice cores, for example, that variations of past carbon dioxide levels are closely linked to changes in global temperatures. During ice ages, carbon dioxide concentrations are low; during warm spells, levels increase.

In general, methane concentrations follow the same trend as carbon dioxide, but the reason has been unclear. Scientists have tried to use models of wetlands (the only major natural source of methane previously believed to exist) to reconstruct the curious variations of past methane levels. Yet they found it difficult to reproduce the reported differences in atmospheric methane levels between glacial and interglacial periods.

THE AUTHORS

FRANK KEPPLER and *THOMAS RÖCKMANN* first discovered methane emissions from plants when they were working together at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany. Keppler earned a Ph.D. in environmental geochemistry from the University of Heidelberg in 2000. He recently received a European Young Investigator Award (EURYI) to build his own research group at the Max Planck Institute for Chemistry in Mainz. Röckmann received his Ph.D. from the University of Heidelberg. In 2005 he was appointed full professor at the Institute for Marine and Atmospheric Research Utrecht in the Netherlands.

LAURIE GRACE AND JANA BRENNING

Questions for Review

TEST YOUR COMPREHENSION

1. What is the best way for scientists to find out how the levels of atmospheric methane changed over the past 1 million years?
   a. By measuring the width of tree rings and knowing that growth (wider rings) is promoted by warm, wet climates
   b. By studying the yields of domestic and wild rice, knowing that yields increase in warm, wet climates
   c. By studying the thickness of annual layers of ice in the ice sheets of Greenland and Antarctica
   d. By examining the ratio of deuterium (a hydrogen isotope) and standard hydrogen in strata obtained from peat bog cores
   e. By measuring levels of methane present in air bubbles trapped in ice cores of known age

2. Before the discovery that plants produce methane, it was difficult to explain the observation that methane levels
   a. remained constant in the face of climate change.
   b. fluctuated in ways that were independent of periods of relative warm and cold.
   c. fluctuated in step with ice ages, so that there were relatively low levels of methane in cold periods and relatively high levels in warm periods.
   d. fell when there was abundant vegetation and rose when vegetation was sparse.
   e. rose nearly continuously starting 100,000 years ago to reach the high levels seen today.

3. A significant concern about atmospheric methane is that, relative to carbon dioxide,
   a. methane is more than 20 times as effective in trapping heat.
   b. methane destroys ozone more effectively.
   c. methane is more toxic to humans and animals.
   d. methane is more combustible.
   e. methane provides greater support to plant growth.

4. For scientists to detect methane produced by plants, it was necessary to
   a. develop more sophisticated methane-detecting instrumentation.
   b. remove all methane from the air in which plants were incubated.
   c. treat plants with chemicals that physically link newly produced methane to the plant.
   d. dry plant tissue to remove the water that interferes with methane production.
   e. maintain moisture in plant tissues to prevent methane desiccation.

5. Most methane production by plants occurs
   a. in the tropics.
   b. in desert regions.
   c. in temperate zones.
   d. in the polar regions.
   e. over the open oceans.

6. Independent support for the idea that plants produce methane came from
   a. satellite measurements.
   b. measures made by oceanographic vessels sailing over open water.
   c. ecologists working in rainforest tree canopies.
   d. foresters measuring methane output in forests of the Pacific Northwest and Alaskan coasts.
   e. laboratory studies showing that decaying plants emit chloromethane.

7. A source of trapped methane (unknown in size, but possibly very large) is
   a. permanent ice sheets in polar regions.
   b. decaying wood, particularly in temperate regions.
   c. methane hydrates in ocean sediments.
   d. the Great Lakes.
   e. carbon dioxide reserves that can be converted to methane.

8. Plants promote global warming by releasing methane, but they also help prevent global warming by
   a. absorbing carbon dioxide.
   b. absorbing oxygen.
   c. releasing oxygen.
   d. contributing to biomass.
   e. respiration.

9. On balance, forests
   a. contribute to global warming.
   b. neither contribute to nor slow global warming.
   c. slow global warming.

10. If all non-crop plants were destroyed in an effort to reduce global warming by methane emissions, then
    a. global oxygen levels would decline sharply.
    b. global carbon dioxide levels would decline sharply.
    c. methane emissions from ruminant animals and bacteria would rise to maintain equilibrium levels of methane.
    d. methane emissions from methane hydrate deposits would increase to maintain equilibrium levels of methane.
    e. a new ice age would be triggered within decades of plant elimination.

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BIOLOGY IN SOCIETY

1. The authors were shocked to read the headline "Global Warming—Blame the Forests" that followed their first press release. How much truth is in the imaginary headline "Crazy Interpretations—Blame the Scientists?" Who's to blame when the press misinterprets or sensationalizes a scientific finding? How often does this occur? For what types of stories is misinterpretation most likely to be a problem?

2. The human role in climate change is an issue that is more contentious politically, due to ideological opposition to the idea, than it is scientifically. How do you think those who are opposed ideologically to the notion of humans contributing to global warming might interpret the finding that plants contribute 10–40% of atmospheric methane emissions? How might the same group interpret the fact that some scientists are skeptical about the amount of methane produced globally by plants? Are either of these interpretations justifiable?

3. How certain can we be about the causes of current global warming? How certain must we be before taking steps to limit emissions of greenhouse gases caused by human activities? Remember that a major reduction in greenhouse gas emissions would require significant, expensive changes in the way our industrial economy and society operate. Are we now certain enough about a human role in global warming that taking serious steps to curb emissions is warranted?

THINKING ABOUT SCIENCE

1. How can methane emissions from wetlands and animals be increasing when natural wetlands and global biodiversity are diminishing?

2. Kilogram for kilogram, methane is 23 times more effective than carbon dioxide as a greenhouse gas. Currently, about 600 million metric tons of methane is released into the atmosphere each year. In 2004, 7,900 million metric tons of carbon dioxide from the burning of fossil fuels was released into the atmosphere. Call the amount of potential global dioxide one global warming unit. How many global warming units does methane contribute annually?

3. How can plant methane production create a situation in which the climate is driven to become warmer and warmer? What event or events would be needed to break this upward spiral? What types of data would you need to test the hypothesis that fluctuating atmospheric methane levels have driven climate change?

WRITING ABOUT SCIENCE

Write a scene in a screenplay about Frank Keppler and Thomas Röckmann's discovery of methane release by plants, a discovery that contradicted the textbooks. Focus the dialogue on the discussion between Keppler and Röckmann as they realize their data is correct, but now face the task of convincing colleagues that accepted wisdom is off the mark.

1 e; 2 c; 3 a; 4 b; 5 a; 6 a; 7 c; 8 a; 9 c; 10 a