TEMPERATURE RISING

As Permafrost Thaws, Scientists Study the Risks

Josh Haner/The New York Times

Katey M. Walter Anthony, a scientist, investigated a plume of methane, a greenhouse gas, at an Alaskan lake. Dr. Walter Anthony is a leading researcher in studying the escape of methane. More Photos »

By JUSTIN GILLIS
Published: December 16, 2011

FAIRBANKS, Alaska — A bubble rose through a hole in the surface of a frozen lake. It popped, followed by another, and another, as if a pot were somehow boiling in the icy depths.

Every bursting bubble sent up a puff of methane, a powerful greenhouse gas generated beneath the lake from the decay of plant debris. These plants last saw the light of day 30,000 years ago and have been locked in a deep freeze — until now.

"That's a hot spot," declared Katey M. Walter Anthony, a leading scientist in studying the escape of methane. A few minutes later, she leaned perilously over the edge of the ice, plunging a bottle into the water to grab a gas sample.

It was another small clue for scientists struggling to understand one of the biggest looming mysteries about the future of the earth.

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In an Alaskan lake, bubbles of methane, a potent greenhouse gas, collect beneath the ice. More Photos »

Experts have long known that northern lands were a storehouse of frozen carbon, locked up in the form of leaves, roots and other organic matter trapped in icy soil — a mix that, when thawed, can produce methane and carbon dioxide, gases that trap heat and warm the planet. But they have been stunned in recent years to realize just how much organic debris is there.

A recent estimate suggests that the perennially frozen ground known as permafrost, which underlies nearly a quarter of the Northern Hemisphere, contains twice as much carbon as the entire atmosphere.

Temperatures are warming across much of that region, primarily, scientists believe, because of the rapid human release of greenhouse gases. Permafrost is warming, too. Some has already thawed, and other signs are emerging that the frozen carbon may be becoming unstable.

"It's like broccoli in your freezer," said Kevin Schaefer, a scientist at the National Snow and Ice Data Center in Boulder, Colo. "As long as the broccoli stays in the freezer, it's going to be O.K. But once you take it out of the freezer and put it in the fridge, it will thaw out and eventually decay."

If a substantial amount of the carbon should enter the atmosphere, it would intensify the planetary warming. An especially worrisome possibility is that a significant proportion will emerge not as carbon dioxide, the gas that usually forms when organic material breaks down, but as methane, produced when the breakdown occurs in lakes or wetlands. Methane is especially potent at trapping the sun's heat, and the potential for large new methane emissions in the Arctic is one of the biggest wild cards in climate science.

Scientists have declared that understanding the problem is a major priority. The United States Department of Energy and the European Union recently committed to new projects aimed at doing so, and NASA is considering a similar plan. But researchers say the money and people devoted to the issue are still minimal compared with the risk.

For now, scientists have many more questions than answers. Preliminary computer analyses, made only recently, suggest that the Arctic and sub-Arctic regions could eventually become an annual source of carbon equal to 15 percent or so of today's yearly emissions from human activities.

But those calculations were deliberately cautious. A recent survey drew on the expertise of 41 permafrost scientists to offer more informal projections. They estimated that if human fossil-fuel burning remained high and the planet warmed sharply, the gases from permafrost could eventually equal 35 percent of today's annual human emissions.


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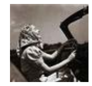
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The experts also said that if humanity began getting its own emissions under control soon, the greenhouse gases emerging from permafrost could be kept to a much lower level, perhaps equivalent to 10 percent of today's human emissions.

Even at the low end, these numbers mean that the long-running international negotiations over greenhouse gases are likely to become more difficult, with less room for countries to continue burning large amounts of fossil fuels.

In the minds of most experts, the chief worry is not that the carbon in the permafrost will break down quickly — typical estimates say that will take more than a century, perhaps several — but that once the decomposition starts, it will be impossible to stop.

"Even if it's 5 or 10 percent of today's emissions, it's exceptionally worrying, and 30 percent is humongous," said Josep G. Canadell, a scientist in Australia who runs a global program to monitor greenhouse gases. "It will be a chronic source of emissions that will last hundreds of years."

A troubling trend has emerged recently: Wildfires are increasing across much of the north, and early research suggests that extensive burning could lead to a more rapid thaw of permafrost.

Rise and Fall of Permafrost

Standing on a bluff the other day, overlooking an immense river valley, A. David McGuire, a scientist from the University of Alaska, Fairbanks, sketched out two million years of the region's history. It was the peculiar geology of western North America and eastern Siberia, he said, that caused so much plant debris to get locked in an ice box there.

These areas were not covered in glaciers during the last ice age, but the climate was frigid, with powerful winds. The winds and rivers carried immense volumes of silt and dust that settled in the lowlands of Alaska and Siberia.

A thin layer of this soil thawed on top during the summers and grasses grew, capturing carbon dioxide. In the bitter winters, grass roots, leaves and even animal parts froze before they could decompose. Layer after layer of permafrost built up.

At the peak of the ice age, 20,000 years ago, the frozen ground was more extensive than today, stretching deep into parts of the lower 48 states that were not covered by ice sheets. Climate-change contrarians like to point to that history, contending that any melting of permafrost and ice sheets today is simply the tail end of the ice age.

Citing permafrost temperatures for northern Alaska — which, though rising rapidly, remain well below freezing — an organization called the Center for the Study of Carbon Dioxide and Global Change claimed that permafrost is in "no more danger of being wiped out any time soon than it was in the days of our great-grandparents."

But mainstream scientists, while hoping the breakdown of permafrost will indeed be slow, reject that argument. They say the climate was reasonably stable for the past 10,000 years or so, during the period when human civilization arose. Now, as people burn immense amounts of carbon in the form of fossil fuels, the planet's temperature is rising, and the Arctic is warming twice as fast. That, scientists say, puts the remaining permafrost deposits at risk.

For several decades, researchers have been monitoring permafrost temperatures in hundreds of boreholes across the north. The temperatures have occasionally decreased in some regions for periods as long as a decade, but the overall trend has been a relentless rise, with temperatures now increasing fastest in the most northerly areas.

Thawing has been most notable at the southern margins. Across huge areas, including much of central Alaska, permafrost is hovering just below the freezing point, and is expected to start thawing in earnest as soon as the 2020s. In northern Alaska and northern Siberia, where permafrost is at least 12 degrees Fahrenheit below freezing, experts say it should take longer.

“Even in a greenhouse-warmed world, it will still get cold and dark in the Arctic in the winter,” said Mark Serreze, director of the snow and ice data center in Boulder.

Scientists need better inventories of the ancient carbon. The best estimate so far was published in 2009 by a Canadian scientist, Charles Tarnocai, and some colleagues. They calculated that there was about 1.7 trillion tons of carbon in soils of the northern regions, about 88 percent of it locked in permafrost. That is about two and a half times the amount of carbon in the atmosphere.

Philippe Ciais, a leading French scientist, wrote at the time that he was “stunned” by the estimate, a large upward revision from previous calculations.

“If, in a warmer world, bacteria decompose organic soil matter faster, releasing carbon dioxide,” Dr. Ciais wrote, “this will set up a positive feedback loop, speeding up global warming.”

Plumes of Methane

Katey Walter Anthony had been told to hunt for methane, and she could not find it.

As a young researcher at the University of Alaska, Fairbanks, she wanted to figure out how much of that gas was escaping from lakes in areas of permafrost thaw. She was doing field work in Siberia in 2000, scattering bubble traps around various lakes in the summer, but she got almost nothing.

Then, that October, the lakes froze over. Plumes of methane that had been hard to spot on a choppy lake surface in summer suddenly became more visible.

“I went out on the ice, this black ice, and it looked like the starry night sky,” Dr. Walter Anthony said. “You could see these bubble clusters everywhere. I realized — ‘aha!’ — this is where all the methane is.”

When organic material comes out of the deep freeze, it is consumed by bacteria. If the material is well-aerated, bacteria that breathe oxygen will perform the breakdown, and the carbon will enter the air as carbon dioxide, the primary greenhouse gas. But in areas where oxygen is limited, like the bottom of a lake or wetland, a group of bacteria called methanogens will break down the organic material, and the carbon will emerge as methane.

Scientists are worried about both gases. They believe that most of the carbon will emerge as carbon dioxide, with only a few percent of it being converted to methane. But because methane is such a potent greenhouse gas, the 41 experts in the recent survey predicted that it would trap about as much heat as the carbon dioxide would.

Dr. Walter Anthony’s seminal discovery was that methane rose from lake bottoms not as diffuse leaks, as many scientists had long assumed, but in a handful of scattered, vigorous plumes, some of them capable of putting out many quarts of gas per day. In certain lakes they accounted for most of the emerging methane, but previous research had not taken them into consideration. That meant big upward revisions were probably needed in estimates of the amount of methane lakes might emit as permafrost thawed.

Most of the lakes Dr. Walter Anthony studies were formed by a peculiar mechanism. Permafrost that is frozen hard supports the ground surface, almost the way a concrete pillar supports a building. But when thaw begins, the ground sometimes turns to mush and the entire land surface collapses into a low-lying area, known as a thermokarst. A lake or wetland can form there, with the dark surface of the water capturing the sun's heat and causing still more permafrost to thaw nearby.

Near thermokarst locations, trees often lean crazily because their roots are disturbed by the rapid changes in the underlying landscape, creating "drunken forests." And the thawing, as it feeds on itself, frees up more and more ancient plant debris.

One recent day, in 11-degree weather, Dr. Walter Anthony and an assistant, Amy Strohm, dragged equipment onto two frozen thermokarst lakes near Fairbanks. The fall had been unusually warm and the ice was thin, emitting thunderous cracks — but it held. In spots, methane bubbled so vigorously it had prevented the water from freezing. Dr. Walter Anthony, six months pregnant, bent over one plume to retrieve samples.

"This is thinner ice than we like," she said. "Don't tell my mother-in-law! My own mother doesn't know."

Dr. Walter Anthony had already run chemical tests on the methane from one of the lakes, dating the carbon molecules within the gas to 30,000 years ago. She has found carbon that old emerging at numerous spots around Fairbanks, and carbon as old as 43,000 years emerging from lakes in Siberia.

"These grasses were food for mammoths during the end of the last ice age," Dr. Walter Anthony said. "It was in the freezer for 30,000 to 40,000 years, and now the freezer door is open."

Scientists are not sure yet whether thermokarst lakes will become more common throughout the Arctic in a warming climate, a development that could greatly accelerate permafrost thaw and methane production. But they have already started to see increases in some regions, including northernmost Alaska.

"We expect increased thermokarst activity could be a very strong effect, but we don't really know," said Guido Grosse, another scientist at the University of Alaska, Fairbanks. He is working with Dr. Walter Anthony on precision mapping of thermokarst lakes and methane seeps, in the hope that the team can ultimately use satellites and aerial photography to detect trends.

With this kind of work still in the early stages, researchers are worried that the changes in the region may already be outrunning their ability to understand them, or to predict what will happen.

When the Tundra Burns

One day in 2007, on the plain in northern Alaska, a lightning strike set the tundra on fire.

Historically, tundra, a landscape of lichens, mosses and delicate plants, was too damp to burn. But the climate in the area is warming and drying, and fires in both the tundra and forest regions of Alaska are increasing.

The Anaktuvuk River fire burned about 400 square miles of tundra, and work on lake sediments showed that no fire of that scale had occurred in the region in at least 5,000 years.

Scientists have calculated that the fire and its aftermath sent a huge pulse of carbon into the air — as much as would be emitted in two years by a city the size of Miami. Scientists say the fire thawed the upper layer of permafrost and set off what they fear will be permanent shifts in the landscape.

Up to now, the Arctic has been absorbing carbon, on balance, and was once expected to keep doing so throughout this century. But recent analyses suggest that the permafrost thaw could turn the Arctic into a net source of carbon, possibly within a decade or two, and those studies did not account for fire.

“I maintain that the fastest way you’re going to lose permafrost and release permafrost carbon to the atmosphere is increasing fire frequency,” said Michelle C. Mack, a University of Florida scientist who is studying the Anaktuvuk fire. “It’s a rapid and catastrophic way you could completely change everything.”

The essential question scientists need to answer is whether the many factors they do not yet understand could speed the release of carbon from permafrost — or, possibly, slow it more than they expect.

For instance, nutrients released from thawing permafrost could spur denser plant growth in the Arctic, and the plants would take up some carbon dioxide. Conversely, should fires like the one at Anaktuvuk River race across warming northern landscapes, immense amounts of organic material in vegetation, soils, peat deposits and thawed permafrost could burn.

Edward A. G. Schuur, a University of Florida researcher who has done extensive field work in Alaska, is worried by the changes he already sees, including the discovery that carbon buried since before the dawn of civilization is now escaping.

“To me, it’s a spine-tingling feeling, if it’s really old carbon that hasn’t been in the air for a long time, and now it’s entering the air,” Dr. Schuur said. “That’s the fingerprint of a major disruption, and we aren’t going to be able to turn it off someday.”

A version of this article appeared in print on December 17, 2011, on page A1 of the New York edition with the headline: As Permafrost Thaws, Scientists Study the Risks.