Clouds Are Yielding Clues to Changes in Climate

Data from satellites and atmospheric probes begin to fill gaps in predictions of global warming.

By WILLIAM K. STEVENS

Fragile and fleeting, impossible to grasp, clouds have long eluded efforts to understand the powerful role they play in regulating the Earth's climate. More than any other single factor, their mysteries have kept scientists from making confident forecasts about global warming and the climatic changes that are expected to accompany it.

Now, in a rush of data from satellite observations and atmospheric probes, scientists are beginning to unravel the complexities of clouds and learn how they modulate the planet's temperature. They are finding, among other things, that the computerized mathematical models on which climatologists largely rely in forecasting climatic change are so far out of touch with reality that they might have to be partly reconstructed, not merely adjusted.

"In some cases tuning may be impossible; you may have to go back to the drawing board and rethink the whole process," said Veerabhadran Ramanathan, a climatologist at the University of Chicago who is in the forefront of the new research on clouds.

Scientists have long known that clouds present a paradox: they both cool and warm the Earth. But the new findings show that these effects are sometimes more powerful than had been thought, and that the heating and cooling effects are delicately balanced. A rise in global temperatures could upset this balance, the experts say, and even a small change could have far-reaching and still-unknown consequences.

The scientists are also finding that clouds display more complexity and variety than had been realized. Clouds in the tropics, for instance, differ from those in the temperate zones, and they affect the planet's heat balance differently. Likewise, clouds over water differ in character and heating effects from those over the continents. Their nature and effects also vary with the season and time of day.

At the same time, in another seeming paradox, some scientists suspect that for all their variety and complexity, clouds may behave according to a relatively simple set of underlying principles and that small-scale differences may balance out on the broad climatic scale. The scientists are working to isolate these principles and bell them down to a succinct concept that can be included in the climate prediction models.

They have not yet reached a point at which they can say how the world's clouds would behave if global temperatures rose, or how their behavior would affect the warming itself. But the most

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3. STRATOCUMULUS
These flat clouds lie in vast low layers over oceans in temperate zones. The tops reflect a surprisingly large amount of sunlight, for a net cooling effect. Global warming could shift them north or south, intensifying or moderating the warming.
Clouds Yield Clues to Global Climate Change

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optimistic among them believe that within 10 years enough will be known so that the models can be substantially corrected. If that happened, climatologists would be able to forecast the timing and extent of the expected global warming with far more confidence than today.

The models currently predict that an expected doubling of carbon dioxide in the atmosphere, largely as a result of the burning of fossil fuels, will cause the average global temperature to increase by 3 to 8 degrees Fahrenheit by about the middle of the next century. Carbon dioxide and other gases trap heat in the atmosphere much as a greenhouse does. Climatologists say this could result in widespread climatic change, increasing the frequency and severity of droughts and destructive storms and cause the sea level to rise.

This warming is not straightforward, however. It is both amplified and diminished by other constituents of the climate system to produce a net warming. Scientists say that all of these modulating factors, none is more important, nor as poorly represented in the models, as clouds.

What Was Known

Years of Research, Little Progress

A big part of the problem is that although experts have been studying clouds for decades, their investigations have been limited to relatively small-scale inquiries in only a few areas of the globe. They have known that clouds form when water condenses around dust particles or other minute nuclei, and that they are mostly air. "You almost wouldn't have predicted them," says Stephen C. K. Co, a cloud expert at the Brookhaven National Laboratory on Long Island, who explains that they are on the order of one part water to a million parts atmospheric gas.

Scientists have also known that for all their evanescence, clouds are the means by which the oceans and the atmosphere interact, and by which both heat and water are distributed around the globe. Sunlight hitting the ocean causes water to evaporate, which rises into cooler air and forms clouds. It condenses and falls as rain, releasing large amounts of latent heat in the process. This heat is the fundamental energy source driving all the winds of the atmosphere.

And they have known that in one guise, the minute cloud droplets reflect sunlight back into space, helping to keep the planet cool, and that in another they trap huge amounts of heat in the atmosphere.

But this is much of what scientists did not know about how clouds affect the global climate. "It was a sampling problem," said William B. Rossow of the Goddard Institute for Space Studies in New York City, who has been analyzing satellite data on cloud characteristics and behavior as part of an international research project. Primarily, he explained, scientists in the past had limited themselves only to studying clouds in the temperate zones and over the continents, where data collection was most feasible in the absence of satellites. "But we just never saw it on the scale of the whole planet," he said.

That is changing. Data collected by satellites and now being analyzed and published, along with the early results of intensive investigations of the workings of important kinds of cloud systems, are starting to provide scientists with the elements they need to put together a coherent picture of cloud behavior.

What's Been Found

Surprising Effects Over the Oceans

By analyzing satellite measurements of the earth's heating as part of the National Aeronautics and Space Administration's Earth Radiation Budget Experiment between 1984 and 1990, Dr. Ramanathan and his colleagues were surprised to find that globally, clouds amplified the greenhouse warming by an unexpectedly large amount — as much as if carbon dioxide in the atmosphere were not merely doubled, but multiplied by 250. But they also found that clouds reflected even more heat from the sun, exerting a net cooling effect on the planet.

Furthermore, they found that the effect is not uniform around the world, and this raises important concerns about global warming. To the scientists' surprise, the analysis showed that the huge storm systems of the tropics, with their towering 10-mile-high, anvil-shaped thunderheads called cumulonimbus clouds, exert a disproportional effect. They trap three times as much heat as clouds trap on a global average, but also reflect so much sunlight that the heating effect is canceled out. The computer models of climate behavior ignore these effects.

Since the tropics account for 20 percent of the earth's surface and the effects of the tropical cumulonimbus clouds are disproportional, the delicate heat balance they maintain is critical. "That raises a very intriguing question," said Dr. Ramanathan. "If the ocean warms, how would the balance shift? Just small changes in either the heating or the cooling could have a significant effect on the tropical heat budget."

A warmer ocean would likely cause more cloud formation, increasing both their heating and cooling effect. They would also be likely to build to higher altitudes, where it is colder. Clouds not only absorb some of the heat emitted by the earth and trap it in the atmosphere, they also emit some of it into space. But in the colder altitudes they emit less, less into space than they absorb below. Thus, said Dr. Ramanathan, higher clouds might upset the tropical heat balance and exacerbate the greenhouse effect.

Moreover, he said, the warmer ocean's production of more clouds could alter global patterns of air circulation and lead to a shift of both desert and moist regions to new latitudes. Analysis of the satellite data also showed that low-lying layers of sheet-like clouds with fluffy, curly edges, called stratus, cover large areas of the North Atlantic, North Pacific and the temperate parts of the Southern oceans. These, it was found, reflect enough sunlight to exert a net cooling effect locally, and this appears to account for some of the overall cooling effect worldwide.

The location of these clouds is determined by the earth's surface and the intricate interrelationships of climate that would be affected by global warming could cause them to shift either northward or southward, said D. What Happened

Pollution Alter th

As part of an initiative to research the nature of pollution, Dr. Ramanathan and his colleagues have been studying clouds over the western United States, which has a high concentration of pollutants. They found that the clouds are denser and reflect less sunlight than normal, which would increase the warming effect. They also found that the clouds are more prevalent over the warmer land areas, which would increase the cooling effect. This indicates that pollution can have a significant impact on cloud formation and climate change.

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New findings underscore the variety of clouds and their effects.

Some Key Clouds In the Global Equation

Cumulonimbus clouds, left: Heavy and dense, they extend vertically up to 10 miles. The cloud's upper portion is often flattened in an anvil shape.

Stratocumulus clouds, below left: Gray or white, or both, their elements are usually arranged regularly and nearly parallel, at heights below 6,500 feet.

Cirrus clouds, below: The highest of clouds, occurring at 20,000 feet, they are detached and featherlike, and often illuminated by the sun when lower clouds are submerged in shadow.

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Since the tropics account for 20 percent of the earth's surface and the effects of the tropical cumulonimbus clouds are disproportionate, the delicate balance of the oceans and the patterns of their global climate may be imprecise in the models’ predictions. For example, a modeler would look upon the predictions with great caution, said Dr. Kiehl. And as a model specialist, he said, he agrees with Dr. Ramanathan that it may be necessary to go back to the drawing board in some instances.

What Happens Inside Pollution Particles Alter the Actions

As part of a 10-year project to investigate cloud systems directly, researchers have also found some surprising characteristics in stratocumulus clouds over the western Pacific, where the sun is bright and the clouds are thin. These small particles are the nuclei around which cloud drops dower. The more particles, the more droplets, and the smaller they are likely to be. This produces a greater scattering effect on sunlight, which makes the clouds brighter and more reflective. Studies in the last three years have demonstrated that sulfate particles produced by the burning of fossil fuels have this effect.

The researchers were surprised to find that the man-made particles might be more important in the formation of the offshore California clouds than had been believed, said Stephen K. Cox of Colorado State University, the chairman of the experimental team. He said some of the clouds were brighter than had been expected, while others were darker.

The particles could produce either effect, he said. If they were big enough, they could form large drop, which would fall as rain. Smaller particles diffuse the cloud and dissipate it. The research team is still searching for a full explanation.

Project Fire has also put in the stratospheric clouds that form a kind of cloud passing over the earth, which is called by some scientists a "snow cloud." These clouds are composed of ice crystals and are sometimes called "mare's tails," a term that had been used in the past to describe a similar phenomenon.

"We detected a surprisingly large population of very small crystals," said Dr. Cox. Cirrus clouds, because of their altitude, have been thought to be heat-trappers. But the team's findings, said Dr. Cox, suggest that the ice crystals reflect more sunlight and could counterbalance the heat-trapping effects of greenhouse gases.

"None of the project's findings have been included in the computer models used to predict climate changes," he said. Indeed, the stratoscumulus clouds off California have not been represented in any way. The Project Fire findings, along with those of Dr. Ramanathan and others, illustrate what Dr. Rossow of the Goddard Institute for Space Studies calls "the variety of styles of cloudiness that occur on the globe." Dr. Rossow has been analyzing data from weather satellites as part of the International Satellite Cloud Climatology Project, which will establish four to six permanent observation sites. Their job, along with aircraft and balloon soundings, will be to measure cloud properties accurately.

These efforts are aimed at improving the prediction models. Cloud scientists are still some distance from incorporating all this information into the models. But they say they are learning the possibilities they have discovered.

Within that complexity, some scientists are beginning to believe that may lie a set of simple principles that explain how all the varying patterns of clouds work together. On the broad climatic scale, said Dr. Rossow, "the clouds may average out." It makes it look as if it's the same thing every day, he said. "It's still complex, but I think we're getting the possibility we can discover it.

In any case, he said, almost all the climate model specialists at some point "will surely be completely redesigning their cloud prediction subroutines." Dr. Ramanathan said that in the next two or three years, it might be possible to identify the major flaws in the treatment of clouds in the models, and Dr. Rossow said he believes that substantial improvements in the models would come relatively soon. "Some of us think it will take something useful in five years," he said. "Some say it may happen for maybe many tens of years.

There may never be a day when we can say, 'I think I understand it.' But our confidence ought to grow."