Science Times

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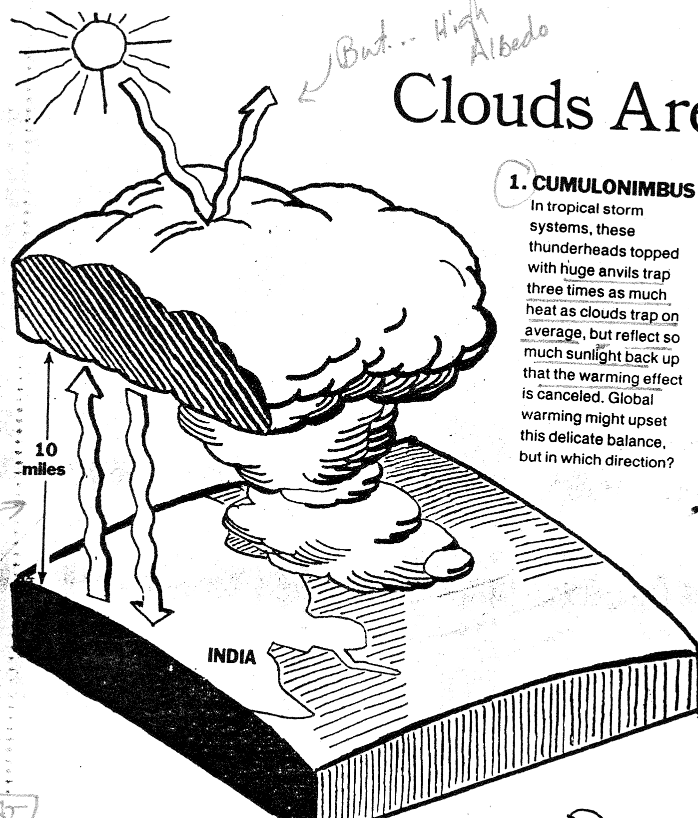
The New York Times

READING I.6

Clouds Are Yielding Clues to Changes in Climate



1. CUMULONIMBUS
In tropical storm systems, these thunderheads topped with huge anvils trap three times as much heat as clouds trap on average, but reflect so much sunlight back up that the warming effect is canceled. Global warming might upset this delicate balance, but in which direction?

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.

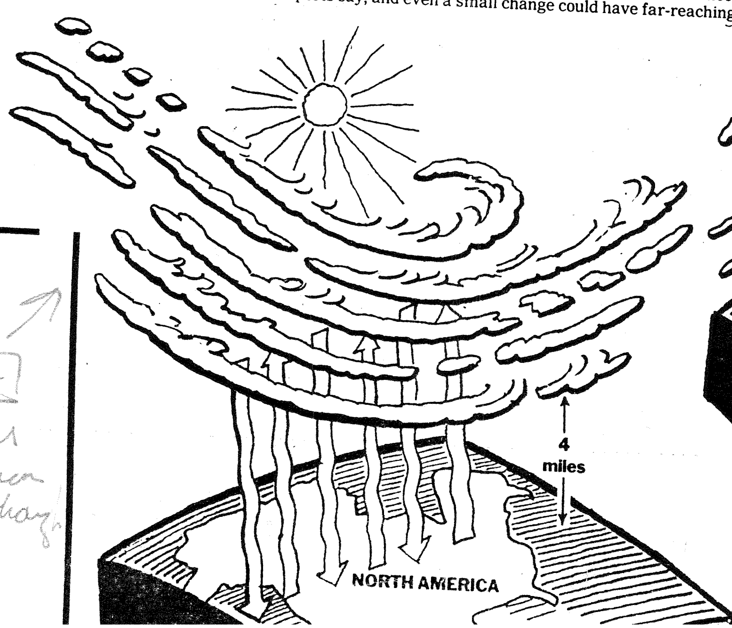
The scientists are also finding that clouds display more complexity and variety than had been realized. Clouds in the tropics, for instance, differ from those in the temperate zones, and they affect the planet's heat balance differently. Likewise, clouds over water differ in character and heating effects 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 boil them down to a succinct concept that can be included in the climate prediction models.

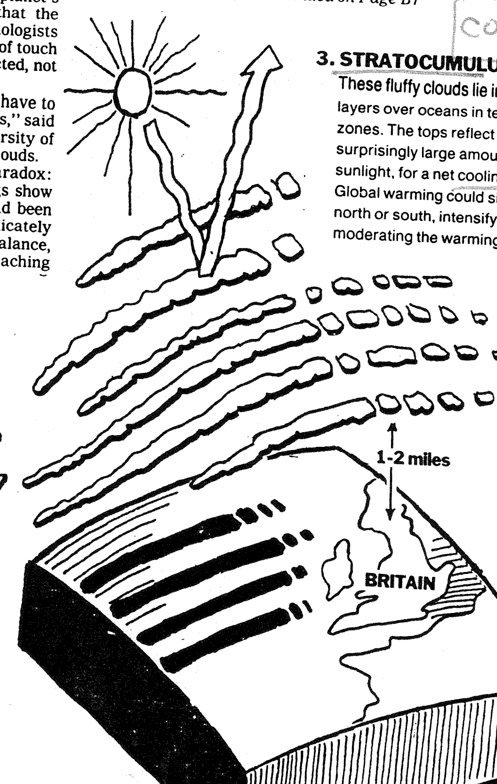
They have not yet reached a point at which they can say how the world's clouds would behave if global temperatures rose, or how their behavior would affect the warming itself. But the most

Continued on Page B7

2. CIRRUS
These high wisps were believed to trap much heat below but reflect little back into space. They have recently been found to have an unexpectedly large number of tiny ice crystals. If these reflect more sunlight than expected, it could counterbalance the heat-trapping effect.



3. STRATOCUMULUS
These fluffy 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.



But... High Albedo

TRAP 3X MORE Than aver.

ROUGHLY EQUAL
COOL = HEAT

CIRRUS Mostly TRAP
HEAT > COOL
but higher albedo than previously thought

Trap because they are high up, cool, radiate little out

COOL > HEAT
Cool more than trap because low & warm

Clouds Yield Clues to Global Climate Change

Continued From Page B5

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, increase 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 of all 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.

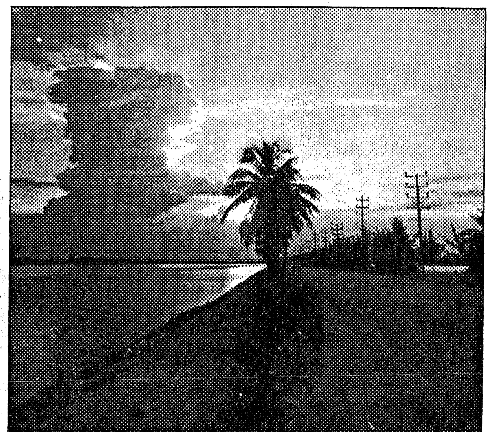
They have known that clouds form when water condenses around dust particles or other minute nuclei, and that they are mostly air. "You almost wouldn't have predicted them," says Stephen Schwartz, a cloud expert at the Brookhaven National Laboratory on Long Island, who explains that they are on the order 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.

Despite this, there was much 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 mostly to studies of 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.

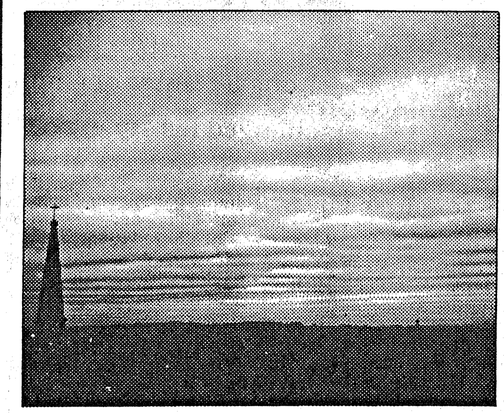


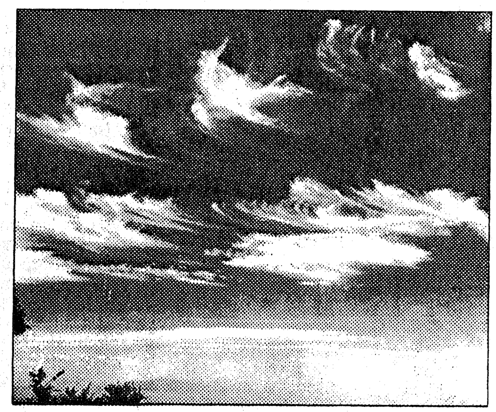
Some Key Clouds In the Global Equation

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 and above, they are detached and featherlike, and often illuminated by the sun when lower clouds are submerged in shadow.





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-topped thunderheads called cumulonimbus clouds, exert a disproportionate 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 disproportionate, 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 clouds to form, 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 air of higher altitudes, they emit 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 contours, called stratocumulus, almost always 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 clouds' overall cooling effect worldwide.

The location of these clouds is determined by ocean temperature, and the intricate interrelationships of climate that would be affected by global warming could cause them to shift either northward or southward, said

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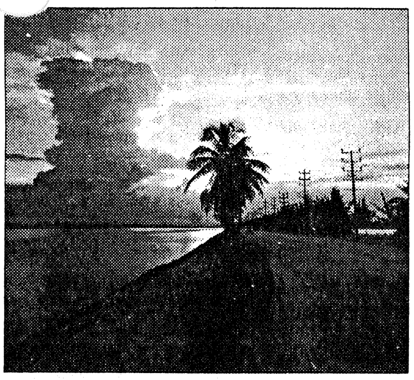

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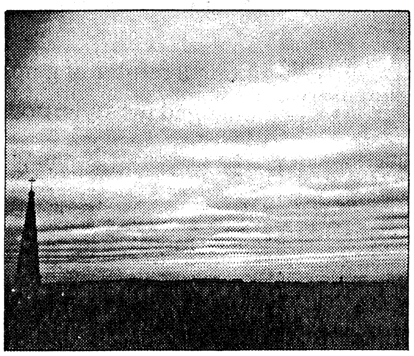

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The location of these clouds is determined by ocean temperature, and the intricate interrelationships of climate that would be affected by global warming could cause them to shift either northward or southward, said Dr. Ramanathan. This, in turn, would expose new areas of the ocean to the sun. Depending on which way they moved, this could exert, in turn, either a warming or a cooling effect.

The surprise, said Dr. Ramanathan, is that the reflectivity of these low-level ocean clouds is much greater than had been thought — up to three times as great, in fact, as the mathematical models give them credit for.

Jeffrey Kiehl, a climate researcher at the National Center for Atmospheric Research in Boulder, Colo., found the difference by comparing the satellite data with the way the clouds were represented in a standard computerized model at his institution. The implication, he said, is that the difference could introduce a fundamental error into the models' predictions.

"I personally, as 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 off the coast of California that are similar to those off the west coasts of other continents. Called Project Fire, the effort by the Government and universities is part of an international cloud research program called the International Satellite Cloud Climatology Project, or I.S.C.C.P. (Fire stands for First I.S.C.C.P. Regional Experiment.) Using data collected from satellites, aircraft and surface observations, researchers have found that these clouds are strongly affected by dust and pollution from the United States.

These small particles are the nuclei around which cloud droplets condense. 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 droplets that would fall as rain, darkening the cloud and dissipating it. The researchers are still searching for a full explanation.

Project Fire has also found that the heat-trapping characteristics of cirrus clouds, the high, feathery clouds composed of ice crystals that are sometimes called mare's tails, are different from what had been thought.

"We detected an unexpectedly 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 effect.

None of the project's findings have been included in the computer models that predict climate changes; indeed, the stratocumulus 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 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.

New findings underscore the variety of clouds and their effects.

This variety has been underscored by the emerging research results, he said. Among the examples cited by Dr. Rossow are these: there is about 15 percent more cloudiness over water than over land. Cloud tops tend to be higher over land than water. There tend to be more clouds in the afternoon than in the morning over land, but over the ocean it is the reverse. They tend to be thicker when the temperature is warmer over land, but when it is cooler over the ocean. In the temperate latitudes, winter clouds tend to be somewhat thicker and higher than in other seasons, but the situation is reversed nearer the equator.

What Is Ahead

Putting New Data To Use in Models

Scientists are just beginning to explore the issue of how these variations fit together to produce a global effect. They have much to learn about how clouds form, maintain themselves and dissipate, and how precipitation occurs.

As part of the expanding research, a the Department of Energy is beginning a 10-year program, the Atmospheric Radiation Measurement Project, that will establish four to six permanent observation sites. Their job, along with aircraft and balloon soundings, will be to measure cloud properties intensively.

These efforts are all aimed at improving the prediction models. Cloud scientists are still some distance from incorporating the new knowledge into the models, partly because of the sheer complexity that is being discovered.

But within that complexity, some scientists are beginning to believe, may lie a set of simple principles that explain how all the varying styles of cloud behavior take place. On the broad climatic scale, says Dr. Rossow, the small-scale phenomena may average out. "It makes it look as if you can manage the problem," he said. "It's still complex, but I think we're seeing the possibility we can describe it."

In any case, he said, almost all the climate model specialists at some point "will surely be competely 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 believed substantial improvement could come relatively soon. "Some of us think we'll know something useful in five years," he said. "Some say it won't 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."