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# Clouds, Clouds, Clouds

*A look at some of the roles clouds play in the life of our planet*

## The stories clouds tell

What is a cloud? How much does an average cloud weigh? What can we tell about the air by looking at clouds?

...o of altocumulus lenticularis clouds is one of ... U.S. Postal Service's Cloudscapes series. ... Carlye Calvin, UCAR Digital Image

Long lines of clouds form "streets" in this view from space. The clouds mark the top of boundary-layer circulations that have their axes parallel to the wind. (Photo courtesy NASA.)

The answers to these and other questions can be found between the covers of a short booklet, *The Stories Clouds Tell* (available from the online NCAR Science Store). Written by NCAR senior scientist Margaret "Peggy" LeMone, the 32-page booklet is filled with color photographs, descriptions, and diagrams to make cloud watching a richer experience.

LeMone has spent a significant part of the last 30 years studying the interaction between Earth's surface and the lowest level of the atmosphere, called the boundary layer. That's where many clouds start to form, giving LeMone the opportunity to study their behavior. Her doctoral thesis explained the formation of a curious pattern in clouds most easily seen from high-altitude aircraft and, by the 1970s, from space. She found that long lines of fair-weather cumulus clouds in the boundary layer, dubbed cloud streets, mark the top of the upward-moving part of horizontal convective rolls—circulations that are oriented parallel to the boundary-layer wind and therefore don't move very much. The circulations are the result of the interplay between winds and buoyancy, which is the lift warm, moist air gets from being less dense than the surrounding air.

More recently, LeMone participated in The International H 2 O Experiment (IHOP2002), one of the largest weather studies ever staged in the United States. To better understand the behavior of water vapor in the formation of summer storms, over 100 scientists gathered observations across the Great Plains that will be analyzed for years to come. Of course, the formation and growth of storm clouds depend on more than the water vapor in the air. For this experiment, LeMone and her colleagues took measurements of heating and moistening at the surface to provide data for computer modeling of storms.

"It's the distribution of those factors that affects where storms get started," she says. The heating can put regional circulation patterns in motion; storm formation is favored where the air moves upward. "All kinds of factors are at work, but even when a clear-cut external force like a front is coming in, it looks like the distribution of moistening and heating at the surface affects how storms develop."

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More about Clouds on the Web

## Artificial clouds and climate change

LeMone is also chief scientist of GLOBE, which conducted the Fall 2004 Contrail Count-a-Thon, a cloud and contrail experiment, in collaboration with NASA on October 14 and 15. Students around the world observed and reported their counts of contrails, the artificial clouds formed from the water vapor in jet aircraft exhaust, as well as associated clouds.

The water vapor in jet engine exhaust condenses to form the long, thin artificial clouds known as contrails

Climatologist David Travis (University of Wisconsin-Whitewater) and colleagues demonstrated the importance of contrails to climate by studying the contrail-free skies over the United States in the aftermath of the September 11 terrorist attacks, when flights over U.S. airspace were grounded. They compared satellite imagery collected September 11-13 with 30 years of cloud-cover data and assembled a history of the temperatures across North America at the same time of year for the same period.

When they compared the 30-year record to temperature readings for September 2001, they found that contrails are narrowing the range of temperature between day and night, making average days cooler and average nights warmer than would otherwise occur.

The contrast between daytime and nighttime temperatures grew from 3 to 5 degrees Fahrenheit (1.5 to 2.5 degrees Celsius) larger under the clear skies following September 11. Regions where contrails are usually present showed the greatest change.

The cooling effect of contrails adds another variable to the puzzle of climate change at regional and global levels.

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Post-Sept. 11 skies offer clues to contrails, climate change

## More pieces of the cloud-climate puzzle

The aircraft-free skies after September 11 were an unusual event that let scientists directly observe how contrails affect climate. Usually scientists must use computer models (sophisticated software that mimics the atmosphere) to study the cloud-climate interplay.

Incorporating clouds into the models is vital because of their role in regulating climate. Low, thick clouds reflect solar radiation back into space and cool Earth's surface. High, thin clouds warm the planet by allowing sunlight to pass through them, yet trapping some of the outgoing infrared radiation emitted by Earth. Clouds remove gases and particles from the atmosphere through precipitation, and they are also at the center of some of the atmosphere's most critical chemical reactions.

Capturing clouds in climate models is no easy task, however. "Many of the important actions in clouds take place on distance scales of a few meters to tens of kilometers or smaller and evolve on time scales of a few seconds to a few hours," explains Phil Rasch, an NCAR climate modeler. "These features can't easily be represented accurately in global models. We have to start making approximations, and the approximations aren't yet very good."

The complexity of cloud physics is another challenge. "There are some processes associated with clouds that we just don't understand well enough to model," Rasch says. "There's a constant effort to improve the approximations. We look for problems in our formulations, try to figure out how they manifest themselves in the climate model, and improve the approximations when we find a solution."

Meanwhile, observational specialists like NCAR's Andrew Heymsfield fly instruments on balloons and aircraft into clouds to learn more about cloud ice and other structures. What they're learning will improve the treatment of clouds in both small- and large-scale models.

These refinements make their way into such tools as the recently updated Community Climate System Model. Scientists at NCAR and elsewhere use the model to project climate up to 100 years or more into the future.

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New probes paint a wet picture of high-altitude cirrus

## Thin layers with a big impact

While the size, shape, and scope of clouds could play a critical role in global climate change, they also have immediate impacts on everyday weather. Some are obvious—that touch of coolness you feel when the sun goes behind a cloud on a hot day. Other effects are more subtle but potentially vital.

Clouds are one factor being considered as NCAR and the Federal Highway Administration put the finishing touches on a system that improves the often-tricky process of keeping highways plowed and treated in winter weather. The Web-based Maintenance Decision Support System (MDSS) may soon save lives, cut costs, and help keep millions of drivers on the move.

The system uses several top-of-the-line computer forecast models. However, according to NCAR's Bill Mahoney, MDSS lead scientist, "models often miss shallow or thin cloud layers that greatly impact road temperature forecasts." Thin cirrus clouds, for example, allow sunlight to filter through by day, but help trap radiation from Earth by night. In both cases, the effect is to keep temperatures higher and potentially keep roads from freezing. "The models need better vertical resolution and physics to handle thin cloud layers," says Mahoney.

## The world's highest clouds

Richard Keen recognized noctilucent clouds in the Colorado sky because he'd seen and photographed them in Alaska. He captured this noctilucent cloud panorama above the Juneau, Alaska, Ice Field, in July 1998. (Photo by Richard Keen.)

Far above even the highest cirrus formations, a rare and exotic cloud may serve as an index of climate change. Unlike most clouds, which inhabit the first 6 miles (10 kilometers) above Earth's surface, noctilucent (night-luminous) clouds form some 50 miles (80 km) above Earth near the top of the mesosphere. At these heights, temperatures reach a chilling -130 degrees Fahrenheit (-90 degrees Celsius). Made of ice crystals, noctilucent clouds can be seen at night because they're so high above Earth that they escape its shadow. But they develop only when and where upper-atmosphere temperatures are cold enough: typically, summertime at high latitudes. Few folks further south than North Dakota have ever seen a noctilucent cloud.

At least not until June 22, 1999. That's when climatologist Richard Keen, a meteorology instructor at the University of Colorado in Boulder (CU), and Mike Taylor, a physics professor at Utah State University in Logan, both looked up into the evening sky. As Keen recalls, he was heading home to Golden, Colorado, at around 9:30 p.m. when he turned northwest and was astonished by his view of "bright, silvery clouds with almost an electric glow." He'd trekked to Alaska the previous year to see the elusive phenomenon, so he recognized what he was seeing immediately. So did Taylor in Utah. And another noctilucent cloud sighting that night was later confirmed south of Durango, Colorado, placing it 500 miles (800 kilometers) south of any previous U.S. report.

What might be bringing noctilucent clouds to lower latitudes? Increases in two greenhouse gases, methane, and carbon dioxide, are one possibility. While greenhouse gases trap warmth near Earth's surface, they reflect it back out to space at higher altitudes, lowering the temperature of the upper atmosphere. The effect is to broaden the geographical spread of high-altitude temperatures that are cold enough to support noctilucent clouds.

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Noctilucent clouds page at LASP
Science@NASA: Strange Clouds

Keen was eager to report what he'd seen to CU colleague Gary Thomas, a noctilucent cloud expert. In 1994, Thomas predicted that, by the start of the 21st century, the clouds would increase in brightness by 5 to 10 times, making them visible over the United States. In a CU report of the Utah and Colorado sightings, Thomas noted that, "while they are a beautiful phenomenon, these clouds may be a message from Mother Nature that we are upsetting the equilibrium of the atmosphere."

### Clouds on the ground: studying fog

It's clear that it's hard to see in fog, but forecasting the occurrence of fog and its impact on aviation is hazy at best. That's why the Federal Aviation Administration (FAA) is funding studies to find out what additional fog forecasting tools forecasters need to give better guidance to pilots and air traffic controllers. Robert Tardif, a graduate research assistant at NCAR, has been working on the problem.

Tardif's first goal was to scope out the extent and characteristics of the fog problem in the New York City region, home to three major airports. He found a whole suite of fog types there. "The variety of types and of scenarios under which fog occurs points out the problem forecasters have to deal with," he says.

The next step was to install a host of instruments to measure visibility, cloud ceiling, soil temperature and moisture levels, rainfall, and other variables on a tower at the FAA field site on the campus of Brookhaven National Laboratory on Long Island, New York. One-minute observations from an automated surface network and weather balloons launched twice a day near the site are adding to the data. The combination is giving Tardif and colleagues a rich picture of local fog events in all their complexity.

The goal is to identify the key mechanisms that influence low cloud and fog behavior and then see whether those mechanisms are well represented in the computer models forecasters are using. "Are we not measuring things now at airports that we should be? Maybe there will be a missing piece in terms of measurement that could provide some help," Tardif says.

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Low cloud ceiling and fog in the Northeastern U.S.
Cloud Ceiling and Visibility Project

### Cloudscapes Stamps from the U.S. Postal Service

In fall 2004 the USPS issued a series of 15 stamps depicting a range of cloud types. Since the stamps were launched in October, National Stamp Collecting Month, the Postal Service encouraged people to learn more about both weather and stamp collecting.


Click here or on the image for a larger version.

The American Meteorological Society and The Weather Channel teamed up with the Postal Service to reveal the weather knowledge behind the beauty of the Cloudscapes stamp series. NCAR celebrated the stamps with an October 17th event at the Mesa Laboratory in Boulder that recognized stamp photographers Carlye Calvin (UCAR) and Richard Keene (University of Colorado, Boulder).

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