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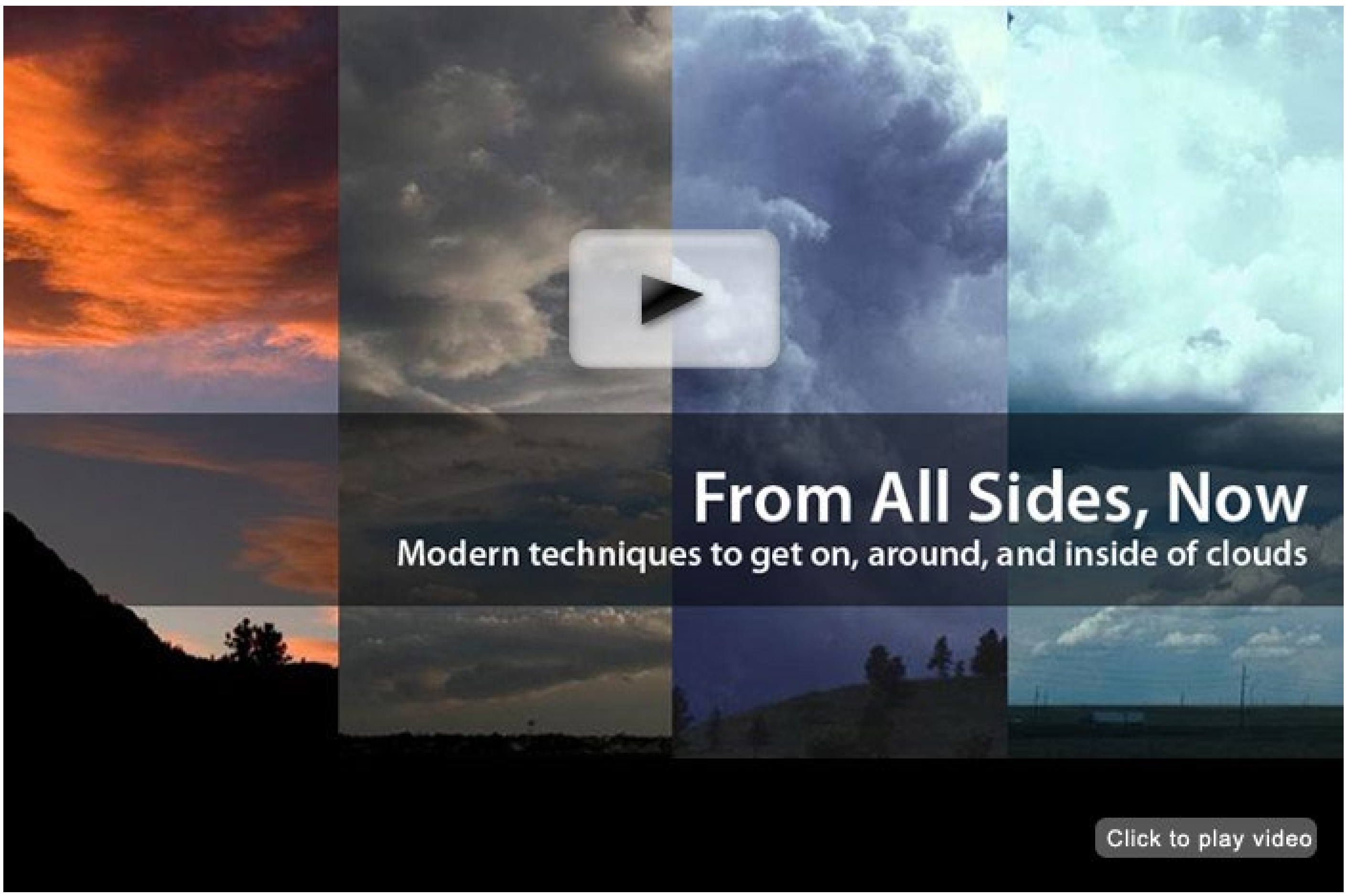
CLOUDS: THE WILD CARD OF CLIMATE CHANGE



CLOUDS: The Wild Card of Climate Change

Webcast

Cloud expert David Randall discusses the important role of clouds in climate change in a webcast entitled, "Clouds: The Wild Card of Climate Change."

Read Dr. David Randall's **opening statement** to his webcast (PDF).

Webcast

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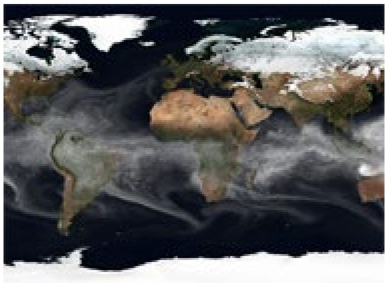

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Clouds: The Wild Card of Climate Change
November 4, 2010
David Randall, Center for Multiscale Modeling of Atmospheric Processes
Colorado State University

Cloud expert David Randall discusses the important role of clouds in climate change in a webcast entitled, "Clouds: The Wild Card of Climate Change."

Credit: *Colorado State University/National Science Foundation*

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The Big Question

WILL CLOUDS SPEED OR SLOW GLOBAL WARMING?

It is a little-known but significant fact that about 70 percent of the Earth's surface is covered by clouds at any given time. But not all clouds are the same; different types of clouds affect the Earth's climate differently. While some types of clouds help to warm the Earth, others help to cool it.

Currently, all of the Earth's clouds together exert a net cooling effect on our planet. But the large and opposing influences of clouds on the Earth's climate begs the question: What will be the net effect of all of the Earth's clouds on climate as the Earth continues to warm in the future? Will clouds accelerate warming or help offset, or dull, warming? Right now, "The scientific community is uncertain about how the effects of clouds will change in the future," says Hugh Morrison, a scientist at the National Center for Atmospheric Research (NCAR) in Boulder, Colo.

That's why, in 1997, the Intergovernmental Panel on Climate Change (IPCC) described clouds as "the largest source of uncertainty" in predictions of climate change. To reduce this uncertainty and improve predictions of climate change/global warming, scientists are now working to better understand the relationships between clouds and climate.

THE ENGIMA OF CLOUDS

Clouds--those cotton puffs in the sky--are but collections of water droplets and tiny ice particles suspended in the sky. But even with their limited types of components, clouds are complex. This complexity is reflected in their nonstop, weather-portending parades across the sky--all the while, as they move, swiftly forming and dispersing; changing hues from alabaster whites to mercurial grays; and billowing into new heterogeneous shapes that are frequently so amorphous they lack so much as defined edges.

As clouds continually change and dance across the horizon, they invariably create a mesmerizing, ethereal mystique.

But many of the very same characteristics that give clouds their mesmerizing mystique also make them vexing, perplexing and difficult for scientists to study. These characteristics include their ephemeral, short life-spans, constant motion, ever-changing shapes, wispy, heterogeneous structures and high altitudes; clouds may reach 12 miles or more above the Earth.

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Image taken by photographer David Thoreson during his 28,000 mile sailing voyage to circumnavigate the Americas to raise awareness about ocean health.

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Another factor that helps shroud clouds in mystery is their status as multi-scale phenomena. That is, the behavior of clouds is determined by complex phenomena operating at a wide range of scales, including:

- cloud particles that are fractions of a millimeter across
- individual clouds that are a few kilometers in diameter
- cloud systems that range over many kilometers
- weather systems that cover many thousands of kilometers.

What's more, cloud phenomena that occur on any particular scale may influence cloud phenomena occurring at other scales. For example, large-scale cloud movements, which are controlled by factors such as wind and turbulence, affect micro-processes, such as the formation of rain droplets, snow and hail, the speed at which these forms of precipitation fall, and their changing shapes.

And by the same token, the formation of rain droplets, snow and hail may influence large-scale phenomena, such as the sizes, shapes and life-spans of entire clouds. Therefore, in order to predict cloud behavior, scientists must not only understand cloud phenomena occurring within various scales, but also the interactions between differently scaled cloud phenomena.

Since clouds interact with their environment over a wide range of scales, according to Morrison, a key to understanding the role of clouds in climate is to better understand these multi-scaled phenomena. Scientists are currently feverishly working to better understand intra and inter cloud processes by continually collecting and analyzing data on clouds and by improving the power of computer models to predict cloud behavior.

CLOUD CLOUT AND DOUBT

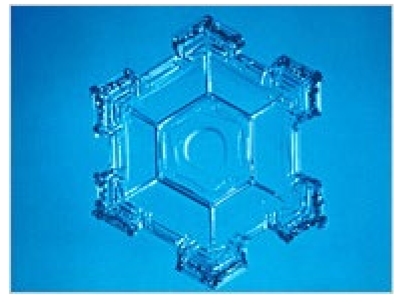
The IPCC reported in 2007 that it projects the Earth’s average temperature to be about 1.8 to 4 degrees Celsius higher by the end of the century than it was in 1900--a rapid rate of increase compared to observed rates of increase in the Earth’s recent history. Scientists could probably narrow down the Earth’s projected temperature range further if they better understood the relationships between clouds and climate as well as other factors, such as the amount of greenhouse gases that will be pumped into the atmosphere by 2100.

Most scientists doubt that the net cooling effect of clouds will ever be large enough to completely offset ongoing warming. But many scientists say that if warming were to increase the number or kind of cooling clouds or decrease the presence of warming clouds, the current net cooling effect of clouds on the Earth's climate would probably increase, and thereby moderate, or offset, ongoing warming.

If warming were to continue, the net cooling effect of clouds would increase and, in a negative feedback loop, perpetuate the moderating force on ongoing warming provided by clouds. The result: The Earth's end-of-the-century temperature may be pulled down toward the lower end of its predicted range.

But, if on the other hand, warming were to increase the number or kind of warming clouds or decrease the presence of cooling clouds, scientists say the current net cooling effect of clouds on the Earth's climate would probably decrease; and an important moderating force on ongoing warming would thereby diminish. The result: The Earth's end-of-the-century temperature may be pushed up towards the upper end of its predicted range.

This resulting rise in temperature would, in a positive feedback loop, tend to promote the formation of even more warming clouds or further reduce the presence of cooling clouds. Either way, temperatures would rise even higher. This temperature increase would tend to further increase the presence of warming clouds or decrease the presence of cooling clouds, and thereby perpetuate the warming cycle.



An ice crystal. Clouds are composed of many small droplets of water or ice crystals that form around condensation nuclei –usually a small particle of dust, ash or smoke. Among the many micro-processes that help determine whether clouds will produce precipitation are the shapes of their ice crystals and the speed and efficiency at which these crystals grow and/or collide to reach sizes that are large enough to fall from clouds.

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NSF-funded Paul DeMott of Colorado State University provides an insider's view (literally) of clouds.

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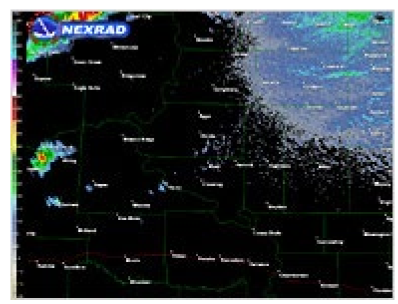

Radar imagery of severe thunderstorms over South Dakota on July 23, 2010. These storms produced a record-setting hailstone measuring 8.0 inches in diameter, 18.625 inches in circumference and weighing an amazing 1.9375 pounds!

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CLOUDS: A SHADY DEAL OR WARM PUFFS?

Why do different types of clouds impact climate differently? The climactic impacts of the three most important types of clouds--stratus, cirrus and cumulus--depend on their heights and thicknesses.

- Stratus clouds: These clouds hang low in the sky--usually within two kilometers of the Earth's surface--and resemble a gray blanket covering thousands of miles of sky. Because these clouds block sunlight from reaching the Earth, they act like a sunscreen or shady umbrella that helps cool the Earth. Therefore, they have a net cooling effect that helps offset warming.

- Cirrus clouds: These clouds are wispy and feathery, and positioned up to 20 kilometers above the Earth's surface. Cirrus clouds let much sunlight pass through them and may also trap the Earth's heat, just as greenhouse gases do. Therefore, they have a net warming effect that helps magnify warming.

- Cumulus clouds: These clouds look like balls of cotton that extend vertically high in the sky. Cumulus clouds, which have sharply defined edges, may form alone, in lines or in clusters. Cumulus clouds can block sunlight, but also trap the Earth's heat. Their net effect on warming depends on their heights and thicknesses.

Cumulonimbus cloud with a rain shaft, an area in the cloud where it is raining.

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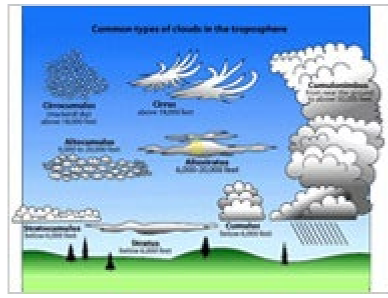

Common cloud types at their approximate altitudes. (Stratus typically form lower than cumulus.)

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Positive and negative feedbacks between clouds and climate.

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CLOUDS
THE WILD CARD OF CLIMATE CHANGE

Computing Clouds

PREDICTING CLOUD POWER WITH COMPUTER MODELS

The main tools used by climate scientists to predict future climate change are computer models. These models work by integrating data on various atmospheric variables, such as atmospheric levels of greenhouse gases, cloud conditions and many other variables, for a particular time period. Then, based on computed interactions between these variables, the models predict the resulting climate for the represented time period.

Because it is impossible to represent all atmospheric conditions over every inch of the planet, most climate models present a simplified version of the Earth; they represent the Earth by dividing it into grid boxes or "grid cells" -- usually each about the size of the state of Delaware. Each of these cells is represented as a single, unbroken uniform area. This means that conditions across each cell--including cloud conditions--are only approximated, generalized or averaged; sub-regions within cells that deviate from such cell-wide approximations, generalizations or averages are not directly represented.

So even though a Delaware-sized cell would be big enough to hold thousands of clouds, a climate model would not represent each of these clouds. Instead, it would treat the entire cell as a single "box" with an "average" cloudiness (a fraction between 0 and 1) representing how much of its total area is covered by clouds. The cell's other cloud characteristics would also be represented statistically in terms of their cell-wide averages.

Climate models identify numbers representing each cell's cloud characteristics by using simplified models of clouds. One recently developed approach involves embedding a cloud model in each cell of a climate model, says David Randall, director of the **Center for Multiscale Modeling of Atmospheric Processes** (CMMAP)--a Science and Technology Center that is funded by the National Science Foundation and is devoted to improving the representations of cloud processes in climate models. In other words, this approach involves integrating cloud data from small cloud models representing each "cell" into a larger climate change model that simulates climate for the entire area covered by the cells.

MODELING CHALLENGES

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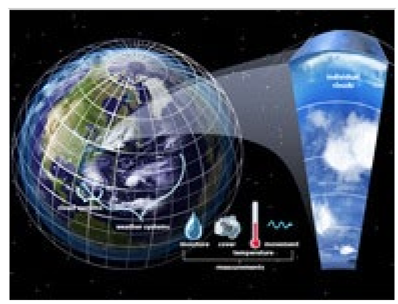
Climate models are based on a three-dimensional mesh covering the Earth and reaching high into the atmosphere. At regularly spaced intervals, or grid cells, the models use the laws of physics to compute atmospheric and environmental variables, simulating exchanges among gases, particles and energy.

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It is difficult to create accurate climate models and cloud models. Obstacles include the many enigmatic interactions between cloud processes operating at various scales (see **The Enigma of Cloud**). Unfortunately, inaccuracies incorporated into representations of cloud processes operating at any particular scale cascade throughout models, influencing predictions of processes operating at other scales.

Other modeling challenges are created by the sheer number of particles and droplets in clouds. After all, even a small cloud that has a volume of only one cubic kilometer may contain more than 10^{17} droplets! It is currently impossible to accurately track such large numbers of particles. Another challenge is representing the many and varied types of cloud and precipitation particles carried by clouds. "Just think of all the different shapes of snowflakes; how these shapes are represented in models can have important effects," says Hugh Morrison, a scientist at NCAR.

This means that it is currently impossible to simulate the ever-changing structure of clouds in a completely realistic way. Nevertheless, by averaging cloud characteristics over grid cells, models try to produce approximate simulations of present and future conditions in the most realistic ways possible.

EVALUATING MODELS

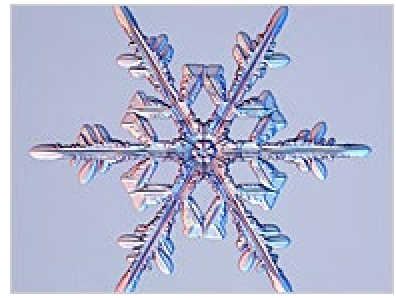
Scientists need to work with a number of different models to predict climate because models that are currently available all have particular strengths and weaknesses. How do scientists evaluate models and determine which aspects of climate they each predict best?

1. By comparing the model's predictions of future conditions to observations, as they become available. This is done by using the climate model to simulate future conditions. The more that simulated climate conditions would resemble actual climate conditions as they develop, the more the model would be trusted to generate realistic, long-term predictions of those climate conditions.
2. By comparing the model's simulations of past and present conditions to recorded observations. This is done by using the climate model to recreate climate conditions for a period--such as the last 100 years to the present--for which records exist. The more the simulated climate conditions would resemble actual conditions, the more the model would be trusted to generate realistic, long-term predictions of future conditions.

"No model is perfect," says James Hurrell, a senior scientist at NCAR. "They all have shortcomings." Therefore, there is uncertainty in even the best climate models--partly because of the difficulties of representing clouds in models.
Scientists are continually improving climate models by identifying discrepancies between predictions or observed conditions and simulations made by climate models, and then working to eliminate these discrepancies. "We are constantly looking for what is wrong with climate models (not what is right with them) in order to determine how we can improve them," says Randall. They do so by applying the laws of physics into models, and by generating and inputting into models additional relevant data on various climatic characteristics, including cloud conditions.

THE COMMUNITY EARTH SYSTEM MODEL

One of the most important climate change models currently used by scientists is the ever-evolving **Community Earth System Model (CESM) ,** which allows researchers



A snow crystal. This image was taken using a specially designed snowflake photomicroscope.

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View of clouds from an airplane above Michigan, September 2010

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NSF-funded Amy Clement of the University of Miami helps clear the air about the relationships between clouds and climate change.
Credit: National Science Foundation
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NSF-funded Amy Clement of the University of Miami helps clear the air about the relationships
between clouds and climate change.

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to conduct fundamental research into the Earth's past, present and future climate states. (The CESM is managed by NCAR with funding from NSF and the U.S. Department of Energy.)

The latest version of the CESM, which was released in June 2010, represents a major improvement over its predecessors. It is currently contributing to an ambitious set of climate experiments that will be featured in the fifth assessment report of the IPCC slated for release in 2013.

The CESM is continually improved by what NCAR's James Hurrell, chair of the CESM scientific committee, describes as "a collective decision." Anyone can join any of the 12 working groups that develop and apply the model, says Hurrell. Through the working group structure, ideas by community scientists are suggested, tested and compared to the current model so that their strengths and weaknesses can be assessed. Then, all the CESM working groups together decide whether to incorporate suggested changes into the CESM."

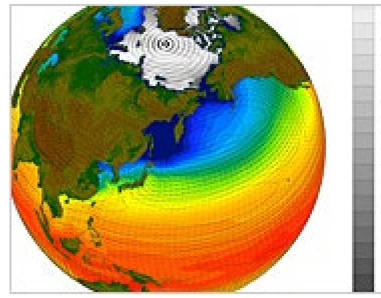
THE FUTURE OF CLIMATE MODELLING

Climate models cannot include as much detail as weather models, and climate projections are made on regional to global scales rather than on local scales--covering far larger spatial scales than do weather models. Also, models simulate global climate over years, decades or millennia--covering far longer periods than do weather models.

Currently, the shorter the time period or the smaller geographic area covered by a prediction generated by large-scale climate models, the less reliable it is. "But climate scientists get up every morning and come to work to try to improve the climate models," says Randall. As part of this effort, CMMAP is currently working to create models whose grid cells are small enough to represent individual clouds.

Also, NSF is currently advancing the development of higher-resolution models by sponsoring--together with the U.S. Departments of Energy and Agriculture--a $49 million joint research program to produce high-resolution models for predicting climate change and its resulting impacts. Called **Decadal and Regional Climate Prediction Using Earth System Models (EaSM)**, the program is designed to produce models that are significantly more powerful than existing models. They will be able to generate predictions of climate change and associated impacts over shorter time periods and over smaller geographic areas than current models are capable of.

But despite the need for higher-resolution models with smaller grid cells, "the need for lower-resolution models will continue into the foreseeable future," says Morrison. Why? Because some applications might require models to simulate long time periods, like thousands of years, that are currently impossible to simulate with the higher-resolution models.



Taken from a larger simulation of 20th century climate generated by the new Community Climate Model (CESM), this image depicts several environmental variables including sea surface temperatures and sea ice concentrations. One way that scientists verify a model's accuracy is by simulating past conditions and then comparing the model results to observed conditions.

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Carlsbad, California, June 2010

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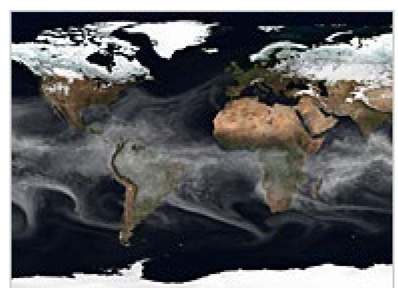

A simulation created by the Community Earth System Model (CESM) showing water vapor that is available to be precipitated as snow or rain during one month in preindustrial times.

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Positive and negative feedbacks between clouds and climate.
Credit: Nicolle Rager Fuller, National Science Foundation

Image taken by photographer David Thoreson during his 28,000 mile sailing voyage to circumnavigate the Americas to raise awareness about ocean health.
Credit: David Thoreson
Image size: 293 KB

An ice crystal. Clouds are composed of many small droplets of water or ice crystals that form around condensation nuclei â€“ usually a small particle of dust, ash or smoke. Among the many micro-processes that help determine whether clouds will produce precipitation are the shapes of their ice crystals and the speed and efficiency at which these crystals grow and/or collide to reach sizes that are large enough to fall from clouds.
Credit: © University Corporation for Atmospheric Research
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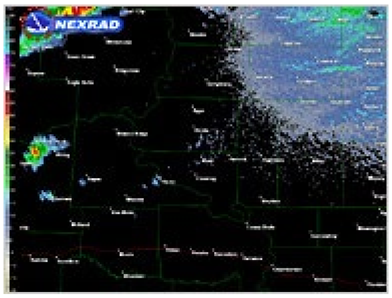
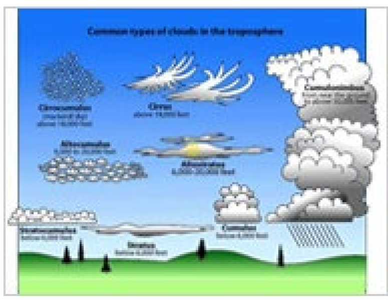
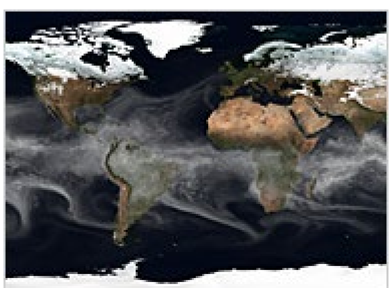
NSF-funded Paul DeMott of Colorado State University provides an insider's view (literally) of clouds.
Credit: National Science Foundation



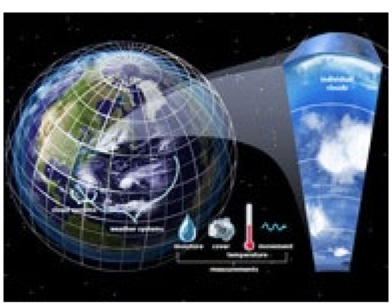
Radar imagery of severe thunderstorms over South Dakota on July 23, 2010. These storms produced a record-setting hailstone measuring 8.0 inches in diameter, 18.625 inches in circumference and weighing an amazing 1.9375 pounds!
Credit: National Weather Service, National Oceanic and Atmospheric Administration
Image size: 347 KB (Animation)



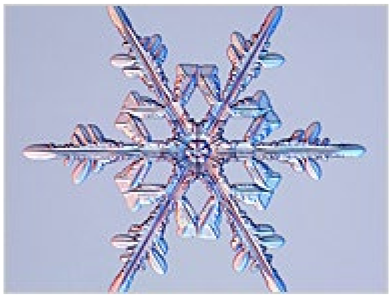
Common cloud types at their approximate altitudes. (Stratus typically form lower than cumulus.) (not to scale)
Credit: ©UCAR
Image size: 54 KB



A simulation created by the Community Earth System Model (CESM) showing water vapor that is available to be precipitated as snow or rain during one month in preindustrial times.
Credit: Visualization created by Jamison Daniel, ORNL



Climate models are based on a three-dimensional mesh covering the Earth and reaching high into the atmosphere. At regularly spaced intervals, or grid cells, the models use the laws of physics to compute atmospheric and environmental variables, simulating exchanges among gases, particles and energy.
Credit: Nicolle Rager Fuller, National Science Foundation



A snow crystal. This image was taken using a specially designed snowflake photomicroscope.
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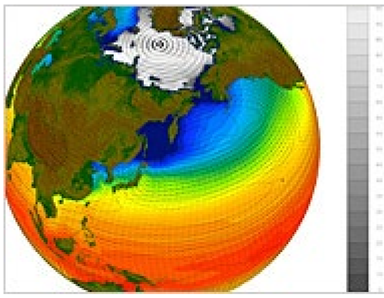

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NSF-funded Amy Clement of the University of Miami helps clear the air about the relationships between clouds and climate change.
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Carlsbad, California, June 2010.
Credit: Kristina Rebelo
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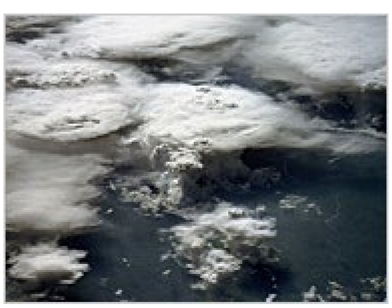

A series of mature thunderstorms in southern Brazil. This photo was taken in February 1984 by an astronaut aboard the space shuttle.
Credit: Image Science & Analysis Laboratory, NASA Johnson Space Center
Image size: 6.74 MB

NSF-funded Paul DeMott of Colorado State University provides an insider's view (literally) of clouds.
Credit: National Science Foundation

the space between them grows. These larger spaces allow the cloud to absorb more light, making it appear gray or black instead of white.
Credit: Jeff Schmaltz, Earth Observing System, NASA
Image size: 345 KB

Image size: 51 KB

Specially equipped plane used by Paul DeMott to collect samples of air entering clouds, or to extract cloud particles from their interiors to measure in real-time their content of ice nuclei. This research is improving our understanding of ice formation in cold clouds and its dependence on ice nuclei.
Credit: John Eisele, Colorado State University

View of clouds from an airplane above Michigan, September 2010
Credit: Kristina Rebelo
Image size: 3.07 MB

Cumulonimbus cloud with a rain shaft, an area in the cloud where it is raining.
Credit: © University Corporation for Atmospheric Research
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