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FEATURES

Does the Earth Have an Iris Analog?

BY DAVID HERRING • DESIGN BY ROBERT SIMMON JUNE 12, 2002

Scientists have known for decades that the Earth's climate is driven by the exchanges of radiant energy between our world and outer space. Over the course of a year, the amount of sunlight entering the Earth system equals the amount of radiant energy reflected and emitted back through the top of the atmosphere (Harrison et al. 1993). The sun beams an average of 340 watts per square meter to the Earth and, in turn, our world reflects 100 watts (or the equivalent of one light bulb) per square meter back up to space. The remaining solar energy (240 watts per square meter) is stored as heat within the air, oceans, and land surface and, gradually, emitted back up through the atmosphere to space.

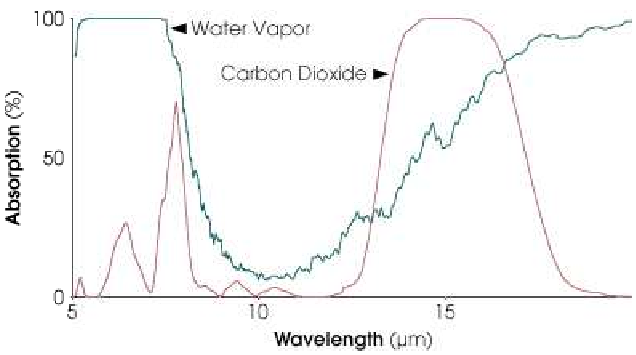
Over the long term, energy that the Earth receives from the Sun must be balanced by heat that escapes back into space. In general, clouds reflect sunlight before it warms the Earth, while gases in the atmosphere such as carbon dioxide and water vapor trap heat, warming the Earth's surface. (Photograph STS109-325-2 courtesy the Earth Sciences and Image Analysis Laboratory at Johnson Space Center.)

Using satellite remote sensors to take global measurements of the amount of sunlight reflected by the Earth and the amount of heat emitted up through the top of the atmosphere, scientists can compute the "bottom line" on the Earth's energy budget. Such measurements reveal which components of the Earth's system are the key drivers of climate.

In the early 1980s Richard Lindzen, a theoretician and professor of meteorology at the Massachusetts Institute of Technology, turned his attention to the "forcings" and "feedbacks" that water vapor and clouds exert on the climate system. He wanted to find out how the climate as a whole responds to changes in water vapor and cloud cover.

"When the hullabaloo began over global warming, it became clear the answer depended a lot on the feedback from water vapor and clouds," he observes. "We (scientists) didn't know how to deal with them." So Lindzen began working on the problem by examining the physics of how water vaporizes.

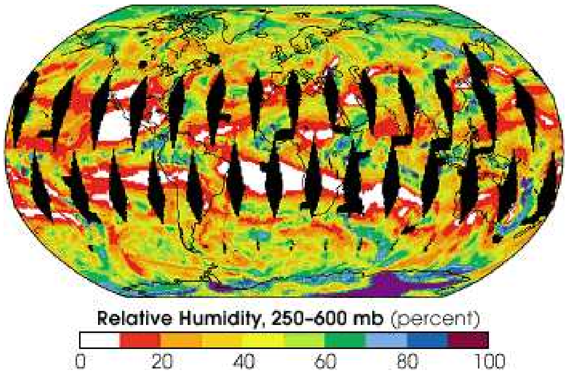
Although carbon dioxide gets most of the bad publicity these days as the critical greenhouse gas, the warming effect of carbon dioxide is minuscule compared to that of water vapor. Water vapor is present in such abundance throughout the atmosphere that it acts like a blanket of insulation around our world, trapping heat and forcing surface temperatures higher than they would be otherwise. At most wavelengths within the thermal infrared energy spectrum (basically heat) that get trapped within Earth's atmosphere you barely even notice the effects of carbon dioxide because water vapor totally dominates the signal. But what makes carbon dioxide so interesting is that the gas absorbs energy in some small segments of the thermal infrared spectrum that water vapor misses. This extra absorption within the atmosphere causes the air to warm just a bit more and the warmer the atmosphere the greater its capacity to hold more water vapor. This extra water vapor then further enhances the Earth's greenhouse effect, far more even than the small warming forced by the added carbon dioxide. Scientists estimate that doubling levels of carbon dioxide in the atmosphere would be about the same as a 13 percent increase in water vapor, because water vapor is roughly eight times more effective than carbon dioxide as a greenhouse gas (Hartmann 1994). In short, if water vapor is the 800-pound gorilla of the Earth's greenhouse effect, then carbon dioxide is the steroid pill that helps water vapor lift temperatures even higher.



Carbon dioxide is the most frequently mentioned greenhouse gas, but water vapor absorbs infrared (heat) radiation much more strongly. Carbon dioxide is significant because it closes a "window" that would otherwise allow certain infrared wavelengths to escape the Earth's water vapor blanket. The graph at left shows the percentage of energy absorbed in a clear tropical sky by water vapor (green) and carbon dioxide (brown). (Graph by Robert Simmon, based on model data from the NASA GSFC Laboratory for Atmospheres)

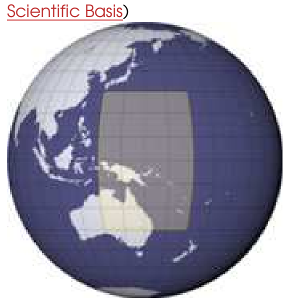
The way in which humidity and rising air masses lead to saturation of the atmosphere and cloud formation in the tropics is a bit different from the way in which those dynamics occur at mid-latitudes. So, in his experiment, Lindzen decided to confine his focus to the tropics. But there is such an intimate relationship between clouds and water vapor in the tropics that it is difficult to get a clear picture of just what the water vapor is doing.

Lindzen says he was influenced by an image produced using data from the Special Sensor Microwave Water Vapor Sounder (SSM/T-2), flying aboard a U.S. military satellite. “The image made it clear that in the tropics you have regions of high humidity and regions of low humidity, separated by sharp boundaries,” he recalls. “At first, we were looking at how humidity changed in the clear regions and we didn’t have a good handle on how the relatively cloudy areas changed. Slowly, it dawned on us that, in the tropics, clouds moisturize the air around them. Clouds are a major source of moisture.”



Humid and dry regions of the tropical atmosphere are very distinct. The image at left shows humidity measured by the SSM/T-2 Atmospheric Water Vapor Profiler at pressures ranging from 250 to 600 millibars (the mid-troposphere; note that the black areas in this image are where no data was collected). Lindzen reasons that areas of low humidity (white) opening and closing helps regulate the temperature of the Earth. Lindzen further hypothesizes that high sea surface temperatures would create storms that precipitated more efficiently, reducing the size of humid areas in the atmosphere. By linking the two ideas he came up with a mechanism that effectively offsets global warming due to a buildup of greenhouse gases by allowing more heat to escape to space. (Image from the IPCC report Climate Change 2001: The Scientific Basis)

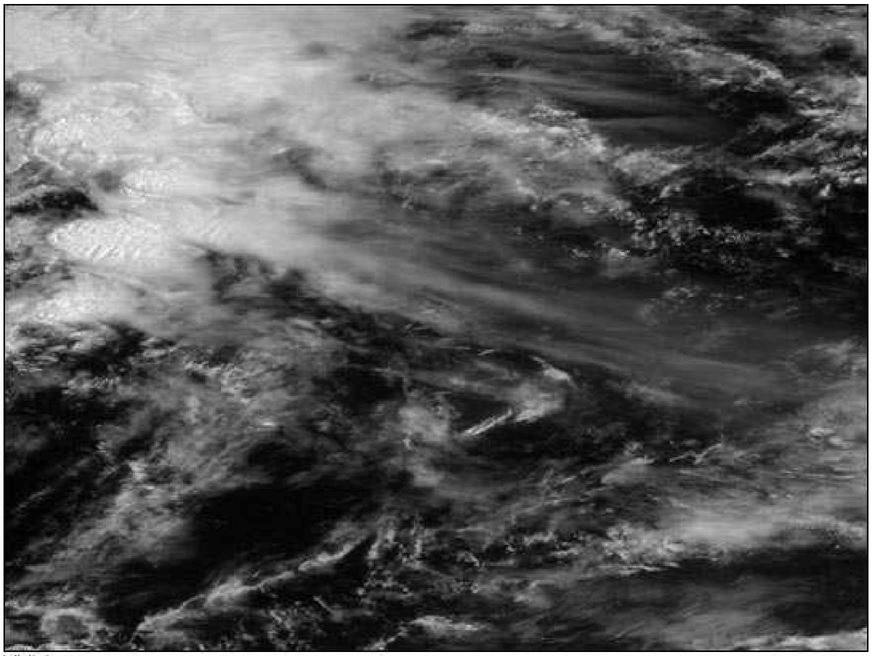
So Lindzen’s team shifted its focus to clouds instead of humidity and used the Japanese Geostationary Meteorological Satellite-5 to make their measurements. That satellite, they reasoned, would provide them the best resolution over both time and space to meet their objective. That satellite’s field of view concentrated their focus on a large patch of Earth ranging from 30°N latitude to 30°S, and 130°E longitude to 170°W. This patch spans an area bordered by the Indonesian Archipelago to the west, the center of the Pacific Ocean to the east, southern Japan to the north, and southern Australia to the south. This area contains the world’s largest and warmest body of water, known as the Indo-Pacific Warm Pool. Lindzen wanted to find out how the types and extent of clouds vary as a function of underlying sea surface temperature.



Lindzen’s team studied the relationship between sea surface temperature and cloud extent in the area of the Indo-Pacific Warm Pool, shown above in yellow. (Map by Robert Simmon)

“We wanted to see if the amount of cirrus associated with a given unit of cumulus varied systematically with changes in sea surface temperature,” he says. “The answer we found was, yes, the amount of cirrus associated with a given unit of cumulus goes down significantly with increases in sea surface temperature in a cloudy region.”

This is the finding that led Lindzen's team to propose that the Earth has an adaptive infrared iris—a built in "check-and-balance" mechanism that effectively counters global warming (Lindzen et al. 2001). Much like the iris in a human eye contracts to allow less light to pass through the pupil in a brightly lit environment, Lindzen suggests that the area covered by high cirrus clouds contracts to allow more heat to escape into outer space from a very warm environment.



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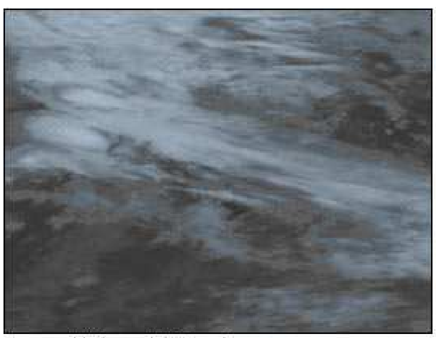
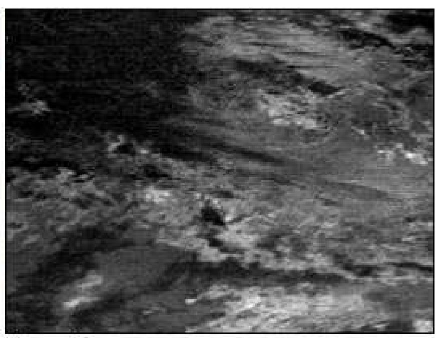


Thermal Infrared (11 μm)



11μm - 12 μm

Lindzen and his team used data from geostationary satellites to measure the amount of high clouds over the eastern tropical Pacific. The above images show GOES data near Hawaii, to the west of the orginal study area (GMS-5 was used in the original study but failed before this article was written). Thin cirrus clouds are streaming (from left to right) off the convective cores of a line of thunderstorms. The lower left image shows infrared data, which correspond to temperature. Cloud top temperatures less than 260K are colored light blue. The lower right

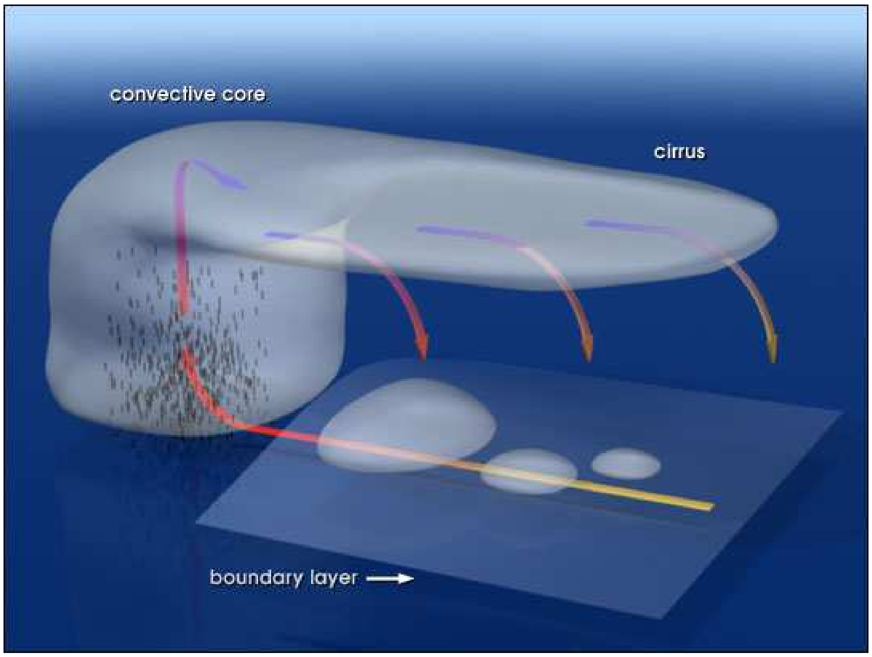
"We argue that a plausible interpretation is that the results reflect a temperature dependence for the cirrus detrainment from cumulus towers," the authors state in their paper. "This dependence appears to act as an iris—that opens and closes dry regions so as to inhibit changes in surface temperature."

Lindzen admits that he still doesn't know exactly how this infrared iris works, but his hypothesis is that the amount of cirrus "precipitated" out from cumulus depends upon what percent of the water vapor that is rising in a deep convective cloud condenses and falls as rain drops. Most of the water vapor condenses, but not all of it rains out. Sometimes the water vapor cannot form droplets into rain fast enough to avoid the strong updraft, and much of this moisture eventually goes into forming high, thin cirrus clouds. But the more moisture rains out of the cloud, the less there is available to form cirrus clouds.

image shows the difference between the 11 and 12 µm channels. Dark areas (in the upper lefthand corner) represent thick clouds. Clouds that were both cold and thick were included in the calculations of cloud-covered area. (Images by Robert Simmon, based on data from the GOES Project)

small visible light animation (380 kb Quicktime)
large visible light animation (15 Mb Quicktime)

"It is well known that the warmer the cloud base is and the more water vapor there is rising in the cumulus cloud, the more efficiently precipitation forms," Lindzen explains. "So this is consistent with what we saw—the warmer the cloudy region, the less cirrus you get. Conversely, as it gets colder, the cloud's condensation efficiency goes down and the more ice crystals get entrained to form cirrus clouds."



Strong convection redistributes heat and moisture in the tropical atmosphere. Distinctive anvil clouds form when hot, humid air (red) rises in a region called the convective core. As the air rises it cools, resulting in heavy precipitation. During the strong convection typical of the tropics the air can rise high into the troposphere (roughly 15 km altitude) where the column is truncated by high winds. This forms high-altitude cirrus clouds that stream out ahead of the storms. Cool air (still with a high relative humidity) drops out of the cap of cirrus clouds, which warms and dries as it falls. This process humidifies the air in the upper troposphere. Near the surface over the tropical oceans (beneath the boundary layer) the air is always humid and often filled with low-level clouds. (Image by Robert Simmon)

"This is a terrifically important feedback," Lindzen concludes, "because if you double the amount of carbon dioxide in the atmosphere but don't have any feedback within the system, you only get about 1 degree of warming (averaged over the entire globe). But climate models predict a much greater global warming because of the positive feedback of water vapor. Yet these models are missing potentially another negative feedback (the infrared iris) which can be anywhere between a fraction of a degree and 1 degree—the same order of magnitude as the warming." (The net result would then be that the Iris' negative feedback cancels the water vapor's positive feedback. The warming for a doubling of carbon dioxide would then return to the 1°C that scientists predict would occur if there were no feedbacks.)

Given the current political and scientific concerns about global warming, Lindzen's colleagues in the

Earth system science community were very interested in his findings. One litmus test for whether or not a new hypothesis is true is whether other scientists can reproduce the same experiment and arrive at the same findings as the original experimenter. Two teams of scientists—one based at NASA's Langley Research Center (LaRC) and the other at the University of Washington—replicated Lindzen's experiment and arrived at surprisingly different conclusions. (Only the LaRC team's experiment is presented here in part 1.)

▶ Evidence Against the Iris Hypothesis

The data used in this study are available in one or more of NASA's Earth Science Data Centers.

Evidence Against the Iris Hypothesis

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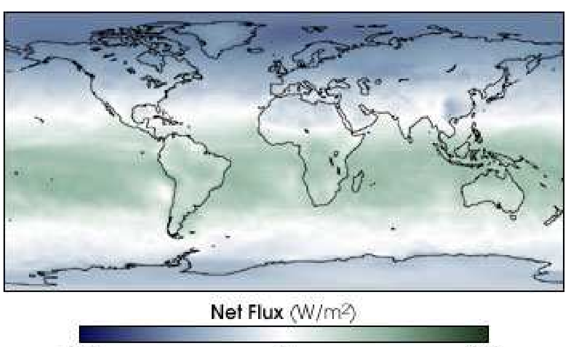
"The Iris Hypothesis is very exciting," states Bing Lin, an atmospheric research scientist at NASA LaRC. "Everybody would like to see tropical clouds changing in response to surface warming and acting to stabilize the climate system. The problem is when we used measurements from the Clouds and the Earth's Radiant Energy System (CERES) sensor, we got significantly different results (from Lindzen)."

Copies of the CERES sensor fly aboard both the NASA/NASDA Tropical Rainfall Measuring Mission (TRMM), launched in November 1997, and NASA's Terra satellite, launched in December 1999. Additional CERES sensors will be launched aboard Terra's sister ship, Aqua, in the spring of 2002. CERES is the most advanced space-based sensor ever launched for measuring Earth's radiant energy fluxes on a global scale.

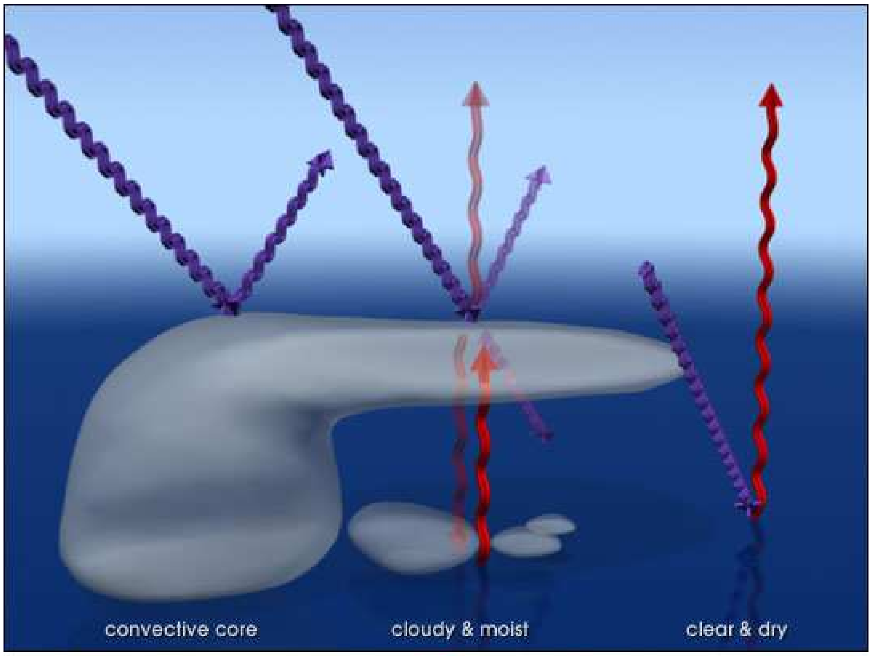


The balance of energy the Earth receives from the sun versus the amount emitted as heat from the Earth is measured by the Clouds and the Earth's Radiant Energy System (CERES). Scientists used these data, combined with estimates of cloud type derived from geostationary weather satellite data, to evaluate the results predicted by the Iris Hypothesis. The image at left shows net energy flux for February 2002 measured by CERES. The amount of energy retained within the Earth system ultimately determines its average global temperature. (Image by Reto Stöckli, based on data from the and CERES science team.)

Lin's team took the measurements made every day by CERES over the tropical oceans and plugged them into the same model that Lindzen used. Instead of the strong negative feedback that Lindzen's team found, Lin's team found a weak positive feedback (Lin et al. 2001). That is, Lin found that clouds in the tropics do change in response to warmer sea surface temperatures, but that the cloud changes serve to slightly enhance warming at the surface. Specifically, whereas Lindzen's experiment predicts that cirrus clouds change in extent to reduce warming at the surface by anywhere from 0.45 to 1.1 degrees, Lin's experiment predicts that changes in the tropical clouds will help warm the surface by anywhere from 0.05 to 0.1 degree (Lin et al. 2001).

The difference between the two experiments can be summed up as follows. According to the Iris Hypothesis, for each square meter of tropical cloudy, moist area that disappears with increasing surface temperature, 70 watts of heat is lost from the planet—like turning off a 70 watt light bulb for every square meter of area. But CERES' measurements of cloud properties tell a very different story—clouds are much more reflective (51 percent instead of 35 percent) and somewhat weaker in their greenhouse effect than Lindzen's model predicts. So instead of turning off a 70-watt bulb for each square meter affected, it is as if a small 2-watt night-light bulb was turned on in every square meter. Hence, the slight warming found by Lin's team instead of the very large cooling found by Lindzen's team.

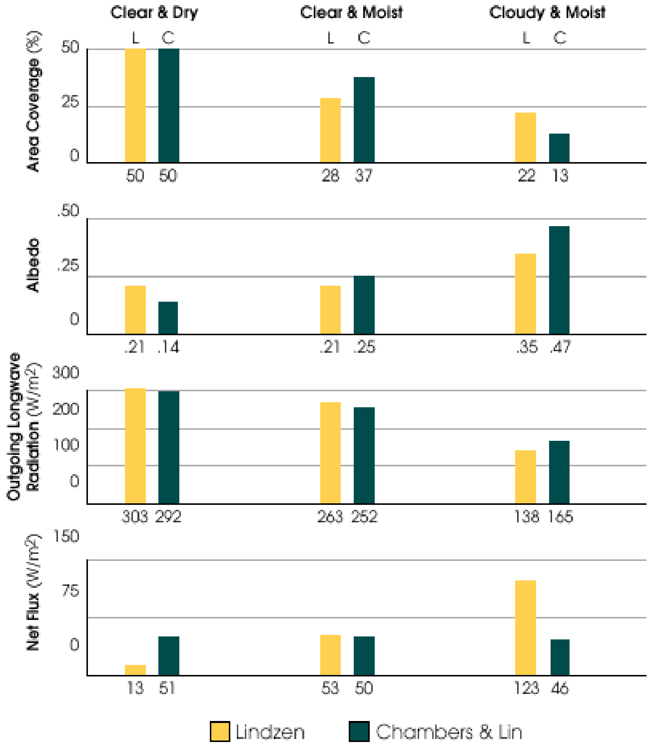
Lin says the reason his team's findings differ so dramatically is because some of the initial assumptions made in Lindzen's model are incorrect. He says that while he has many minor differences of opinion with Lindzen on this subject, he has three major disagreements. For starters, he says, the Indo-Pacific warm pool region does not serve as a model for the tropics all around the world. The waters there are, on average, much warmer than the rest of the tropics and so convection (warm, upward-moving air) is much stronger. Therefore, the area covered by deep convective cumulus clouds (thunderheads, basically) and cirrus clouds is not the same throughout the tropics. In the Indo-Pacific warm pool, these two cloud types cover about 13 percent of the region, whereas they only cover about 10 percent of the world's tropics on a global scale (Lin et al. 2001). Lin's team found that while tropical cloudiness does change as sea surface temperature changes, there is a large reduction in total cloud amount—roughly 10 percent cloud cover as compared to the 22 percent proposed by Lindzen's team.



Different types of clouds have different effects on the balance of energy received and emitted by the Earth. In areas covered by the cumulus towers of a thunderstorm's convective core (left) almost all the Sun's energy is reflected. The cold cloud tops radiate very little energy out into space. Cirrus clouds (the cloudy and moist region, center), on the other hand, reflect some shortwave energy, but let some through to the surface. Likewise, they emit some heat (longwave energy) but redirect some back to the surface. Clear and dry regions (right) are almost the inverse of convective cores—most of the solar energy is absorbed by the surface, much of which is eventually emitted as thermal infrared radiation back out to space. In the clear regions, reflected energy increases as low level clouds increase, while as humidity increases less longwave energy is emitted. (Image by Robert Simmon)

Secondly, Lin disagrees with Lindzen's proposed physical model of the clouds themselves. "Deep convective clouds very strongly reflect sunlight back to space," he states, "but their relative area of coverage is small." Cirrus clouds, on the other hand, are very extensive and cover large areas. They can be thin enough to allow sunlight to pass through, or they can also have a high reflectivity. Cirrus provides a much larger "canopy" over the tropics so, from a radiative perspective, those clouds are actually more important than deep cumulus clouds.

The third major disagreement between Lin's and Lindzen's experiments pertains to the amount of heat escaping from cloudy regions. CERES measurements reveal that 155 Watts per square meter escaped the atmosphere over cloudy, moist regions, which is significantly more than the 138 Watts per square meter that Lindzen's team assumed (Lin et al. 2001).



In the graphic on the left, "L" refers to Lindzen's team and "C" refers to Chambers and Lin. Both teams used the same equations to predict climate change, but they used different data sources and made different assumptions for the values of some variables that model the behavior of clouds. The table at left shows the contrasting values used by the teams. The most important differences were in the cloudy and moist region. Lindzen et al. used an albedo of 0.35 while Chambers et al. used an albedo of 0.47. Values of net flux for the region were 123 W/m^2 for Lindzen and 46 W/m^2 for Chambers. (Table by Robert Simmon)

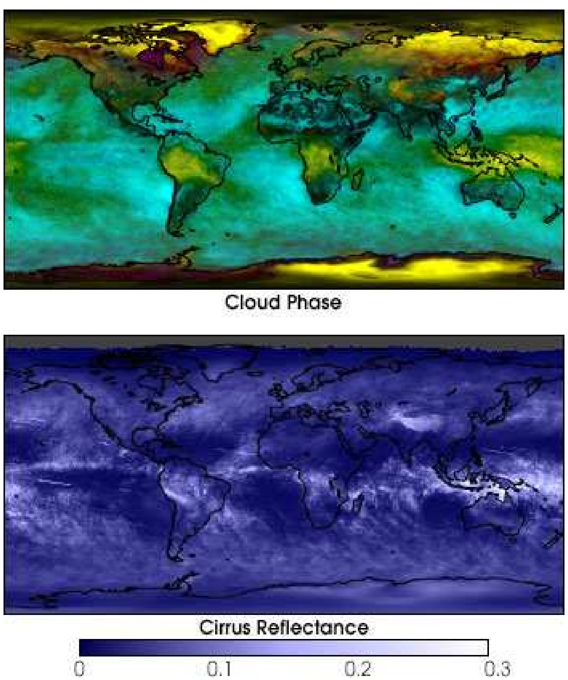
In summary, Lindzen's team suggests that higher sea surface temperatures lead to less cloudy, moist skies and a corresponding increase in clear, dry skies. Lin disagrees with Lindzen's interpretation of the cloud physics. In their paper, Lin's team wrote that the much smaller albedo and lower outgoing heat flux assumed by Lindzen exaggerated the cooling effects of the outgoing radiation over cloudy, moist regions while minimizing the warming effects of incoming sunlight through regions covered by cirrus (Lin et al. 2001). Based upon CERES data, Lin's team concluded that the reduction in cloudy, moist skies allows extra sunlight to warm the surface by up to 1.8 Watts per square meter—a small but positive net energy flux (Lin et al. 2001).

"Our results are based upon actual observations that are used to drive global climate models," Lin concludes. "And when we use actual observations from CERES we find that the Iris Hypothesis won't work."

▶ Reconciling the Differences
◀ Does the Earth Have an Iris Analog?

Reconciling the Differences
Currently, both Lindzen and Lin stand by their findings and there is ongoing debate between the two teams. At present, the Iris Hypothesis remains an intriguing hypothesis—neither proven nor disproven. The challenge facing scientists is to more closely examine the assumptions that both teams made about tropical clouds in conducting their research because therein lies the uncertainty.

The next step in resolving the Iris debate will be to use satellite-based measurements of clouds' physical properties—like cloud altitude, fraction, thickness, and ice/water particle phase. Sensors on the TRMM and Terra satellite missions routinely measure these cloud physical properties, which scientists will match in time and space with CERES' new measurements of radiant energy fluxes. This matching will then allow scientists to determine whether the Iris Hypothesis works for a wide range of ice cloud conditions. The Moderate Resolution Imaging Spectroradiometer (MODIS), aboard Terra, has a channel uniquely sensitive to cirrus clouds. By discreetly measuring radiant energy at a wavelength of 1.38 micrometers, MODIS can precisely measure thin cirrus clouds even when they occur over bright low clouds, providing scientists their first ability to examine the Iris Hypothesis in the context of multiple cloud layers. MODIS can also determine whether clouds are made up of ice particles or water droplets.



New data products from NASA's most recent satellites will help scientists resolve the controversy surrounding the Iris Hypothesis. The top image at left shows cloud phase for February 2002 from the Moderate Resolution Imaging Spectroradiometer (MODIS Science Team). Yellow indicates cold, high-altitude ice clouds, cyan corresponds to water clouds, and magenta shows undetermined (possibly ice clouds over water) clouds. The lower image shows cirrus clouds. Dark colors indicate no cirrus clouds, and white indicates cirrus clouds reflecting 30% or more of the incoming sunlight. Notice how the areas of ice clouds in the tropics (in the top image) correspond to cirrus clouds (bottom image).
(Images by Reto Stöckli, based on data from the MODIS science team.)

Historically, it has been very difficult for scientists to measure clouds' properties in multi-layer cloud formations using passive remote sensors. In 2004, scientists grappling with this problem will gain one of the most powerful tools ever developed for studying multi-layer cloud properties on a global scale. In that year, NASA will complete the launch of its "A-train"—a series of satellites that fly in formation around the Earth. In the lead will be the Aqua spacecraft planned for launch this spring (2002), carrying both the MODIS and CERES sensors. Following Aqua will be the Calipso and Cloudsat missions for making vertical profiles down through cloud layers nearly simultaneous with MODIS and

CERES observations. These new tools will enable scientists to explore clouds on a global scale in ways only dreamed of in the past. Perhaps then these arbiters of the Earth's energy will finally reveal their secrets.

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◀ Evidence Against the Iris Hypothesis

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