New instrument reveals raindrop formation in warm clouds

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How do raindrops form? It's a simple question, but the answer is far from elementary. Tiny water droplets somehow merge to become full-sized raindrops, but the details remain a mystery.

Now, scientists at the University of California, Santa Cruz, are closing in on an explanation with a new instrument they developed that measures the sizes of water droplets in clouds. Their findings point to complex mixing processes in clouds that promote the formation of raindrops, said Patrick Chuang, assistant professor of Earth and planetary sciences at UCSC.

Scientists think they have a good theoretical understanding of how raindrops form in cold clouds, where ice crystals play a key role, Chuang said. So he and his graduate student, Jennifer Small, are tackling the more puzzling problem of how raindrops form in warm clouds, like those that produce summer showers. They will present their findings on December 11 at the annual meeting of the American Geophysical Union (AGU) in San Francisco.

Knowing how clouds make rain is critical for improving the accuracy of climate models and predicting the effects of global warming, Chuang said. Water vapor is a potent greenhouse gas, and rain is the primary regulator of how much is in the air, he said. Rain is also one of the ways a cloud reaches the end of its life. This is important because clouds reflect sunlight, affecting global temperatures by regulating how much solar energy reaches the Earth's surface.

Condensation of water vapor in clouds creates tiny water droplets about 10 to 20 microns in diameter--less than the width of a human hair. These droplets are far too small to fall as raindrops, which are about a millimeter (a thousand microns) across and a million times heavier. To make raindrops, the droplets need to collide and stick together to create larger and larger droplets, Chuang said.

When scientists simulate this process with computers, raindrops form in one or two hours. In the real world, however, rain can start to fall within 15 minutes of cloud formation. Something must be speeding up the mergers of tiny droplets, which are so light they float around in clouds and avoid the collisions necessary to make raindrops.

Droplets with a diameter of about 55 microns or larger are heavy enough to fall through the cloud, merging with other droplets at a rapid pace. The real mystery, then, is how the tiny, 10- to 20-micron droplets become 55-micron droplets, Chuang said. One way to speed up the coalescence of droplets is to stir them up.

"If you stir up the droplets, they will more readily collide with one another," he said. "There are many ideas as to what the mixing mechanism is, but no one knows for sure how it comes about."

For decades, scientists have been debating over two main mechanisms. One proposal involves chaotic swirls of turbulence that churn on millimeter- to centimeter-sized scales. Another idea is a process called entrainment that happens when dry air mixes with moist air at the edges of clouds.

It has been difficult to find unequivocal evidence for either hypothesis because there have been no instruments that could measure water droplets in the key size range of 30 to 100 microns. So Chuang led the development of a new instrument to do just that, working in collaboration with Artium Technologies, Inc. Data gathered with the new instrument suggest raindrops form through a combination of both entrainment and turbulence.

"Until now, no one's been able to look at that process of how drops form--it's a missing link that has been in contention for 50 years," said Small, who will present their work at an AGU poster session.

Chuang's device--called a phase Doppler interferometer--attaches to the wing of an airplane and uses lasers to measure droplet sizes while the plane flies through clouds. Small and Chuang first used it over the course of six weeks in December 2004 and January 2005 above the Caribbean island of Antigua. The experiment was part of Rain In Cumulus Over the Ocean, a collaborative project involving scientists from around the country and funded by the National Science Foundation and the National Oceanic and Atmospheric Administration.

Small and Chuang measured the sizes of droplets in clouds, and found droplets larger than 55 microns in sinking pockets of drier air at the tops of clouds. This implies that the process of entrainment, which tends to occur at the tops of clouds, helped create the large droplets. The fact that the researchers found large droplets at cloud tops contradicts suggestions that large droplets form from particles like dust in the cloud, because such big particles would have sunk to the bottom. The fact that large droplets were grouped together and not randomly distributed throughout the cloud also challenges the notion that large droplets come from an outside source like sea spray.

Entrainment could explain most of the droplets they saw, but the findings suggest turbulence also plays a role, Small said. Turbulence, however, is inherently complicated and difficult to study. As a next step, the researchers will try to incorporate both entrainment and turbulence into a simple computer model and see if it re-creates their observations.

Source: UCSC