Looks like rain

By Mark Anderson, *NewScientist*

Not all clouds produce rain. And if you ask meteorologists why, after a few hand-waving explanations they will probably confess that they don't really know.

While the mechanisms of cloud formation are well understood, no one knows for certain what makes some clouds produce rain and others not. Models of what happens inside a cloud take into account general data like wind speed and the air's humidity, but fudge the inner mechanics of clouds.

There is a lot of room for improvement, and solving the mystery will not only help improve climate models, but could improve the reliability of cloud seeding as a way to induce rain.

To estimate the chances of rain, meteorologists and climate modellers have to fall back on observations of which types of clouds tend to produce rain and which do not, says Steve Derbyshire, a weather modeller at the UK's Meteorological Office in Exeter.

What forms a raindrop?

What modellers like Steve would love is a clear model that explains the precise physics of raindrop formation. There is no shortage of ideas – at least four competing alternatives have been put forward – but until now we have not had the data to conclusively rule any of them in or out.

That may be about to change, thanks to the most comprehensive study of cloud formation so far, which has just been completed.

The conditions necessary for clouds to form are well understood. Air temperature drops with altitude, so as warm damp air rises and cools, the moisture it carries condenses onto specks of dust or soot, tiny salt crystals and other microscopic particles floating about – called cloud condensation nuclei (CCNs) – just as moisture in your breath condenses on a cold day.

The droplets created when water molecules condense spontaneously onto CCNs can grow to around 10 micrometres in diameter in under five minutes. And that's where the mystery begins.

For some reason, these tiny droplets sometimes – but not always – continue growing, swelling up to a million times their original volume in around 30 minutes.

Droplets that grow this big, typically one to two mm in diameter, become too heavy to be held suspended in the cloud by updraughts and so fall to the ground as rain.

But what causes this sudden and rapid growth of droplets in some clouds, and why is the process absent in others?

Crucial early stage

The answer may lie in a crucial early stage in droplet growth. At first, the droplets that condense onto CCNs can easily gather more water molecules as they condense out of the cooling cloud. But once the droplets reach a diameter of around 10 micrometres, even a small increase in size means adding many millions of water molecules.

Relying purely on condensation to grow the droplets becomes like filling an Olympic swimming pool one cup at a time – a very slow process. It can take days for condensation alone to produce raindrops, says Sonia Lasher-Trapp, an atmospheric physicist at Purdue University in Indiana.

But once droplets reach approximately 40 micrometres, the problem disappears as they now have a significant chance of colliding and amalgamating with one another. "We call that stage 'collision and coalescence', and once that process gets going, you get rain very quickly," says Sonia.

So the crux of the mystery is this – what makes some droplets bridge the gap and grow from 10 to 40 micrometres?

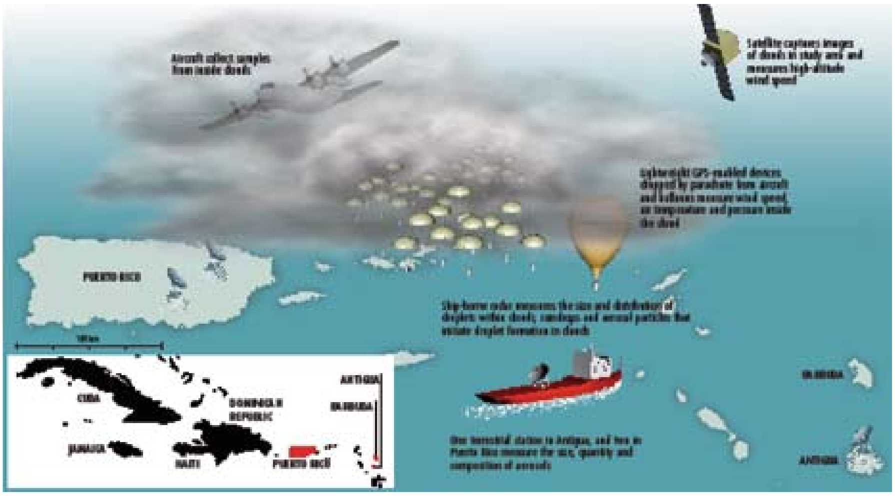
FOUR MAIN THEORIES

Four main hypotheses have been proposed to explain this.

- The first of these was developed in 1973 by Hendrik Tennekes Pennsylvania State University and John Woods, then at the University of Southampton in the UK. They calculated that turbulence inside a cloud might crash droplets together faster and more efficiently than simple cloud models, and their successors now suggest that turbulence lowers the bar for collision and coalescence closer to 10 micrometres, eliminating the 10 to 40-micrometre gap altogether.
- Yet turbulence may only be part of the story. In 1982, David Johnson of the Illinois State Institute of Natural Resources suggested that just a few 40-micrometre droplets could be enough to trigger a rainstorm. His idea relies on the fact that large aerosol particles, several micrometres in diameter, are known to exist in the atmosphere. Droplets formed by

Science is getting closer to answering why some clouds produce rain and not others.

FIGURE 1: Inside a rain cloud – the RICO project is designed to produce the most comprehensive insight to date into the factors that make the clouds produce rain



condensation on these oversized CCNs have a headstart, and so can reach the 40-micrometre threshold more quickly. "It's a nice, simple idea. If you've got big particles, you make raindrops quickly," says Sonia. But she points out there's a flaw in this model. When it rains, larger particles drop out of the clouds faster, so the amount of rain they can be responsible for creating is small.

- In 2000, Alexei Korolev and George Isaac of the Meteorological Service of Canada in Toronto revived an older model, nicknamed the 'entrainment model'. They calculated that the tops of some clouds sweep up parcels of cold, dry air so abruptly that they create turbulence and thus the conditions for extra condensation and coalescence. Korolev and Isaac calculated that this can produce enough 40-micrometre cloud droplets to start the runaway formation of rain. But this still fails to explain how rain is produced in large cumulus clouds.
- Another model was put forward in 2005, when Raymond Shaw and Alex Kostinski of Michigan Technological University suggested a new twist on David Johnson's giant aerosol idea. Although there's only a tiny chance of two 10-micrometre droplets colliding, Shaw and Kostinski calculated that it only takes a few such droplets to collide and merge for larger droplets to form that will, in turn, start the runaway train of collision and coalescence. "To form rain, you don't need all the droplets to collide with each other. Only a few are needed to get this process going," says Raymond Shaw.

THE RICO PROJECT

To help determine which model, or combination of them, is right, Bjorn Stevens of the University of California, Los Angeles, has launched the Rain In Cumulus over the Ocean (RICO) project, which aims to be the most exhaustive empirical study of warm rain to date. He plans to analyse the movement of water droplets in clouds in minute detail, and from that work out what is really going on in rain clouds.

Between November 2004 and January 2005, RICO researchers studied clouds forming over a 20,000-square-km patch of the Caribbean Sea around Antigua and Barbuda. Three research aircraft were flown through the study region, which measured the variation in droplet size within the clouds and also dropped hundreds of lightweight GPS-enabled beacons to study air currents within them.

Members of the team operating from ships used radar to build up accurate profiles of water density in the clouds, and the movement of droplets in them. On land, there were more radar stations and aerosol measurement sites. Finally, RICO tapped into visual and infrared spectroscopic measurements made from NASA's Terra satellite (see Figure 1).

These measurements should at last allow researchers to distinguish between the various models of rain formation. "RICO will allow us to advance the art of cloud simulation to the point where we can begin to quantitatively evaluate these ideas," says Bjorn Stevens. If, for example, the giant aerosol model is valid, there will be more rain on days when a lot of large aerosols are present in the atmosphere.

Things are not looking good for it, as preliminary analysis of the RICO data shows no evidence for such a link. Ruling out the others will be less straightforward, though, and will require more sophisticated analysis of the data.

Observations from RICO have even suggested a new twist on existing models. "We saw clouds forming in the debris or wake of old clouds, and that was new to us," says Bjorn, describing how particles from evaporating clouds were observed being consumed and turned into a new cloud as a pulse of warm, moist air rose from the sea.

It is possible that can initiate rain-making, he suggests, as this recycling is likely to cause droplets from the parent clouds to combine and grow. So far, though, it has yet to be borne out by observation.

Whichever theory wins out will have to explain both how raindrops form and why they sometimes fail to form. "You'd like a theory that can form rain relatively quickly, but on the other hand can still allow for all those clouds we know and love that don't form rain," says Bjorn.

The whole story is unattainable

But understanding the behaviour of water droplets at the micrometre scale, crucial as it is, will never provide the whole story. A complete theory of rain formation will have to take into account everything from submicrometre aerosols to wind and convection currents within and around clouds, right up to the interaction of weather fronts hundreds of km wide.

The mass of data collected by RICO will be relevant to all these factors, but at the same time its sheer volume will pose a problem for researchers. There will be far too many measurements for the computational model to cope with, Sonia says, so modellers will have to select representative phenomena at each significant size scale.

If the puzzle of raindrop formation can be solved, the conclusions will reach beyond meteorology. The cooling effect of small, puffy cumulus clouds as they reflect sunlight is linked to the sizes of the droplets they contain.

So understanding how raindrops form should help answer crucial questions about how the climate might change in the years ahead. "In a future climate that might be warmer, can we expect clouds to help us out?" asks Sonia. "Or might it go the other way, and help warm Earth even more?"

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