Inside information

Earth's climate depends strongly on clouds. But what really goes on within these layered structures? **Heike Langenberg** reports on two satellites that aim to find out.

There's more to clouds than meets the eye. Look up on an overcast day, and you'll be presented with a sea of grey. But this blanket blotting out the Sun is merely the base of an intricate layered structure that rises vertically through the atmosphere.

The composition of these layers helps to dictate what effect the clouds have on our climate. The results can be dramatic — but little is known about how these effects come about. Two satellites, scheduled for launch next month, are set to change all that.

Named CloudSat and CALIPSO, these satellites will use radar and an equivalent technology based on light waves, known as lidar. They will cut through the layered structure of clouds to see how water droplets and airborne particles, or aerosols, are distributed around the globe.

"This is a truly exciting time," says Graeme Stephens, a climatologist at Colorado State University and head of the CloudSat science team. "We're entering a new era of Earth observations with these missions."

Clouds are one of the last great unknowns when it comes to understanding Earth's climate. They can both absorb and reflect the Sun's radiation before it reaches the planet's surface. They can also capture outgoing radiation from Earth. The scope of this effect depends in part on the distinct layering of the clouds and the variations in colour, density and altitude.

The small water droplets that constitute clouds, and the even tinier particles that make up aerosols, act on scales much smaller than the 100-kilometre grids typically used in climate model calculations. Even worse, the distributions of clouds and aerosols can change rapidly over time, which limits the usefulness of observations taken during patchy measurement campaigns.

The Intergovernmental Panel on Climate Change recognized such uncertainties in its most recent report, citing cloud and aerosol effects as among the least understood of the factors that affect Earth's climate.

Cover story

But clouds are too important to climate for them to be ignored. A change of only about 1% in global cloudiness can either mask or double the effect that a decade's worth of greenhouse-gas emissions have on the amount of heat lost to space from Earth, says Bruce Wielicki, a climate researcher at NASA's Langley Research Center in Hampton, Virginia.

And human activity can bring about changes in global cloudiness. Global warming caused by greenhouse-gas emissions can change the planet's water cycle, for example, and tiny aerosol particles emitted in pollution can change cloud properties and precipitation.

Researchers continue to debate whether climate change has already brought about long-term changes to incoming solar radiation by altering cloudiness and so leading to either a dimming or a brightening on a global scale[1–3]. Such uncertainties are rooted partly in a lack of continuous, accurate cloud measurements from around the planet.

Until now, most observations have measured only total cloud thickness. The new missions will go much further. One of CALIPSO's tasks, for instance, will be to observe the monthly global mean cloudiness down to variations of just 0.1%, says David Winker, who heads the satellite's science team at the Langley Research Center.

Modelling cloud and aerosol dynamics presents problems for climate prediction, as the uncertainties are difficult to constrain[4]. Until now, getting data on the vertical distribution of cloud layers has been restricted to occasional reconnaissance flights. As a result, climate researchers cannot accurately estimate how aerosols will affect the radiative properties of clouds, a process known as the first indirect aerosol effect. Current satellites cannot tell whether or not aerosols and clouds occur at the same altitude, and so cannot tell whether the two are truly linked.

With its 3-millimetre wavelength radar, CloudSat is designed to detect relatively large water droplets in both thick and thin clouds. CALIPSO — a tortured acronym for Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation — will use much shorter wavelengths to distinguish the fine details of thinner clouds and aerosols. Combining this

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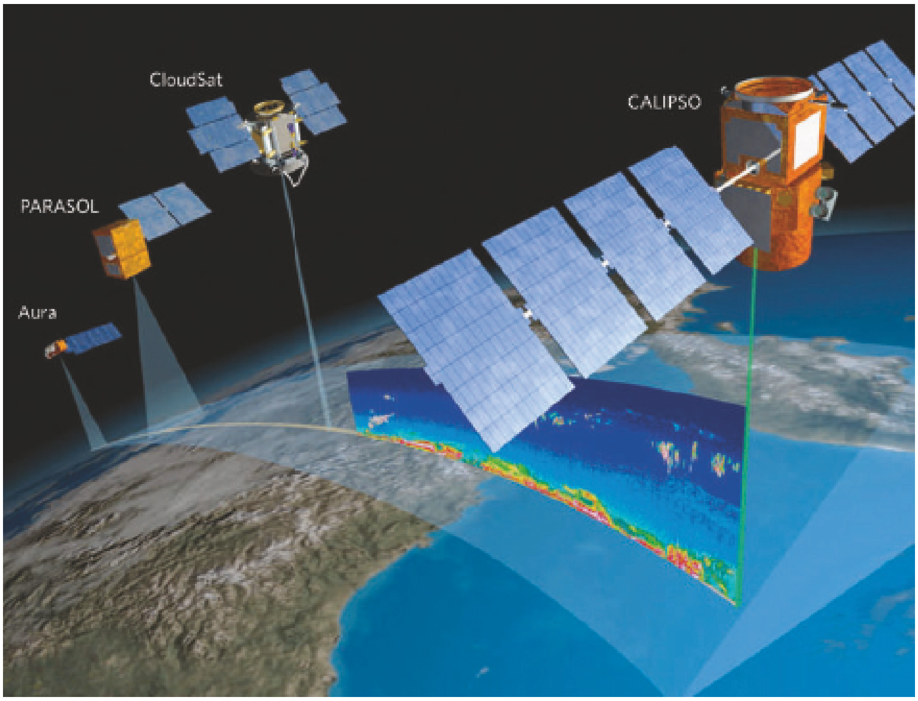

When they launch, CloudSat and CALIPSO will join a group of Earth-observing satellites called the A-train.

information should provide a new benchmark for existing climate models, says Ulrike Lohmann, a climatologist at the Swiss Federal Institute of Technology in Zurich.

The two satellites will fly in formation about 700 kilometres above Earth's surface, and will measure the same spot in the sky within 15 seconds of each other. These near-instantaneous observations will allow them to identify when clouds and aerosols are truly in the same layer, as opposed to located in separate layers that just happen to be vertically aligned.

Making a splash

CloudSat will also observe rain, so that researchers will similarly be able to tell when precipitation occurs in the same air mass as aerosols and cloud droplets. That, in turn, will help them to investigate the second indirect aerosol effect — how aerosols affect precipitation and cloud lifetime on a global scale[5]. "CloudSat will be like a medical scan revealing the inner workings of clouds," says Stephens.

Unlike many satellites, CloudSat and CALIPSO carry 'active' instruments, which send out their own electromagnetic signals — radio waves for CloudSat's radar and light waves for CALIPSO's lidar. These instruments record the time it takes for the signal to bounce off an obstacle, such as a cloud, and return to the satellite, thus revealing the cloud's altitude.

CloudSat's radar will be able to cut through all but the densest clouds. The shorter-wavelength lidar on CALIPSO cannot cut through thick or frontal-storm clouds, but should be able to profile about 60% of all clouds, says Winker.

The idea of using both radar and lidar to study clouds and aerosols from space has been around since at least the early 1990s, Stephens notes. But putting both instruments on one satellite proved too costly. By splitting the project in two, NASA spent $200 million on CloudSat and $175 million on CALIPSO. France's space agency helped to build the latter, and Canada contributed a key element to CloudSat's radar.

Both satellites will be launched on a single rocket no earlier than 26 October from the Vandenberg Air Force Base in California. They will join three Earth observation satellites already in place: Aqua, which investigates Earth's water cycle; Aura, which focuses on air quality and stratospheric ozone; and PARASOL, which measures the direction and polarization of light in the atmosphere.

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> — Ulrike Lohmann

Together, the satellite formation is called the 'afternoon constellation', or the 'A-train', because it crosses the equator at about 1:30 p.m. local time. One final satellite, the Orbiting Carbon Observatory, is slated to join the A-train in 2008. With only about 8 minutes between the passage of Aqua, the first satellite in the A-train, and Aura, the formation's tail end, the instruments see largely overlapping portions of the sky.

"The A-train as a whole will sample practically all the clouds above Earth," says Stephens. Aqua's observations of cloud optical properties, in particular, should be invaluable in interpreting CloudSat's information on cloud layering.

CloudSat and CALIPSO will also complement each other, as aerosols are intricately linked to the formation of clouds. In aerosol-rich air, for instance, clouds tend to be composed of a large number of small water droplets — a phenomenon that can affect the brightness of the clouds as well as their capacity to produce rain.

Not all aerosols have the same effect. Most aerosols simply help cloud droplets to condense, but soot particles can also absorb some of the Sun's radiation and so warm the atmosphere, potentially thinning the cloud layers. CALIPSO will be able to distinguish the size and shape of aerosol particles. As those from human sources are typically ten times smaller than particles from natural sources, this should allow researchers to track specific sources of pollution.

Arctic role

Another area in which the satellites might contribute is charting Arctic clouds. To 'passive' instruments, which don't send out their own radar or lidar signals, these bright, cold clouds are hard to distinguish from the icy surface they float above. The active instruments on CloudSat and CALIPSO should be able to get around this problem by resolving these clouds into three-dimensions — making them stand out against the white background much like objects in a 3-D film do when the viewer dons red–green glasses.

CloudSat and CALIPSO's new observations should help modellers to see whether their simulated clouds are not only over the right region but also at the correct height. Repeating measurement slices through similar atmospheric conditions should uncover ways to formulate the model equations and, eventually, create more realistic models. "The statistical information from satellite data is invaluable for the validation of climate models," explains Lohmann.

Yet for all their strengths, the two satellites cannot solve all the research problems of clouds and climate. Ideally, scientists would be able to trace air masses as they move, in order to study the evolution of clouds in the presence or absence of aerosols. CloudSat and CALIPSO will capture only a frozen picture in time, rather than the entire dynamic movie.

But for now, climatologists are excited about the prospect of getting so much fresh information and finally plugging some holes in their understanding of Earth's climate. For once it seems it's not a bad thing to have your head in the clouds. ■

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