# Tilting at clouds


**Graeme O'Neill** discovers there is more to clouds than meets the eye.

As the Top End's hot, dry season yields to the annual Wet, an intense tropical thunderstorm known as Hector emerges from an apparently clear Darwin sky at about 4 o'clock on most afternoons. But the clarity of that sky is deceptive, according to Dr Stuart Young from CSIRO's Division of Atmospheric Research.

During last year's Maritime Continental Thunderstorm Experiment on Melville Island, (one of the Tiwi Islands north of Darwin), a laser-based instrument developed by the division discovered a thin, virtually transparent layer of cirrus cloud at an altitude of between 16 and 18 kilometres, near the boundary between the troposphere and the stratosphere.

Young says the 'lidar' instrument detected a similar almost invisible layer of cirrus over Kavieng, in Papua-New Guinea, during the TOGA-COARE project in 1993, an international experiment designed to study the interaction between the tropical ocean and the convective atmosphere, and its influence on climate.

High-altitude cirrus cloud is composed of tiny ice crystals. It has a strong impact on the Earth's radiation budget because, although it reflects some of the solar energy entering the top of the atmosphere back into space, it re-radiates absorbed infrared energy back to the Earth and has a net warming effect. Also, because it is so thin, it is susceptible to global warming.

Young says it remains to be determined whether the cirrus layer is a permanent feature in the tropical sky, and whether it influences Hector or tropical storms elsewhere in the world, but its influence on tropical radiation budgets, and in satellite remote sensing of the Earth's surface and atmosphere, must be considered.

'We're not quite sure about its origins, but it may be the residue of previous thunderstorms which push ice crystals up into the region just below the tropopause,' Young says. 'The larger ice crystals precipitate as rain or evaporate, but the finer crystals fall slowly and remain suspended in the atmosphere for a considerable time.'

The lidar was developed in-house at a capital cost of only $230 000, largely from components that were custom-designed and manufactured locally. It gives the division a sophisticated, versatile and mobile tool for studying clouds and other atmospheric phenomena, including the behaviour of plumes from power stations and industry.

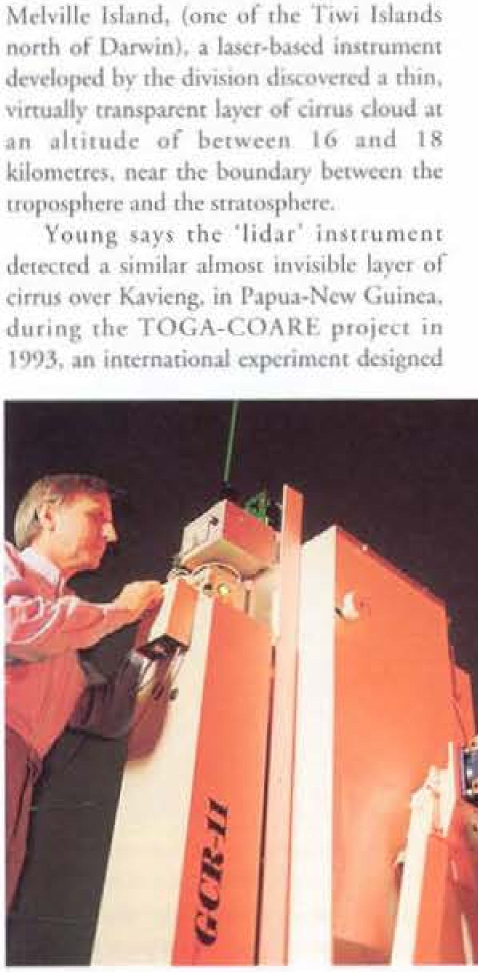
A lidar is a laser-based device that fires brief, intense beams of coherent light through the atmosphere. Gas molecules in the atmosphere, water droplets, ice crystals and dust variously transmit, absorb or backscatter the light, or rotate the plane of the polarised beam. A sensitive 35 cm telescope attached to the laser detects the returning light; the intensity and polarisation of the backscattered light yields details of the structure, density and composition of clouds or plumes in the beam's narrow path.

The new instrument is far more flexible than the division's original lidar, which was acquired in 1975 at a cost of $110 000. Two of the most important advances are the capability of operating in an eye-safe mode at a wavelength in the near ultraviolet region of the spectrum, and the ability to make rapid three-dimensional measurements of the atmosphere.

Young says the original instrument could only be operated at a fixed wavelength of 694 nanometres; the deep red beam from its ruby laser was potentially hazardous to eyes, so during experiments the division had to contact aviation authorities to ensure aircraft stayed out of the surrounding airspace.

The new lidar employs a neodymium-YAG laser, which is more efficient than its predecessor's ruby laser. It has a primary wavelength of 1064 nanometres in the near-infrared region of the electromagnetic spectrum and is equipped with devices that double and triple this primary frequency, to produce beams at two other wavelengths: 532 nanometres (bright green) and 355

David Whillas




**Dr Stuart Young, manager of the lidar facility at the Division of Atmospheric Research, uses the instrument to view the stratospheric dust layer. This information is used to assist in calculating the climate effects of major volcanic eruptions.**

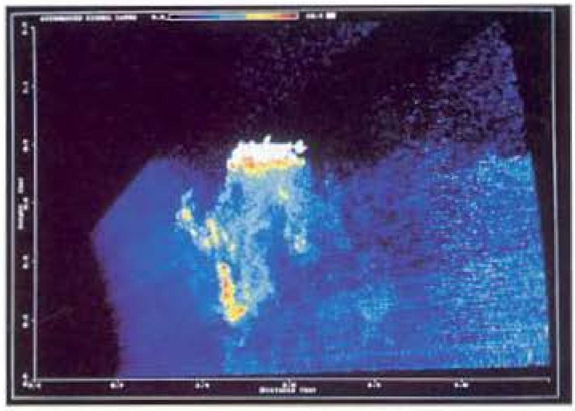
nanometres (invisible near-ultraviolet). When the potentially harmful green and infrared beams are blocked leaving only the UV wavelength, the lidar is eye-safe at any distance beyond 80 m.

The old lidar was also limited in its ability to monitor details of what was happening in a large volume of atmosphere because it could be fired only once a second, and only scanned slowly.

'When we started building the new lidar in 1990, we really needed a system that could acquire data more rapidly,' Young says. 'When you're tracking a power station plume moving through turbulent atmosphere, you need a high sampling rate.'

The lidar builds up a three-dimensional picture of the atmosphere by making a series of scans in elevation. Each scan is like a vertical, fan-shaped 'slice' of the atmosphere and is produced by firing a sustained burst of up to 128 laser pulses at a rate of 10 pulses per second, while recording the backscattered signal at each successive elevation angle. While the lidar is being realigned for the next scan at a new azimuth angle, data from the last scan is downloaded onto a computer which then displays each two-dimensional image sequentially, in almost real time. The plan view of where the lidar detects the smoke plume is superimposed onto a map of the study area in an adjoining display panel on the computer screen (see picture).

The optical and digital systems for capturing, separating, transforming and analysing the data are so efficient that they



**A 'slice' of the Kwinana power station plume as captured by the lidar. The plume is being mixed below an inversion layer. The white area at the top of the image is a strato-cumulus cloud which marks the top of a thermal updraft carrying the plume upward.**

can record simultaneous data streams from any two of the three wavelengths at which the laser operates. They also record the polarisation of the signal, which can help the scientists to better distinguish the components of a cloud or plume.

For example, spherical water droplets in clouds backscatter the laser light without changing its original horizontal plane of polarisation. In contrast, ice crystals rotate some of the light into the vertical plane. Polarisation data collected by the lidar can therefore be used to characterise the location and relative abundance of ice crystals in clouds.

## Have lidar, will travel

The new lidar can be mounted on a platform in a caravan and towed almost anywhere in Australia, or shipped to offshore locations. At Cape Grim in north-western Tasmania, the lidar gathered data on cloud structure for a study into the effects of maritime aerosols on the ability of clouds to reflect solar radiation.

In another project even further from home, the lidar was part of a major study used to validate and refine an atmospheric dispersion model of the airshed around the Kwinana industrial area, south of Perth. The model is used by the WA Department of Environmental Protection to help regulate sulfur dioxide emissions from local power stations and industry. Plume dispersion from Queensland's Tarong power station had been studied previously with the old ruby lidar.

Young says the new lidar's first commercial project was at Pasminco's lead smelter at Port Pirie in South Australia. The company was considering investing in new smelting technology to reduce sulfur

**Above: Tracking the plume from Kwinana's power station as it mixes with the atmosphere. The lidar measurements helped to validate a plume-dispersion model used to determine ground-level concentrations of sulfur dioxide.**

**Inset and right: Inside the lidar's control caravan. The scene outside is relayed inside via a video camera mounted on the lidar. Green lines on the computer screen show the coordinates of the scan being taken by the lidar, with the position of the plume marked in yellow. The vertical, fan-shaped slice through the plume is shown on the left panel of the computer display.**

dioxide emissions, and needed to know where and how the sulfur dioxide from the smelter plume would disperse under a range of atmospheric conditions. The normally invisible gaseous plumes were made visible by injecting them with fly-ash from a nearby power station.

The lidar's laser beam can penetrate up to 200-300 m into thick, low-level cumulus cloud, while cirrus 10 km deep has been penetrated. It can also be used to study high-altitude phenomena. After the Mt Pinatubo eruption in the Philippines in 1991, it was used to measure concentrations of volcanic dust and sulfate aerosols at altitudes up to 50 km.

While the division has no plans to manufacture the lidar commercially, it has developed the instrument and the associated scientific expertise to assist enterprises such as power stations, mining companies or refineries to solve problems associated with the tracking, identification of sources, and modelling of the dispersion of airborne emissions.

Enquiries from enterprises that might be interested in making use of its new instrument and scientific expertise are welcome. Contact: Dr Stuart Young, (03) 9239 4589, fax (03) 9239 4444, email: stuart.young@dar.csiro.au.

### More about the lidar


Barton IJ Prata AJ Watterson IG and Young SA (1992) Identification of the Mt Hudson volcanic cloud over SE Australia. *Geophysical Research Letters*. Vol. 19 No 12 pp1211-1214, June 19.

Sawford BL, Young SA, Noonan JA, Luhar AK, Hakker JM, Carras JN, Williams DJ and Rayner KN (1996) The 1995 Kwinana Fumigation Study - 1. Program Overview, Experimental Design and Some Results. *Proc. 13th International Clean Air and Environment Conference* Adelaide, Sept. 1996.

Young SA (1995) Analysis of lidar backscatter profiles in optically thin clouds. *Applied Optics*. Vol. 34 No 30 pp7019-7031, Oct. 20.


## Around the world in eight days

ON August 20, 1991, unusual, hazy clouds were encountered by jet aircraft flying between Melbourne and Sydney. Reports of an unpleasant sulfurous odour were given by crew and passengers. After studying satellite images of the phenomenon, scientists decided that the strange 'clouds' were neither water nor ice, but were likely to have been a mixture of volcanic ash and sulfur dioxide.

Eight days later, this was confirmed, with help from CSIRO's lidar, which was in operation at the Division of Atmospheric Research at Aspendale, south-east of Melbourne. Fortunately, the lidar's beam was directed skyward at the time, recording the progress of a volcanic cloud from Mt Pinatubo in the Philippines which had erupted on June 15. The Pinatubo cloud had taken just over a month to reach Melbourne and was still hovering overhead, contributing to a series of stunning, orange sunsets. Now it had company.

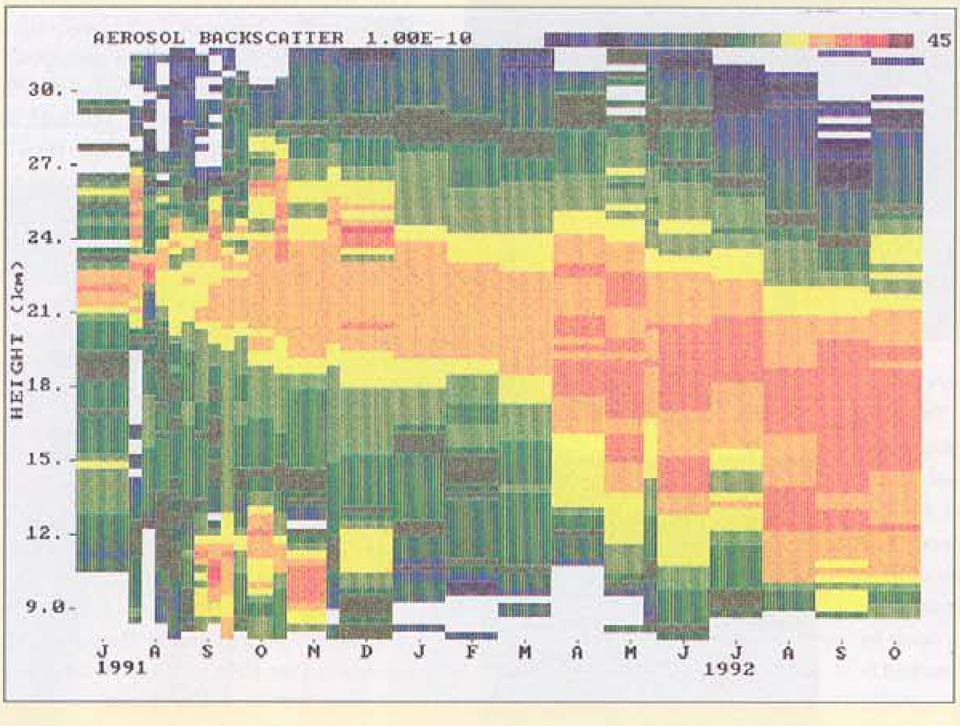
On August 28, the lidar received a strong backscattered signal from a layer situated 12 kilometres above the ground,. The layer was below the Pinatubo cloud, but above the tropopause, higher than the location of water/ice clouds at these latitudes. A closer look at the lidar and satellite data indicated that these clouds also were volcanic in origin, almost certainly from Mt Hudson in southern Chile which had erupted violently on several occasions from August 12 to 15.

Most of the debris from the eruption would have fallen out within a few hundred metres of the volcano, leaving only the smallest ash particles, volcanic gases ($SO_2$, HCl, $CO_2$) and water vapour as the major constituents of the drifting volcanic clouds. But because the winds near heights of 10 km are strong, the clouds were transported around the globe in only eight days.

Volcanic clouds pose a significant hazard to aircraft, because of the damage they cause to the jet engines, the windscreen and leading edges and to the electronics systems. Corrosion of surfaces due to sulfuric acid can also occur. It is important to determine the location and movement of these hazardous clouds as rapidly as possible and to relay information to air traffic.

Scientists at the division are developing methods of detecting and forecasting the movement of volcanic clouds, using information from a range of sources such as satellites, climate models, and the lidar.

*Bryony Bennett*




**The atmosphere above Melbourne as seen by the lidar during 1991 and 1992. The large, red area represents the height and density of a volcanic cloud originating from Mt Pinatubo. The small red area in the lower left of the image shows an ash cloud from Mt Hudson in southern Chile.**