Scientists calibrate the radiometer before the cloud-seeding aircraft commences a search pattern above the target area.

The AWSE research aircraft contains a battery of sophisticated equipment for measuring clouds.

Aircraft-mounted instruments measure the density of supercooled liquid water in clouds and their temperature at various heights.

Photos: CSIRO Division of Atmospheric Research

More rain for Melbourne catchments

Cloud seeding, out of favour for many years, now looks like an economic means of boosting Melbourne's water supply.

Despite its reputation as one of Australia's wettest cities, Melbourne (with an average annual rainfall of 65 cm over the central metropolitan area) is, in fact, only half as rainy as Sydney (which has an annual average of 121 cm).

Those facts aren't just of interest to meteorologists: they are immediately relevant to consumers. Water is so valuable to Melbourne that its 'retail' price — the cost to the end user — ranges from \$150 to \$560 per megalitre (ML), among the highest water costs in Australia. The catchments of the Melbourne metropolitan area receive 640 000 ML of water in an average year in the form of rain; the city consumes 470 000 ML, with the balance held in storage. While the city's water use is growing by more than 2% a year, its catchment areas and storage facilities aren't; so the Melbourne and Metropolitan Board of Works (MMBW), responsible for managing the city's water supply, is primarily concerned with managing demand by conserving water and educating consumers in using water more wisely.

To support its conservation strategies, MMBW is working with the CSIRO Division of Atmospheric Research in an attempt to augment supplies by increasing rainfall in the main Thomson catchment area by an expected 10–20% through cloud seeding. The area was chosen because it has 'orographic' clouds — created by the movement of cool, moist air up and over hills and mountains, in this case the Baw Baw Plateau to its south-west. The clouds release their load of rain into the catchment to the north-east: a 10% increase in rainfall over the catchment would only involve the release of 1% of all the water, including water vapour, contained in the clouds, so there's no risk of reducing rainfall downwind.

The CSIRO/MMBW cloud-seeding project has significant economic potential. Its value to Melbourne is threefold: first, it has the potential to reduce capital expenditure by postponing the construction of new water-storage projects costing hundreds of millions of dollars; second, every megalitre of rain produced by cloud seeding would cost just \$30; and third, the MMBW values every addition to rainfall (1 mm of rain over the catchment adds 487 ML of

water) at $180 per ML — roughly equivalent to a value of $88 000 for every additional millimetre derived from cloud seeding.

The CSIRO involvement with cloud seeding began with a bang in February 1947, when Division of Radiophysics scientists dumped 70 kg of dry ice from a circling DC-3 into the top of a cloud west of Lithgow, N.S.W. Within a quarter of an hour rain began to fall... and kept falling for hours. It is regarded as the world's first successful rainmaking experiment.

In the early 1950s, silver iodide 'smoke' produced by burning a solution of acetone and silver iodide replaced dry ice: this method was as effective, and less cumbersome than carrying hundreds of kilograms of dry ice aloft.

Cloud seeding became more efficient when sensitive aircraft-mounted instruments were developed to assess the right kinds of clouds for seeding — for example, by estimating how much supercooled liquid water, which would be converted into precipitation, they contain. This can be determined by measuring the cooling caused by water droplets impacting on a heated wire that projects from the fuselage.

Unfortunately, researchers also learned that the ideal cloud in which to stimulate raindrop formation is uncommon in many areas, and CSIRO closed down its cloud-seeding program in the early 1980s because it felt too little success had been achieved to justify increasing costs.

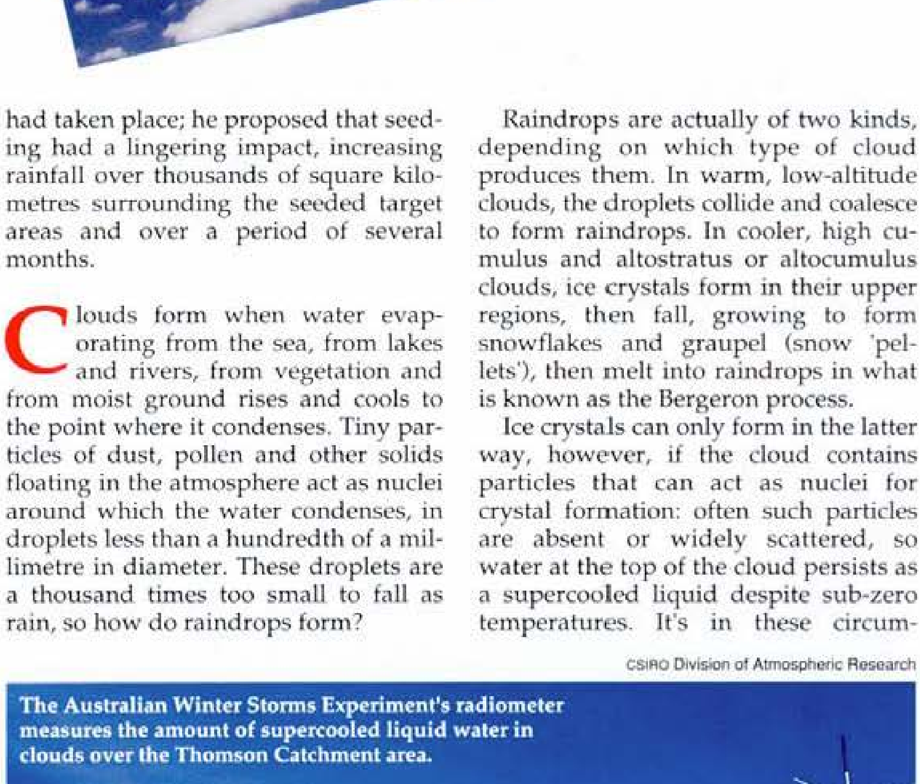
By 1985, however, long-term quantitative studies had revealed that the program had apparently been more effective than anybody had expected. Dr Keith Bigg of the Division's Cloud Physics Laboratory discovered that the very act of seeding in one area seems to have affected cloud formation and rainfall in nearby areas where no seeding had taken place; he proposed that seeding had a lingering impact, increasing rainfall over thousands of square kilometres surrounding the seeded target areas and over a period of several months.

Clouds form when water evaporating from the sea, from lakes and rivers, from vegetation and from moist ground rises and cools to the point where it condenses. Tiny particles of dust, pollen and other solids floating in the atmosphere act as nuclei around which the water condenses, in droplets less than a hundredth of a millimetre in diameter. These droplets are a thousand times too small to fall as rain, so how do raindrops form?

Raindrops are actually of two kinds, depending on which type of cloud produces them. In warm, low-altitude clouds, the droplets collide and coalesce to form raindrops. In cooler, high cumulus and altostratus or altocumulus clouds, ice crystals form in their upper regions, then fall, growing to form snowflakes and graupel (snow 'pellets'), then melt into raindrops in what is known as the Bergeron process.

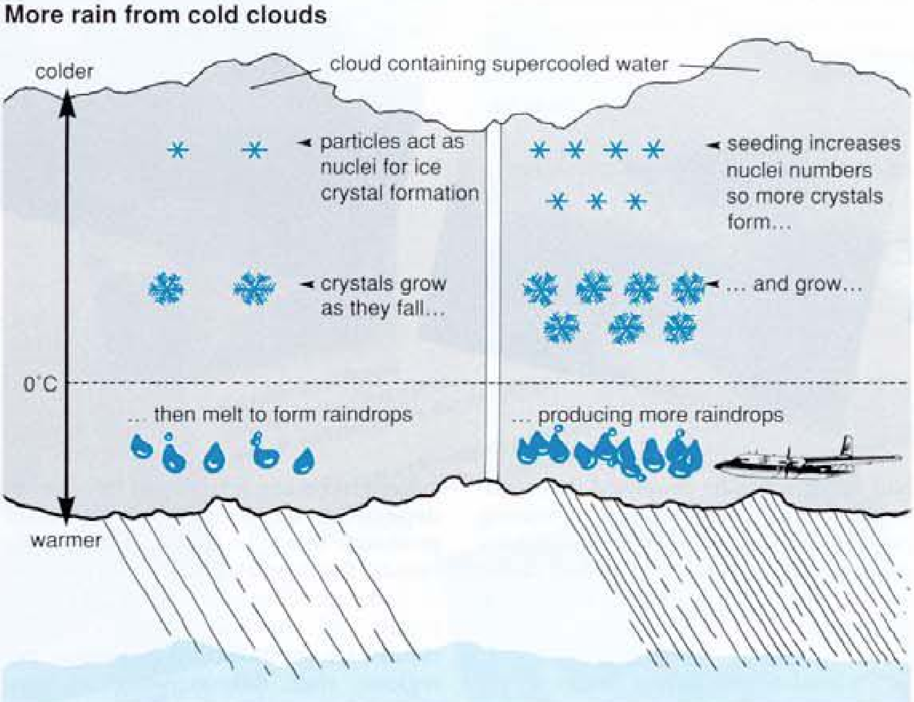
Ice crystals can only form in the latter way, however, if the cloud contains particles that can act as nuclei for crystal formation: often such particles are absent or widely scattered, so water at the top of the cloud persists as a supercooled liquid despite sub-zero temperatures. It's in these circum-

CSIRO Division of Atmospheric Research



The Australian Winter Storms Experiment's radiometer measures the amount of supercooled liquid water in clouds over the Thomson Catchment area.

More rain from cold clouds



Seeding provides more nuclei for crystals to form around, and as a result more rain falls.

A fresh look brings good news

In 1985, Division of Atmospheric Research scientist Dr Keith Bigg startled his colleagues with the news that cloud seeding had been more effective than previously believed: previous analyses hadn't looked at the effects of seeding on 'control' (unseeded) areas, or over a long enough period.

Rainfall records for seeded areas and surrounding regions revealed that, over a 10- to 20-year period, rainfall increased by more than 10% not only in the target area but also in an area at least 10 times as large — and that rainmaking experiments hitherto written off as failures had in fact added consistent amounts of rain over thousands of square kilometres.

The apparent 'failure' came about because cloud seeders nominated a fresh target area every 10 to 12 days according to a pre-arranged schedule. Because they assumed the effects of seeding lasted only a day or so, they used the same areas alternately as targets and controls, not realising that persistent effects were simply adding ice nuclei to almost all the clouds in the area... and that wind patterns would blow those clouds over the entire experimental region.

Dr Bigg found that ice-nuclei numbers boosted by cloud seeding persist at increased levels for weeks or months: in fact, rainfall reached its peak 10 days to 3 weeks after seeding! While there is no clear explanation of this phenomenon, one factor may be the apparent persistence of silver iodide in the soil.

According to Dr Bigg's calculations, cloud seeding deposits about 0·1 mg of silver iodide per square metre of ground each year. Plants retain only a fraction of this, and most ends up in surface soil. But silver on its own has no ice-nucleating properties, and while iodine has some ice-nucleating ability it is already present in soil in much greater quantities than cloud seeding adds.

American research in the 1960s suggested that silver iodide might react with essential oils produced by plants, slowly releasing ice nuclei, but Dr Bigg put forward a more radical hypothesis. Most substances that act as efficient ice nuclei have surface regularities that match the lattice spacing of ice crystals, and it has been discovered that many common plant and soil bacteria have this property.

He suggests that silver iodide can increase the numbers of soil bacteria with the right kinds of surface regularities for initiating the growth of ice crystals, and that these bacteria are dispersed into the atmosphere during wet or windy weather (aerial surveys have shown that wind-borne bacteria, as well as dust particles and pollen, are common in ice nuclei). Recent research has shown that soil bacteria added to snow-making machines to improve their performance tend to lose their ice-nucleating ability over successive generations: perhaps these bacteria need to take up trace quantities of silver iodide to maintain their ability.

stances that cloud seeding can work: the silver iodide crystals act as centres for the Bergeron process, providing nuclei around which ice crystals can form, then fall and melt as additional rain. Dry ice produces the same effect by lowering temperatures to the point where ice crystals are forced to form.

A small amount of silver iodide in a cloud goes a long way: adding 1 kg at a cloud temperature of $-5°$ causes 10^{14} ice nuclei to form, enough to seed a cloud 10 cubic kilometres in size; at $-10°$, 10^{16} ice nuclei form — enough for a 1000-cu.-km cloud.

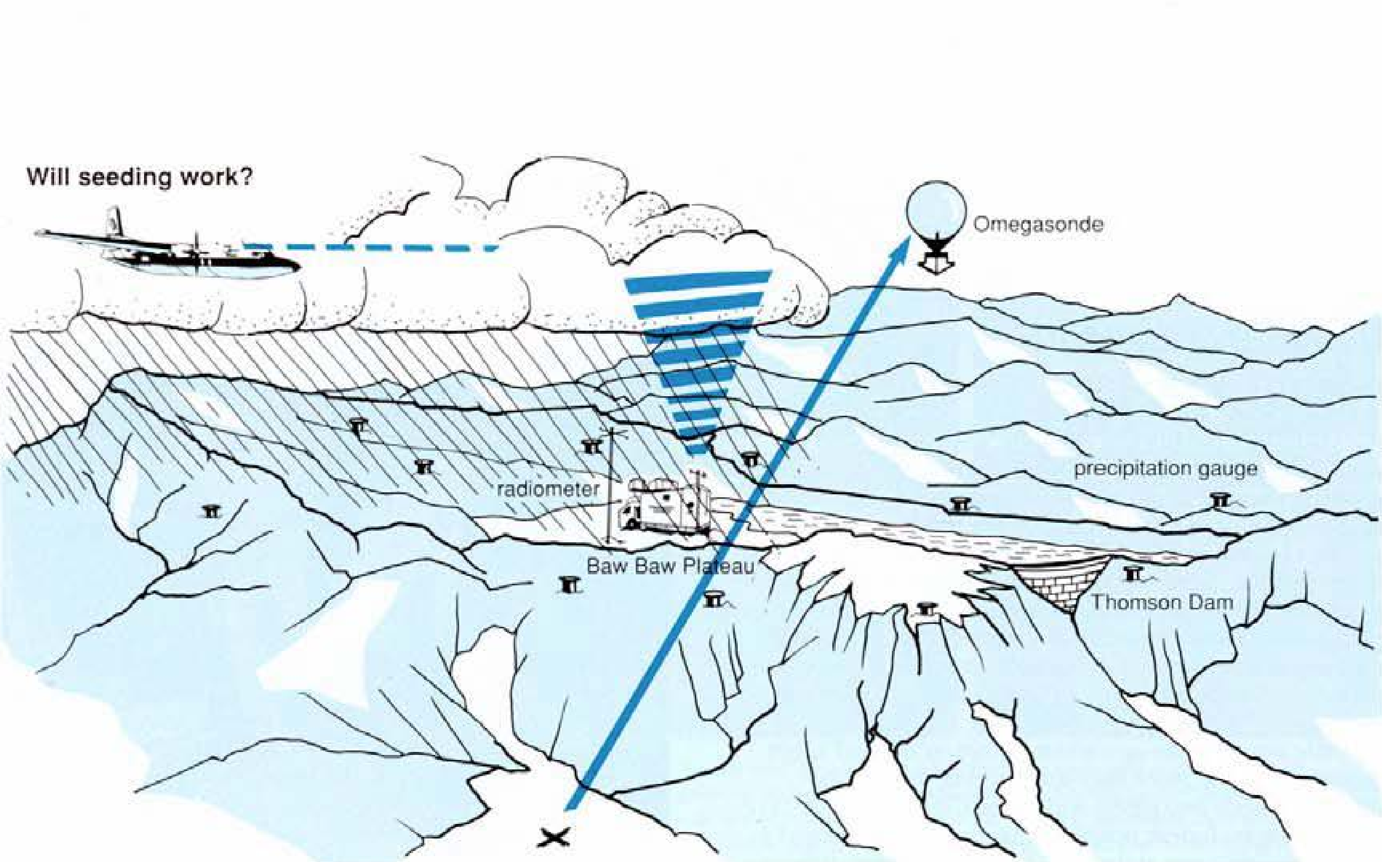
Originally, seeding added silver iodide to clouds in an attempt to stimulate them to release at least some of the rain they contained. Now, however, Division researchers are adding silver iodide to clouds that are already about to release rain in an attempt to make them release more: to improve the clouds' efficiency as producers of rain. The effect is similar to hanging out a wet towel on the clothesline: the towel will drip for a while (in clouds, this is known as a low precipitation flux), but will soon stop. Wring out the towel, however, and it will produce a lot more water.

The new approach seeks to wring more water out of clouds by increasing the precipitation flux. Learning more about such clouds and about their meteorological characteristics is one of the goals of the Australian Winter Storms Experiment (AWSE), a multifaceted cloud study under the direction of Dr Alex Long of the Division. This study will add to our knowledge of how to increase rainfall in the Baw Baw Plateau–Thomson catchment area.

It's a 4-year field studies and analysis program, which began with field studies in 1988 and 1990. Analysis of data collected during the field-work phase will continue until 1992.

The initial phase of the project involves identifying the right clouds for seeding. They must have a cloud-top temperature of between $-7°$ and $-25°$, a depth greater than half the height of the cloud base above the ground and more than 0·1 g of liquid supercooled water per cu. m; they must be likely to remain seedable for at least 20 minutes; wind speed at the seeding level must

Will seeding work?



be less than 90 km an hour... and, of course, the wind has to be blowing in the right direction.

If AWSE proves successful, the right clouds and the appropriate time for seeding will be identified with a truck-mounted microwave radiometer stationed on the Baw Baw Plateau. The radiometer will collect data automatically on the amount of supercooled water in clouds (measured from bottom to top) and transmit this information to a data-collection node at the Division's Aspendale headquarters, together with data on temperature, relative humidity, wind speed and wind direction as a function of height obtained from balloon-borne 'Omegasondes'.

Researchers at Aspendale will assimilate and combine the radiometer and Omegasonde data and estimate the supercooled liquid water flux across the catchment area. If it is sufficient, they will recommend seeding.

The seeding aircraft — a Piper Navajo — will fly back and forth along a straight line perpendicular to the wind. Burners mounted beneath the wings of the aircraft will be ignited and silver iodide 'smoke' released. Updraughts will carry this to the clouds, where the particles will act as ice nuclei (alternatively, seeding can be accomplished by dropping dry ice into shallow clouds).

Fortunately, the researchers do not have long to wait to see the results: rain begins half an hour to an hour after seeding, and continues for a similar period, but analysis of the seeding requires dozens of such successes to compare rainfall records with measurements of supercooled liquid water flux in clouds before and after seeding began.

While the CSIRO/MMBW project does not seek to emulate the spectacular successes of cloud-seeding history (rainfall increases of up to 36%, in target areas as well as control areas, were recorded in New England from 1958 to 1963), it nevertheless intends to make clouds more efficient in yielding thousands of dollars' worth of 'liquid gold' for Melbourne — helping the city balance its growing water needs with its far greater need to make the best and most efficient use of its water supplies.

Carson Creagh

More about the topic

The Melbourne winter storm cloud seeding experiment for urban water supply augmentation. A. B. Long. *Proceedings of the Fifth World Meterorological Organisation Conference on Weather Modification and Applied Cloud Physics, Beijing.* (WMO: Geneva 1989.)

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Rainmaking: the state of the art. *Ecos* No. 16, 1978, 15–18.

What are the best clouds to seed? *Ecos* No. 24, 1980, 18–19.

Cloud seeding: its effects may linger. *Ecos* No. 45, 1985, 3–7.

To check whether conditions are right for cloud seeding, a truck-mounted radiometer can gather data on the supercooled water content of clouds while balloon-borne Omegasondes provide temperature, relative humidity and wind measurements.