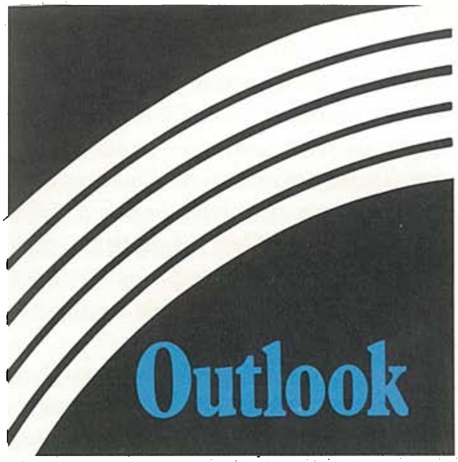



Dr Keith Bigg.

Air outback–clean but not virginal

In southern Tasmania the air is about as clean as it can be. On the mainland away from our cities the air is also clean by world standards. But it now appears that industrial pollution already affects almost everywhere on the continent to some degree.

This may seem surprising. After all, Australia is a very large land mass, and nearly all its population and industry resides along the south-eastern coastline, in the south-west corner, or at the eastern end of the Great Australian Bight. Vast areas remain practically uninhabited, so it should be possible to get away from industrial contamination.

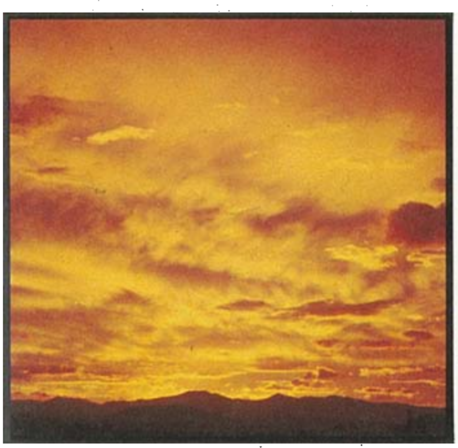
With this idea in mind, Dr Keith Bigg of the CSIRO Division of Cloud Physics began looking at the tiny particles found in the lower atmosphere. To understand the situation over Australia, he needed to compare particle levels of sites on the mainland and Tasmania with others in Antarctica and in remote oceans that were thought to be unpolluted. His work was tied in with the proposal to establish an atmosphere-monitoring station in Tasmania, which will form part of a global network of 'baseline' stations. These will keep a watch on any atmospheric changes that may affect the climate.

But first, what are atmospheric particles, and how might they affect us? We have all seen dust blowing off a dirt road, and salt spray moving inland from a large surf. These are familiar examples of particles. However, they are comparatively huge, and relatively few travel far from their sources. Much more common are very tiny particles less than one-tenth of a micron in diameter. For every 'giant' particle more than 1 micron across there may be a thousand or more very tiny ones. These particles are found in huge numbers in city smoke, and in natural 'blue hazes'.

Clouds affected

Such minute particles interest scientists because some of them affect clouds, and hence, possibly, our climate.

Some particles attract water. The minute water droplets that make up a cloud form by condensing on those water-attracting particles larger than a certain size. The higher the concentration of these particles within a cloud, the greater will be the number of water droplets. But with the greater number of droplets each one will be smaller, since it obtains a smaller share of the available water. The concentration and size of the water droplets affect several properties of clouds—including the amount of sunlight that they will reflect back into space, and the chances that they will release rain. A cloud containing a few large droplets will be much more likely to produce rain than another with many small ones.


Particles in the air affect clouds, and hence our climate also.


Breaking waves are a natural source of 'giant' particles.

Research in many parts of the world (including Australia) has shown that the majority of the small particles consist of ammonium sulphate or sulphuric acid.

Where do they come from? It seems almost certain that they form from gases in the atmosphere—sulphur dioxide and ammonia are ubiquitous trace contaminants in even the cleanest air. Most seem to be found near land.

In heavily populated regions like much of the United States and Europe, most of these atmospheric particles derive from industrial pollution. Cities may have as many as 100 000 per cubic centimetre of air, while over the sea-shore away from cities in these regions the level averages a much lower 10 000 per cu. cm. This compares with a background level of about 200–400 per cu. cm in clean air over Antarctica or over parts of the ocean remote from land.

By comparison, Dr Bigg has shown that the air over remote parts of continental Australia on average contains about 700 particles per cu. cm, while the sites considered for the baseline station in southern Tasmania average less than 200—lower than levels reported over many remote oceans.

The particle levels over continental Australia seemed remarkably low—especially since much of the continent is usually free of clouds, which mop up these particles. During one set of measurements made in the region of Lake Eyre the concentration dropped to near the oceanic background level.

Possible sources

Six sources have been put forward by scientists here and overseas to explain why particle levels are highest over land, even when there is no industrial pollution.

They have suggested the following sources:

- ▶ drying soil
- ▶ gases given off by the vegetation
- ▶ particles being carried down from higher altitudes
- ▶ gases given off by marine life between the high- and low-tide levels
- ▶ fires
- ▶ gases in the atmosphere from other sources

Volcanoes, geysers, and other vents in the earth's surface that spew out sulphurous gases are natural sources. However, we do not have any of these in Australia. The other major sources of sulphur-containing gases are industry and cities.

These theories could be tested fairly easily using an aircraft fitted with particle-detecting equipment.

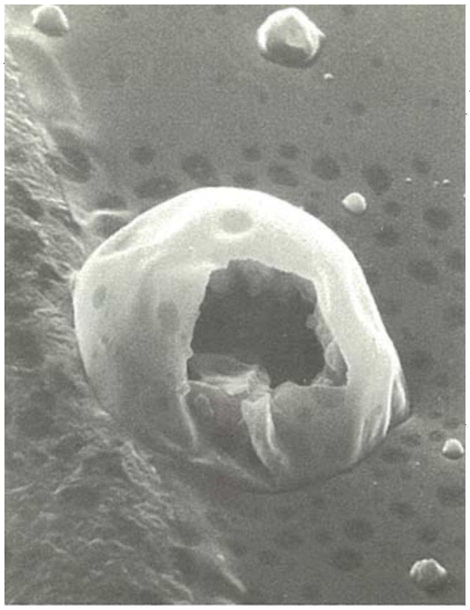
Dr Sean Twomey of the Division of Cloud Physics had made the suggestion that particles accrue from drying soil, but the idea had never been tested. By good luck central Australia was drying out after heavy rain during one of Dr Bigg's experiments. He and his colleague Mr David Turvey were therefore able to fly over Lake Torrens, Lake Frome, Lake Amadeus, and Lake Eyre during November 1975 under conditions that should have been ideal for particle formation. Ground temperatures rose to about 40°C, so the soil should have been drying out rapidly.

They detected no increase in the numbers of particles over these areas.

Experiments carried out in the United States and the south-west of France have demonstrated that particles will form there over pine forests from the terpene vapours emitted by the trees. Australian vegetation also gives off large quantities of the chemicals, so its forests and open woodlands could be expected to contribute large numbers of particles too.

To test this, the two scientists flew at low levels across the coast to remote areas. They tried this over almost uninhabited forested coastlines in western Tasmania, north-western Australia, and the Gulf of Carpentaria. If the forests were contributing particles, then the numbers detected should rise as the aircraft flew inland from the coast.

Once again, they detected no increase at all. So it appeared that the vegetation also was contributing little—a surprising result in view of the overseas research. However, it has been suggested that the process of forming particles from terpenes needs nitric oxide as a catalyst. This common urban pollutant may have been in adequate supply over regions with relatively high population densities, but not over the almost uninhabited Australian forests.



Exploded salt particle as seen by an electron microscope. It used to be thought that giant particles exploding when drying were a major source of small ones.

Come from above?

What about the idea that the particles are replenished from air at higher altitudes?

The particle levels over continental Australia seemed remarkably low.

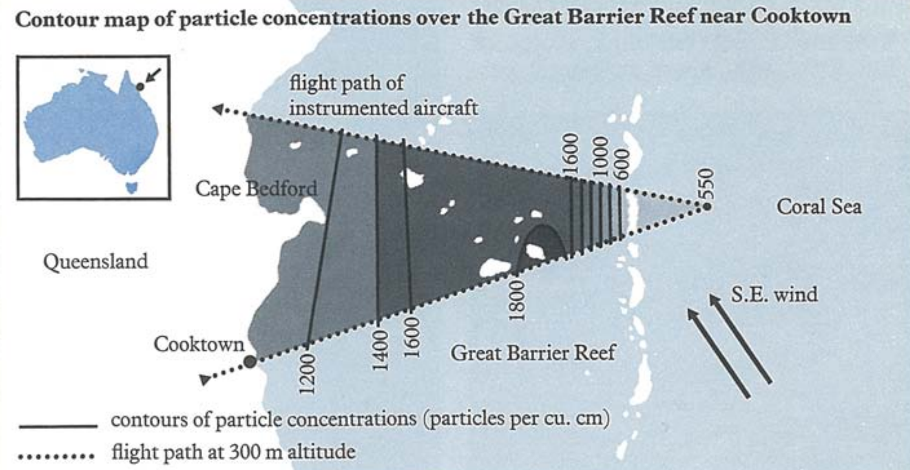
Over Australia, the air is often separated into two or more fairly sharply divided layers by temperature inversions. The lowest inversion usually dictates the height of fluffy cumulus clouds. Inversions usually exist also on cloudless days, and they limit air-mixing between different altitudes. They disappear when depressions, cold fronts, or thunderstorms pass, and considerable mixing may then take place.

Particles form in the upper atmosphere and, as lower down, they consist mainly of ammonium sulphate or sulphuric acid. Once formed—from sulphur dioxide in volcanic gases or other sources like industrial pollution—the particles may remain in the upper atmosphere for a long time, since clouds rarely reach high enough to wash them out.

At the highest levels reached by clouds, particle concentrations average about 180 per cu. cm. Near the ground the much greater atmospheric pressure would raise that concentration to about 1000 per cu. cm—enough to make an appreciable difference to the particle load if mixed into clean air at low levels. It's quite possible that over southern Tasmania with its very clean air, mixing from higher levels does help in maintaining particle concentrations lower down. Elsewhere this effect would be swamped by other sources.

The experimenters confirmed that the one major natural source of particles seems to be the intertidal areas along the coast. Pioneer work by J. Aitkin, father of atmospheric particle-counting, had suggested this in 1897. The current theory is that the particles form from dimethyl sulphide gas given off by drying marine algae when exposed at low tide. Indeed in

Contour map of particle concentrations over the Great Barrier Reef near Cooktown



Particles in the air seemed to be formed over the Great Barrier Reef. Concentrations were lowest out at sea; they were highest over the Reef, and fell again towards the coast.

the laboratory this gas does oxidize to stable particles.

As it happens, not many places around the Australian coastline have extensive reefs that become exposed at low tide, so in most places the intertidal zone is very narrow. Obviously detecting particles given off by such a localized source would be difficult, and only possible when calm conditions prevailed. Under such conditions, most flights across the Australian coast did yield detectable increases.

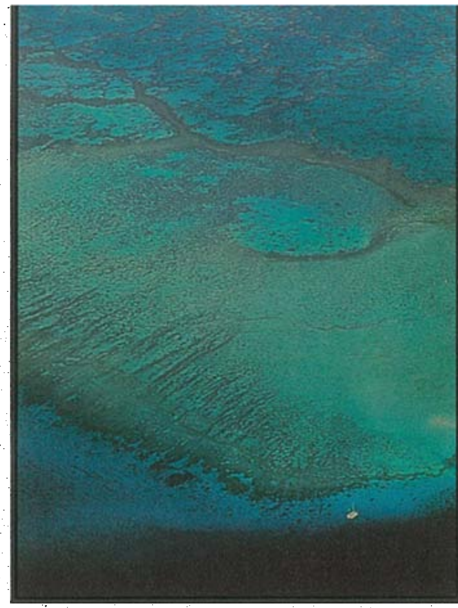
To clinch the argument, two scientists made a series of flights across the Great Barrier Reef—that huge area of shoals and reefs. They chose sunny days when the wind was blowing towards the Queensland coast to ensure no contamination from there, and they did indeed record large increases in particle numbers over the Reef. Further measurements now being made on Heron Island with an automatic counter should show whether the particles are made day and night, and how their production relates to the tides.

Industry investigated

How does the output from the coastal intertidal zone compare with that from our industries and cities? Dr Bigg used the same aircraft and instruments to find out the particle loads contributed by these sources.

Several industrial centres put large amounts of sulphur dioxide into the atmosphere. Mt Isa is particularly isolated, and located in an area where clear skies are the rule (clouds mop up small particles). The chemical nature of the emissions from the Mt Isa chimney were already the subject of study by Mr David Williams of the Division of Process Technology (see *Ecos* 3). It puts out a lot

Industry seems to produce a major proportion of all the particles.



Great Barrier Reef—our largest natural source of small particles.

of sulphur dioxide, vast numbers of very small sulphuric acid particles, and relatively few giant ones.

Dr Bigg and Mr Turvey made a series of flights across the plume downwind of the chimney. Most of their samples came from within 180 km of Mt Isa, but some came from as far away as 550 km. They always picked up the plume with ease, even though it was already 300 km wide when 550 km from the chimney. They were not able to make flights even further away because of bushfires that would have confused the results.

The numbers of particles actually increased as the plume moved further away from the Mt Isa smelter. This apparently surprising result is explained by the fact that in the presence of water vapour the particles form by sulphur dioxide changing to sulphuric acid under the influence of sunlight. Near the chimney, when the particles are close together, the acid condenses onto already existing particles. But as the plume becomes diluted by the atmosphere, new particles form instead. Quite probably, the particle output from Mt Isa trebles in a day's travel as more particles are created, with the result that the smelter's contribution must be similar to that of the whole Barrier Reef!

At a point 1000 km downwind of Perth and Kwinana, the researchers found that the particle concentration was still five times the background level. However, the

Sydney produces only about as many particles as Mt Isa—or the Barrier Reef.

particle loads coming from this industrial complex were not measured. The industries of Whyalla and Port Pirie seem to have outputs similar to that of Mt Isa.

Cities too

Large cities must be considerable particle-producers, but air traffic control procedures made getting measurements of particles blowing out of cities much more difficult. However, Dr Bigg and Mr Turvey have been able to make large numbers of measurements as they departed from and approached Sydney, and have pieced together a picture of the situation there. This suggests that Sydney produces only about as many particles as Mt Isa—or the Barrier Reef—a result that surprised Dr Bigg. No doubt Melbourne's particle production is much the same. More-exact figures will be obtained from future measurements.

And what about fires? Forest, grass, or sugar-cane fires are common somewhere on the Australian continent for much of the year—from late spring to early autumn in the southern half, and from late winter to early summer in the northern tropical half. All the cane fires, most of the grass ones, and some of the forest fires are deliberately lit, so the particles coming from these hardly qualify as coming from natural sources. What sort of particle output do they have?

The experimenters encountered a line of fires in the Great Dividing Range in north-eastern Australia during September 1974. They found an apparent combined particle output from these particular fires of between two and five times that of the Mt Isa chimney. Other fires were estimated to give off similar numbers of particles to the Mt Isa chimney.

Sugar-cane fires and bushfires are other sources of particles in the air.

Dr Bigg's calculations show that most of the particles in the lower atmosphere are likely to be Man-made.

Incidentally, even when the air was quite blue with smoke, particle concentrations rarely rose above 5000 per cu. cm (compare this with the 10 000 per cu. cm in air over the sea-shore away from cities in Europe and the United States). City air that is noticeably less turbid may contain ten times this concentration.

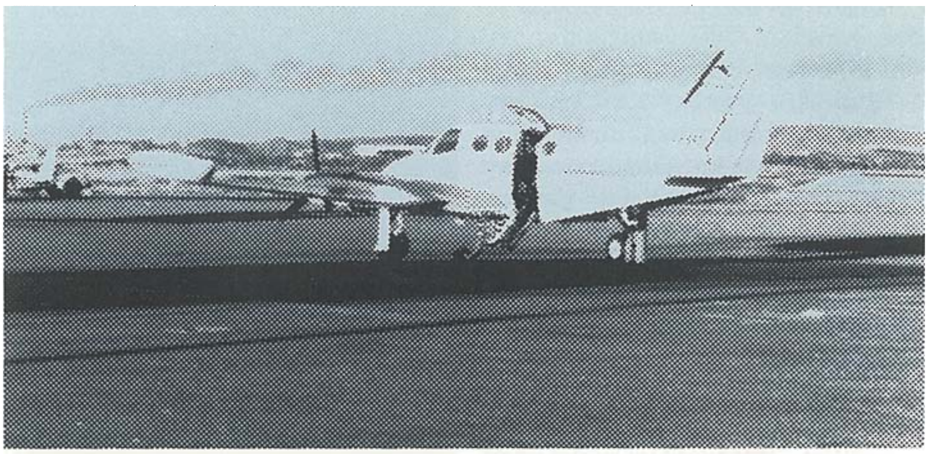
Rough though they are, Dr Bigg's calculations show that for much of the time most of the particles in the lower atmosphere are likely to be Man-made. In particular they come from industry and cities. In fact the total particle loading over the Australian continent in the lower atmosphere is probably only equivalent to about 3 days' output from industrial sources. Contributions from the Barrier Reef and other tidal areas are relatively small by comparison.

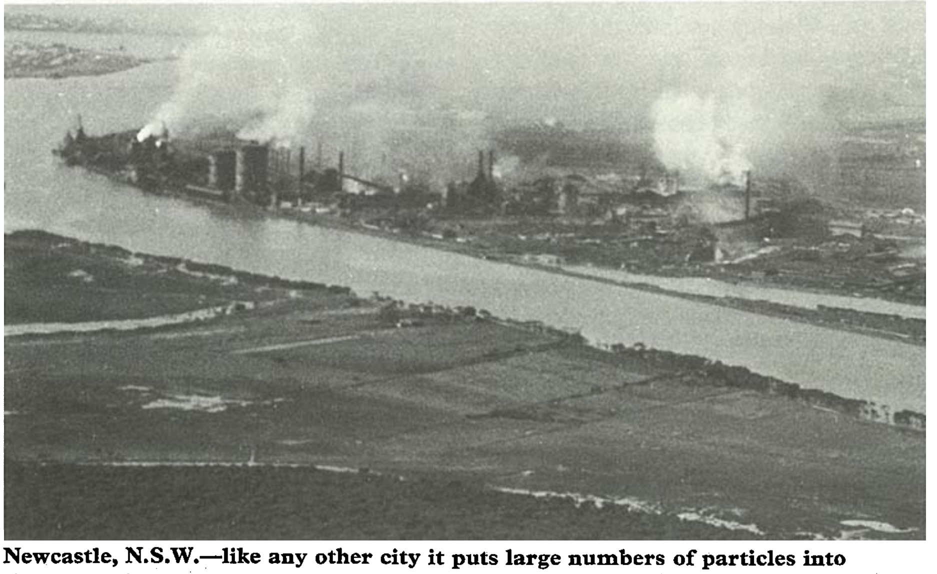
Luckily, not all of our city and industrial output accumulates over Australia. It's only with southerly or easterly winds that the bulk of this pollution will spread over the continent. These particular winds come off the sea and bring in cloud or rain, both of which reduce the numbers of particles greatly.

Location important

Mt Isa is less well placed. In fact it's strategically located for spreading particles all over the continent, especially in winter. This smelter lies to the north of the track taken by anticyclones, so winds from a generally easterly direction are very common. Since the winter climate of northern Australia is usually sunny and dry, the particles from this source will decrease only very slowly. The plume will tend to be swept westwards or south-westwards and so into the westerly wind belt that covers the southern part of the continent at this time of year.

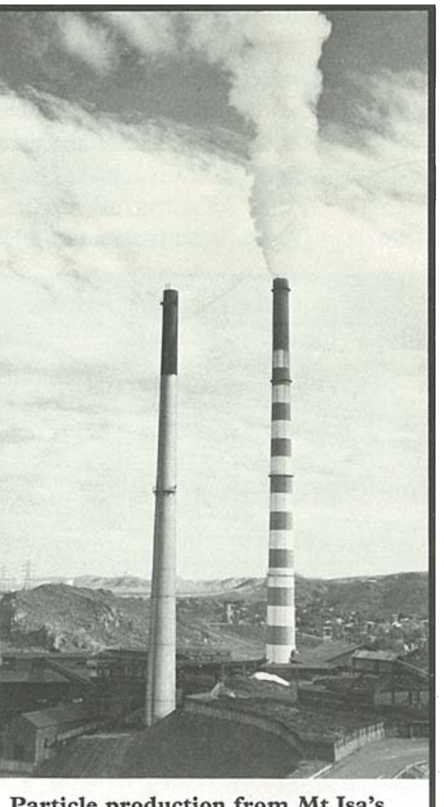
Dr Bigg calculates that only 16 days of output from this one source could account for all the particle load over Australia. It doesn't, of course—considerable numbers of particles must be removed by passing cold fronts and other atmospheric activity. Nevertheless, there are long cloudless periods in winter when much of the chimney's output must reach the southern half of the continent.





Newcastle, N.S.W.—like any other city it puts large numbers of particles into the atmosphere.

These studies have another implication. Large amounts of iron ore, natural gas, and oil have been discovered in north-western Australia, and a large industrial complex, including steelworks and oil refineries (both large producers of sulphur dioxide), has been proposed. This area has a low rainfall, little cloud, high temperatures, and strong on-shore winds. Dr Bigg points out that it could hardly be better placed for spreading pollution over the whole continent. Inevitably, if built, the complex will cause some increases in the concentrations of particles in the air. Whether or not this increased particle load will have any net effect on the climate, we just don't yet know.



Particle production from Mt Isa's chimneys seems to equal that from the Great Barrier Reef.

More about the topic

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