# Tracking Melbourne's smog by plane

Melbourne shrouded in smog.

A full-blown case of photochemical smog strikes Melbourne eight days a year, on average. On these days ozone, the principal constituent of photochemical smog, builds up to concentrations of more than 100 parts per billion at one or more of the Victorian Environment Protection Authority's monitoring stations.

That's not too good, in that the EPA recommends that 100 p.p.b. (averaged over an hour) should not be exceeded more than three times a year. But, compared with Sydney, Melbourne gets off lightly. Since 1975, ozone in excess of 100 p.p.b. has been recorded somewhere in Sydney's monitoring network on about 50 days a year.

In a paper to the Clean Air Conference in Adelaide this month, the question is asked (and an answer provided): why the difference? The paper comes from the Urban Air Pollution Group of the CSIRO Division of Atmospheric Physics, led by Mr Tony Evans. Other members of the Group are Dr Ian Weeks and Mr Tony Eccleston.

The paper makes the point that pollution figures for the two cities are not necessarily comparable — Sydney has more monitoring sites, and the Melbourne sites may not be located in the most smog-prone areas. Nevertheless, it would seem that, for such a large city, Melbourne is relatively smog-free. Certainly the authors disagree with those who, on noting that maximum ozone levels recorded in both cities are comparable (for example, in 1979 Sydney reached 170 p.p.b.; Melbourne, 150 p.p.b.), jump to the conclusion that photochemical smog is an equally severe problem in both.

Flying through Melbourne's smog cloud in a specially instrumented Twin Beechcraft B50, at altitudes from 300 m to 1000 m, the scientists could trace the movement of the cloud and determine its origin and fate. Melbourne misses out on numerous smogs, they discovered, because the light winds and warm cloudless days necessary for producing ozone comprise just the weather conditions that disperse the bulk of the smog cloud over the rural area to Melbourne's west.


**Preparing to load instruments on board the aircraft.**

Some of the meteorological factors influencing the formation of smog over Melbourne were reported in *Ecos* 22. That article described work by Dr Kevin Spillane, of the same CSIRO Division, who used weather records, statistics, and laboratory models to elucidate the cause. The present work goes beyond the broad inferences drawn from models and sets out to examine in detail the structure and behaviour of real smog clouds.

## Up in the air

The advantages of using an aircraft to study a 'parcel' of smog are considerable. An instrumented vehicle can find out a good deal, but it suffers interference from local emissions and it can lose track of a selected parcel if winds are erratic. Mr Evans and his team found the Beechcraft ideal for following pollutants in Melbourne's windy conditions, and essential for making measurements over Port Phillip Bay.

The plane was valued for its ability to take a sample representative of the average smog concentration: from near the ground to the height of the inversion layer.

A mobile van, fitted with an ozone monitor, assisted the aircraft in tracking a pollution cloud. The van's vital items of equipment included a theodolite and a stock of party balloons. Balloons, when inflated with helium to a fixed diameter (56 cm) and released, rise at about 2·5 metres per second; from each one's angle of ascent, as measured regularly by the theodolite, the scientists gauged the wind's speed and direction at all heights.

During the summer smog seasons of 1978–79 and '79–80, the Urban Air Pollution Group set out in plane and van to track down as many Melbourne smogs as they could.'From Dr Spillane's work they knew that smog only formed on clear days with light winds. Consequently, when such days were forecast, the team geared up to go. They made some 40 forays into smoggy Melbourne from the relative clarity of the Division's Aspendale base — on the bay 25 km from the city centre.

The scientists missed probing the smog on three days, but the routine EPA measurements showed that no serious smog (above 100 p.p.b.) occurred then.

The standard procedure was to station the van 2–3 km downwind of the central business district at 7 o'clock in the

Apart from the Newport–Altona and Dandenong areas, Melbourne has no identifiable large industrial source of the emissions that produce photochemical smog. That leaves most of the blame with road traffic.

The EPA has estimated that, in the Port Phillip Bay area, motor vehicles are responsible for 75% of the nitrogen oxides and 45% of the hydrocarbons (the latter figure rising to 50–60% outside of refinery areas).

Calculations by Mr Evans deriving emission strength from vehicle density accord with measurements made from the CSIRO aircraft and confirm that motor vehicles are indeed the chief culprits.

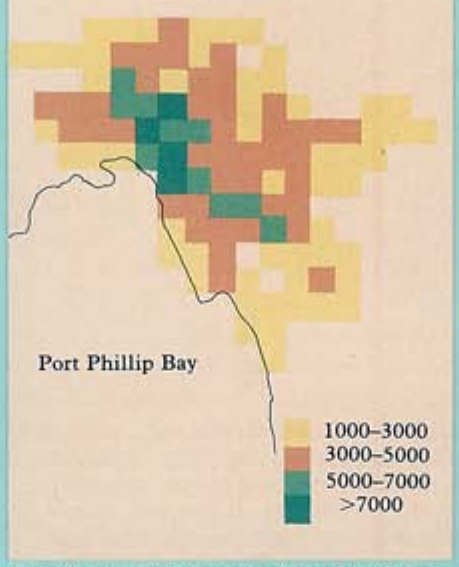
From figures supplied by the Country Roads Board, the Melbourne City Council, and the Australian Bureau of Statistics, he drew up a map of Melbourne showing the city's traffic density in the morning peak hour (7 a.m. to 9 a.m.). It is reproduced on this page.

He then applied a simple mathematical formula to calculate the expected concentration of pollutant precursors produced by all these vehicles, assuming certain emission rates and knowing the inversion layer height and the speed of the wind. Another assumption is that outside peak hours traffic density falls by one-third.

The emission of nitrogen oxides from all vehicles is fairly constant, averaging about 2·5 grams for each kilometre each one travels, irrespective of its speed or acceleration. This figure comes from the Department of Transport.

For hydrocarbon exhaust emissions, the Australian Academy of Technological Sciences suggests a figure of 3·0 grams per vehicle-kilometre. To this must be added 1·0 g for evaporative losses, giving a total hydrocarbon emission rate of 4·0 g per vehicle-kilometre.

The density of Melbourne's peak-hour traffic




**The figures are the number of vehicle-kilometres travelled per square kilometre in an hour. Grid is 3 km square.**

The level of precursors arising from these emissions was calculated for a smoggy day in February 1980, when the mixing depth was 300 m and the wind speed 6 km per hour. Based on the vehicle-density map, the calculated level of nitrogen oxides varied (depending on the sampling point) from 65% to 93% of the level measured from the air. This agrees well with the EPA's figure of 75%.

The calculated hydrocarbon emissions ranged from 35% to 57% of the measured figure, somewhat below the EPA's 50–60%.

There's another way in which the contribution of motor vehicles to hydrocarbons in the air can be pin-pointed. Practically all the acetylene found in the air comes from vehicle exhausts and, importantly, the substance does not break down or react with other pollutants, making it an ideal inert tracer.

Scientists find some difficulty in pinning down the exact proportion of acetylene emitted in a vehicle's exhaust stream. The proportion has been variously reported to be anywhere from 6% to 8·5%. However, 4·5% of air captured over Melbourne by the plane was found to be this chemical. This suggests that motor vehicles contribute between 55% and 75% of the total hydrocarbon burden. The remainder presumably comes from the paint and solvent industries.

morning and keep releasing balloons — about three an hour could be managed. Each balloon was followed by theodolite to around 1000 metres altitude and the wind speed data immediately radioed to the aircraft. As the emissions from the city drifted downwind, the van moved so as to be as close as possible to the centre of the smog cloud.

However, the plane played the major role in acquiring data. Aboard were instruments to measure and record concentration of ozone and nitrogen oxides, number of particles per cubic metre, temperatures, relative humidity, and altitude. The plane's crew also managed to take about 30 air samples during the course of each flight. The samples were later analysed in the laboratory for hydrocarbons and carbon monoxide.

**The EPA's monitoring van.**

A flight usually lasted from 9 a.m. until noon. After refuelling, the plane returned to the air to follow events during the afternoon. The flight plans for the day included soundings to locate the height of the inversion layer, an excursion upwind of the city to measure the cleanliness of the incoming air, circling of the central business district, and repeated traverses of the smog cloud downwind of the city.

For photochemical smogs to strike, pollutants — hydrocarbons, particulates, and nitrogen oxides — need to be bottled up below an inversion layer and irradiated with sunshine strong in ultraviolet. Ozone builds up as chemical reactions between these 'precursors' proceed.

*The most concentrated parcel of emissions was that issuing from the city centre during the morning traffic peak.*

Preliminary measurements showed that, despite large intermittent emissions of nitrogen oxides and hydrocarbons from the Altona petrochemical plants, the most concentrated parcel of emissions was that issuing from the city centre during the morning traffic peak. (The afternoon peak is not smog-producing because, by then, strong sun-

shine has gone.) The 'mixed layer', from the ground to the inversion layer, was found to be, as its name conveys, fairly uniform. This simplified the plane's task of following the centre of the smog cloud, in that the plane's altitude did not seriously affect the concentration measurements.

### Recipe for smog

After Mr Evans and his team had observed a number of smoggy days, a clear pattern of events surrounding the build-up of pollutants began to emerge.

The parcel of smog from the central business district was the main focus of study. Plotting the paths that the smog cloud took on various days revealed what was going on.

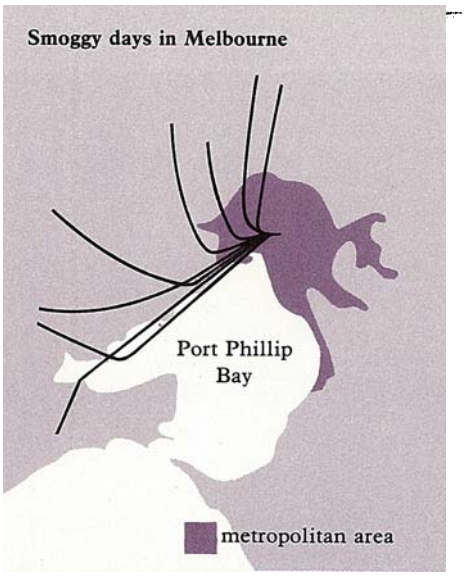
The paths fell conveniently into two categories — those that gave rise to an ozone concentration of 100 p.p.b. or greater, and those that did not.

The classical Melbourne smog starts off with relatively calm conditions in the morning, during which pollutants accumulate. Invariably, the smog drifts in a generally south-westerly direction. And then, about midday, a bay breeze steers the smog northwards.

The Group found that the ozone concentration in these smog parcels generally reached 100 p.p.b. by about noon, and continued to increase during the afternoon as chemical reactions in the cloud proceeded. Those occasions when ozone levels in the smog cloud failed to reach 100 p.p.b. could be attributed to insufficient sunlight, low temperature (slowing down the chemical reactions involved in producing ozone), or excessive dilution. Air can be diluted in a horizontal direction by strong winds or vertically by a substantial mixing depth (due to a high inversion layer).

Most significantly, during the whole period of the study, there was not one occasion when the ozone in the main parcel of smog from the central city exceeded 100 p.p.b. over the metropolitan area. This was because the conditions that led to high ozone also meant that the smog was taken to the rural outskirts of Melbourne.

For the same reason, neither the emissions from the Altona petrochemical plants nor those from the Newport power stations contributed to pushing metropolitan ozone levels above 100 p.p.b. Rural levels are another matter, of course, and ozone readings exceeding 150 p.p.b. were recorded there by the aircraft.

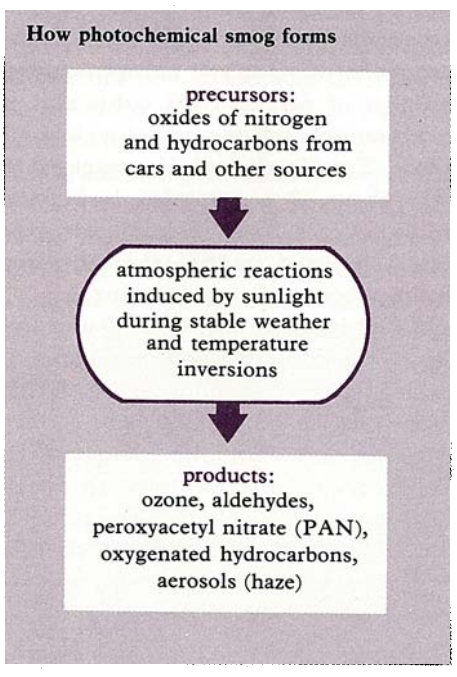



**The map shows, for the eight smoggiest days recorded by the CSIRO team, the path taken by smog parcels originating in the central city. A common feature is the generally north-easterly wind that, later in the day, is given a push from the south by the bay breeze. The same wind pattern is likely to take smog from the suburbs in the morning and return it over Melbourne in the afternoon.**

### A second parcel of smog

Nevertheless, despite the fact that the main parcel of smog from the central city affected rural areas only, on a number of occasions the EPA measured an ozone concentration exceeding 100 p.p.b. over the metropolitan area.

Mr Evans' team discovered that the emissions responsible originated from the eastern and southern suburbs. The concentration of pollutants built up by vehicles in this suburban area is weaker than that generated in the central business district. But there are factors to compensate for this weakness.




**Photochemical smog is usually worst around noon, after the precursors have received a good dose of sunlight.**

Firstly, this area offers a north-easterly wind a long stretch of suburbs to traverse, allowing the wind to accumulate a considerable quantity of pollutants before going out over Port Phillip Bay.

Secondly, after north-easterlies have taken pollutants over the bay, later in the day a southerly bay breeze blows them back over the city.

Finally, during the time the pollutants spend over water, the mixing depth does not increase appreciably. This means that they are not diluted as they are when, over land, the inversion layer rises as the day warms up.

The explanation is that the inversion layer only rises because the air below it is warmed by the ground (which is warmed by the sun). Over water this does not happen — the water temperature remains essentially constant and therefore so does the depth of the mixed layer.

*A clear pattern of events surrounding the build-up of pollutants began to emerge.*

With all these factors working together the relatively weak source of pollutants from the south-eastern suburbs leads to higher ozone levels over the city than does the major source of the central business district. This happened two or three times in each of the years the study was in progress.

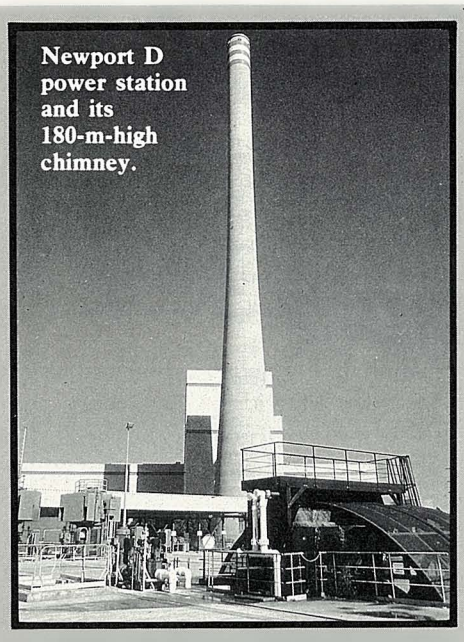
### The lucky city

It is now fairly clear why Melbourne doesn't have the pollution problems of Sydney. The emissions from the south-eastern suburbs of Melbourne — the ones that linger around the city — reach only 60% of the concentrations of the main central city emissions.

In Sydney, by contrast, emissions from the central city, power stations, and refineries may all contribute to a smog that spreads over the metropolitan area.

Conceivably, there could be wind conditions in Melbourne — a light northerly, for example — that would sweep all the emissions together; a bay breeze might then blow them back to the city. Fortunately, light northerly winds are very rare.

# The impact of Newport power station



**Newport D power station and its 180-m-high chimney.**

Even before it was built, people hotly disputed the contribution to air pollution that the 500-MW Newport D power station, close to Melbourne's centre, would make.

The debate was confused by lack of knowledge of what environment the Newport emissions would be adding to. EPA measurements of pollutants are taken at ground level, not at a height of 180 m where the Newport stack makes its contribution. The EPA measurements vary greatly depending on the wind direction, but are typically two to three times higher than the CSIRO aircraft measurements.

These aircraft studies have enabled the source and concentration of pollutants at chimney height to be determined. This means that the effect of meteorological factors and Newport emissions on air cleanliness can be realistically gauged.

Now that Newport D has begun operation (commissioning began at the end of last year), the CSIRO scientists have begun a study in which they use their plane to sample gases emitted by the Newport D stack.

Despite the 180-m-high chimney designed to take emissions above the inversion layer, environmentalists have feared that, when winds blew from the west, Newport's emissions would contribute to smog over central Melbourne. Fortunately, during the 2 years of the team's observations, no high-ozone day has ever been accompanied by a westerly wind.

Trouble is more likely to come, the team has found, from a north-easterly wind. In this case, the wind will send a stream of pollutants from the suburbs along the western shore of the bay. If any emissions from Newport are trapped beneath the inversion layer, they will mix with this stream. The area likely to be most affected is between the coast and an arc some 30 km inland — stretching from Mt Anakie, through Bacchus Marsh, to Sunbury.

The precise location of the impact area depends on the result of the collision between the north-easterly wind and a generally south-easterly bay breeze that arrives about noon. The smog parcel carried by the combined wind reaches its maximum concentration of ozone in mid afternoon — citizens located underneath the smog parcel at that time inhale the highest concentration of ozone.

A north-easterly air stream from the suburbs brings with it at peak hour, over each kilometre of front, 300–450 kg of nitrogen oxides per hour, Mr Evans has found. Newport could add an estimated 375 kg of nitric oxide per hour to this stream. Calculations show that, if the emissions become trapped below the inversion layer, this will raise the level of nitrogen oxides by 50–75% at a distance of 14 km. The plume at this point will be 1·6 km wide.

What effect will this extra level of nitrogen oxides have? The immediate effect of nitric oxide is to destroy ozone, but interactions with other smog components later on may lead to a net increase in ozone. The end result will depend on the amount of hydrocarbons in the air and the fraction of stack emissions trapped below the inversion.

Mr Evans' Group is attempting to measure these factors. Their work is being done in conjunction with the EPA through its consultant company Form and Substance Inc., and forms part of the EPA's Melbourne Airshed Study.

During the investigation, scientists are adding an inert tracer chemical, sulfur hexafluoride, to the stack emissions. The aircraft crosses the plume at various altitudes to find out how the emissions spread out. Obviously, weather conditions affect the spread markedly.

The commonest situation leading to a smoggy day in Melbourne is a gentle morning wind of less than 10 km per hour from the north-east. Mr Evans would expect the worst smogs — more than 150 p.p.b. ozone — to be produced by a wind of about 5 km per hour, which takes the pollution to the middle of Port Phillip Bay at the time the bay breeze arrives to blow it back.

Of course, while Melbourne residents may thank the bay breeze for blowing away pollutants from the large source of the central business district, the 200 000 people who live in the rural area to the north and the west of the city may, on that score, consider the breeze unwelcome.

Whatever your attitude to the bay breeze, it is a fact that we have very little understanding of its behaviour. An accurate description of the breeze, including the variation with height and the distance it penetrates inland, is urgently needed to achieve this, Mr Evans believes.

**Mr Tony Eccleston atop Newport power station with a theodolite to fix the aircraft's position.**

The EPA's routine monitoring of smog levels gives little information on the source or path of emissions. Mr Evans suggests that setting up a more extensive network of wind-measuring stations would be a very desirable complementary step.

One interesting finding from the CSIRO study is that a policy directed towards keeping vehicles out of the central business district would have little effect on the severity of smogs experienced in the metropolitan area.

*Andrew Bell*

## More about the topic


An aerial survey of Melbourne's photochemical smog. L.F. Evans, I.A. Weeks, and A.J. Eccleston. *Proceedings, Clean Air Conference, Adelaide, August 1981.*

Melbourne's ozone pollution. A. Bell. *Ecos* No. 22, 1979, 13–14.