New clean-air umbrella

Breathe deeply! . . . Bryony Bennett outlines research aimed at maintaining air quality, inside and out.

We are all consumers of air, yet when it comes to assessing its quality, our senses can fail us. Many air pollutants – such as nitrogen oxides, fine dusts and lead – have no taste or smell, and we can't discern their touch.

Instead we rely for our supply of clean air on governments and environment protection authorities, supported by consultants and scientists. Together they develop monitoring, planning and regulatory procedures to combat threats to air quality that are posed by expanding energy, industrial and transport needs.

To promote CSIRO's work in this field, a new air-quality program has been established. It involves some 40 scientists from four divisions: Atmospheric Research; Coal and Energy Technology; Building, Construction and Engineering; and the Centre for Environmental Mechanics.

The program draws together studies of indoor air pollution (see story on page 24) and outdoor air pollution. It also recognises the interdependency of two different approaches to understanding how pollutants are transported and transformed in the atmosphere.

The first approach, adopted at the Division of Atmospheric Research, uses laboratory experiments and numerical modelling to simulate the way pollutants move (see 'Modelling the atmosphere with water', *Ecos* 78).

While these scientists are 'at the lab' simulating plumes in water tanks and wind tunnels, their colleagues from the Division of Coal and Energy Technology are flying through and driving under real plumes to measure and photograph what happens 'in the field'.

Each approach has its pros and cons. Scientists can repeat laboratory experiments as often as they like, but can't easily do the same in the atmosphere. Field experiments produce 'one off' measurements that are difficult to repeat.

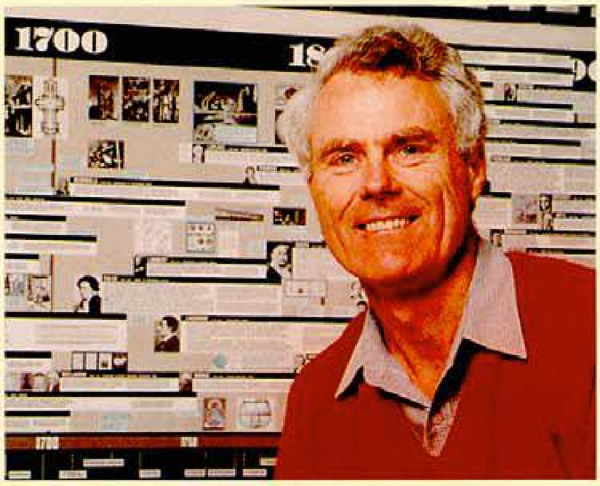
But no matter how many times a simulation is performed in the lab, environmental processes can't be reproduced exactly. When real plumes are measured, no such problem exists. And, after all, it is what goes on in the real world that drives the air-quality program.

The two approaches complement one another in a way that has helped scientists to explain through mathematics, environmental processes in the atmosphere. When this has been achieved, a new kind of 'lab experiment' becomes possible, one that relies on computers.

Computer models are being increasingly used to explain processes that we once considered 'miracles of nature', and many air-quality models have been developed. Some of these are known as 'regulatory models', and are used by industries seeking approval to set up, modify or extend their activities.

Regulatory models are based on standardised methods of predicting plume dispersion: a sort of 'common language' that enables emissions from individual industries to be compared. These models offer environmental protection at a reasonable cost. But one factor limiting their accuracy is the difficulty of representing fully the dispersion of plumes in a variety of conditions (see story on page 20 for convection conditions).

Another limitation is that they reliably predict pollutant dispersion only to about 10 kilometres from the source. To study air-quality on a regional scale, however, requires analysis across distances of perhaps 200 km. These problems are two of the many being tackled by CSIRO scientists. Following are some of their methods and achievements.


David Whillas

Dr Brian Sawford: coordinator of CSIRO's air-quality program.

Maths:

'If we could explain everything in English, we wouldn't need maths.' These are words of senior principal research scientist, fluid dynamicist and mathematician Dr Brian Sawford, the person in charge of CSIRO's new multi-divisional air-quality program.

During his 20 years at the Division of Atmospheric Research, Sawford has devoted countless hours to explaining through mathematics, the way that pollutants move through the atmosphere.

On one wall of Sawford's office at the Division of Atmospheric Research is a

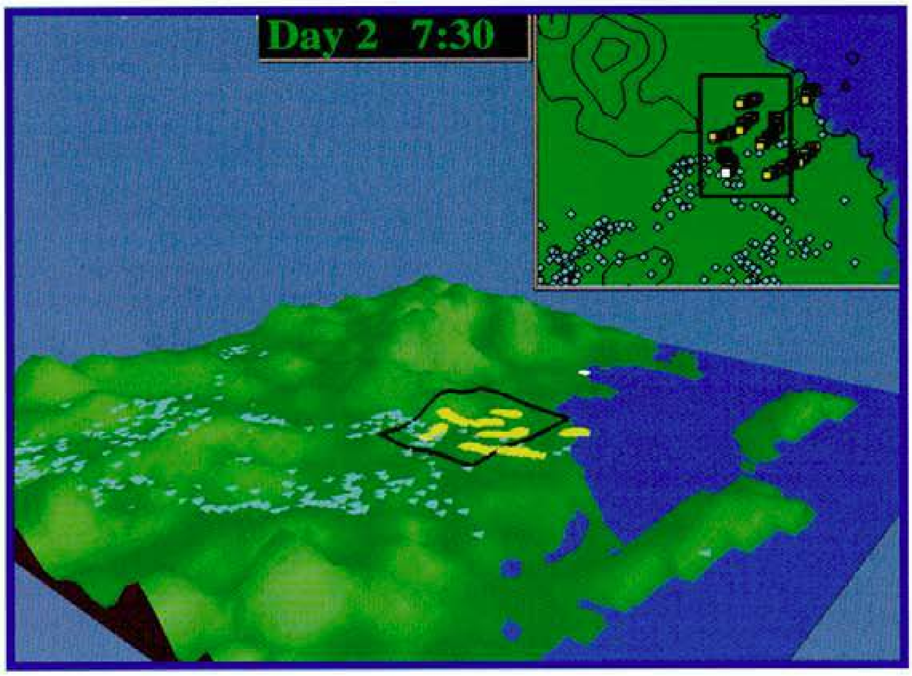
Regional planning simplified

AUSTRALIA is the most urbanised country in Asia, the world's fastest-growing region. By 2010, more than 85% of an estimated 22 million population will live in Australia's urban centres.

These cities are small compared with New York, Tokyo or Mexico City, each home to more than 15 million people, but according to CSIRO's Dr Peter Manins, we should not be complacent about the quality of our air.

Manins is the manager of CSIRO's Environmental Consulting and Research Unit (ECRU), which is based at the Division of Atmospheric Research at Aspendale, Victoria. Since 1990, the unit has contributed to major air-quality studies for electricity providers and urban planning authorities in Tasmania, Victoria, New South Wales, Queensland and Western Australia. South Australia is next.

The studies have revealed a set of local factors, common to many of our coastal cities, that cause the recirculation of air pollutants. Understanding these factors is vital when it comes to predicting the impacts on air quality of potential new power stations, industries and urban settlements.



A summer day in Brisbane simulated by LADM. The blue emissions are from the evening of day one and the yellow emissions are from the morning of day two. At 7.30 am on day two, the blue emissions are recirculating and combining with the yellow ones. (Source: CSIRO Environmental Consulting and Research Unit.)

To help them in this complex task, scientists at the division have developed a computer system that models the transport, diffusion and chemical reactions of emissions for distances of hundreds of metres to a few hundred kilometres. Put simply, the Lagrangian Atmospheric Dispersion Model (LADM) uses data about the weather, terrain and emissions from a particular region to predict how the pollutants will disperse and change. (See below if you're curious about Lagrange.)

LADM has been used by Manins and his team at ECRU to:

- advise on sites for new power stations in NSW's Upper Hunter Valley and Newcastle regions;
- determine pollutant dispersion in the Sydney region for the NSW Metropolitan Air Quality Study urban planning project;
- predict the dispersion of emissions from eight potential sites for a new power station between Brisbane and Cairns;
- assess the impacts of proposed industrial developments; and
- design networks for air-quality monitoring in Perth and Brisbane (see story on page 19).

a universal language

poster featuring pen-and-ink profiles of significant mathematicians from AD1000 to the present, and summaries of their contributions to the discipline.

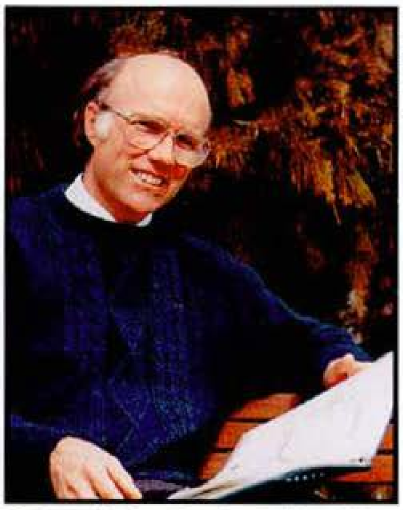
Mathematics is a language through which natural processes can be explained and simulated. Accurate simulation, however, depends on how closely the mathematics mirrors natural processes.

The challenge for scientists such as Sawford is to select and apply the mathematical theory that best describes particular processes. One example is the dispersion of pollutants under turbulent, or convective, atmospheric conditions.

The theory that Sawford has applied to the subject comes from a French man named Joseph Louis Lagrange. It's Lagrange's mathematical theory applied to fluid motion that Sawford and his colleagues have taken from an 'esoteric research topic' to a practical tool for regional modelling of air pollution.

Before Lagrange came into favour, the theory of a different mathematician, a contemporary of his called Leonhard Euler, was traditionally applied to the task. The Eulerian modelling approach involves selecting fixed points on a grid and calculating the changes in average pollutant concentration predicted to occur there as the pollutant disperses.

The Lagrangian approach, however, involves following a tiny volume of air containing a constant concentration of pollutants as it travels throughout a three-dimensional region of the atmosphere, calculating its next direction of travel en route. The average concentration at any point is then determined from the probability of finding the tiny pollutant volume at that point.


David Whillas

Dr Peter Manins: One day we'll be able to simulate whole regions in great detail.

According to Manins, LADM has opened up a new industry that didn't previously exist: the study of regional air pollution problems that extend perhaps 200 kilometres. He calls this 'total airshed management'.

As well as covering more ground, whole-airshed studies must consider the influence on regional air flows of climate, terrain and proximity to the coast. These factors affect the 'assimilative capacity' of a region (its ability to absorb air pollutants).

The assimilative capacity of Australia's major cities is poor, largely due to their coastal location. As a result, air pollution levels are at times no better than Tokyo and New York (see Tables 1a and 1b).

Pollutants recirculated

By applying LADM, CSIRO scientists have found that Australia's coastal capitals experience sea breezes and other winds that recirculate pollutants over their original source of emission, enhancing the build-up of photochemical smog. One example is Sydney's sea breeze drainage system, (see 'Smog moves west as Sydney grows' *Ecos* 70), product of a coastal location, local topography and nearby mountains.

This recirculation of pollutants is exacerbated by the fact that in Australia most industries are sited less than 5 km from the coast, often in undulating terrain, valleys, or next to escarpments.

Any proper assessment of regional air quality therefore requires a knowledge of both the pollution emitters and of the assimilative capacity of the receiving environment. These factors are accounted for in two separate components of LADM.

The first part of LADM sets up the predicted wind patterns for the area of study for a specified time period. These data are saved and used to simulate dispersion of pollutant particles.

The study area is divided into a three-dimensional grid system. A total area covering 500 x 500 km, for example, would probably be overlaid with a 50 x 50 x 25 grid of points.

A typical set of meteorological conditions for the region is entered. Included are large-scale (synoptic) winds; a set of temperature changes in the vertical; and estimates of cloud cover. Factors that affect the synoptic winds at a local level – such as terrain and vegetation height and type, soil type and moisture content – are included.

Using this information, LADM calculates the direction and speed of winds and the kind of turbulence to be expected for each grid point at frequent intervals (for example, every five minutes). The result is a broad simulation of the air flows across the region for one to three days.

Predictions made on this scale, however, are too coarse to accurately model winds in a local valley, or near coastal features. To gain a more detailed view, the model is re-run on a finer scale, such as 50 x 50 km, with a resolution of perhaps 1 km x 1 km, and as fine as a few metres in the vertical. These predictions are saved for the second modelling stage.

The second component of LADM uses these air-flow predictions to simulate the movement of pollutant particles across the region.

Firstly, the rate and volume of emissions from each source (existing or proposed) in the study region is specified. Streams of particles are then 'released' from each source into the 'atmosphere'.

Once they are set free, the particles wait while LADM calculates their speed and direction of travel, according to the air flows and turbulance in their vicinity. Upon receiving their instruc-tions, the particles move to their new locations, pausing again while their next move is calculated, as though in a 'drunkard's walk'.

This procedure continues until the the end of the simulation period is reached, or until the particles reach the ground. The concentration of pollutant particles at ground level is important, because it affects the air we breathe.

To predict these concentrations, LADM counts (over the averaging time-period required) the number of pollutant particles that are present in boxed areas adjoining the ground surface. This count can also be made at any other location or height.

Armed with this information from LADM, the scientists can predict the impacts on air quality of proposed power stations and industrial or urban developments. They can also advise on optimum networks for air quality monitoring to ensure that potential 'danger zones' are not overlooked.

One of LADM's most attractive features – from an aesthetic point of view – is its graphical representation of particle dispersion. Even the most jaded urban planner would be intrigued by the plumes of coloured particles that snake across the screen in response to local air flows. The three-dimensional scene can even be rotated to be viewed from different directions. This capability means that, in addition to a written report, the team at ECRU can present to its clients a video simulation of plume dispersion in their region.

According to Manins, LADM is recognised worldwide as a leading air-pollution dispersion model. Having applied it during air-quality studies in most Australian cities, Manins is keen to market the model here and overseas. He clearly believes that models such as LADM will be the planning tools of the future, and not only in relation to air quality. 'One day we'll be able to simulate whole regions in great detail', he says.

Table 1a. **Annual average concentrations of nitrogen dioxide**

City	*Year*	*NO_2 (µg/m^3)*
New York City	1990	98
Sydney	1988	67
Melbourne	1984-90	66
Tokyo	1988	64
Newcastle	1990	15

Table 1b. **Annual average concentrations of total suspended particulate matter**

City	*Year*	*TSP (µg/m^3)*
Sydney	1984-85	86
Newcastle	1990	82
Tokyo	1988-89	53
New York City	1986-87	50
Melbourne	1990	40