New skills in predicting atmospheric pollution*

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Prologue

Humanity has prospered because we have had the ability to exploit, for our own benefit, the environment in which we exist. Using 'to exploit' to mean 'to turn to good account', the benefit has been the propagation of our species and improvement in our quality of life. Studies of population dynamics in animal species show, however, that the timing of the peak in numbers is often determined by resource limitations. These limits can arise both because of a steady increase in numbers and because of a depletion in resources themselves; the first often leads to the second. Nature is brutal and uncompromising in solving this problem by abruptly reversing the population trend, but humanitarianism aggravates the problem and skirts the ethical dilemma posed by survival.

Perhaps we shouldn't be surprised that in some areas we now seem to be approaching that resource limitation stage ourselves. With world population increasing as projected (Fig. 1), it is unrealistic to hope that rational policies that will reverse this trend in the mid-term future will be universally adopted. Also, human history is so thoroughly grounded in environmental exploitation that it is clearly going to be difficult, if not impossible, to slow down and to achieve a stable state of so-called 'sustainable development' before transgressing a critical point. Accordingly, while attempting to ameliorate the adverse trends, an important strategy is to develop an ability to predict the likely changes in order to plan to adapt and to attempt to maximise beneficial effects.

Overpopulation is endemic on earth. It is evident not only in the rural saturation of China, the famines of Ethiopia, the pathetic overcrowding of Calcutta and the suffocating atmosphere in Mexico City but also in the occasional breakdown of city services in New York, in the traffic problems of London and the sewage overload in Sydney. Even the atavistic internecine strife in southeastern Europe and the Middle East may be exacerbated by too many people for too few resources. The Gaia theory might well include social stress and conflict in the checks and balances regulating the earth as a whole.

Fig. 1 World Population (adapted from 'World population growth and response', Population Reference Bureau, Washington D.C. 1976).

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From such arguments it is reasonable to cite increasing population as the root cause of major threats to the world community. Proceeding from the chronic to the acute (Fig. 2), these threats include depletion of non-renewable resources, global atmospheric change, species depletion (reduction in biological diversity), aspects of warfare and disease, land use change (and associated land degradation) and waste accumulation and disposal as it affects land, water and air. The last of these is the topic of this address.

Many problems associated with waste disposal involve the emission of pollutants into the lower atmosphere. Often atmospheric chemistry is important for understanding both how emissions affect the chemical mix in ambient air and how subsequent reactions change the atmospheric composition. This paper is limited, however, to considering physical meteorological factors that affect the fate of waste emissions. The transport and dispersion of these pollutants are influenced by the characteristics of the emission source, the ambient broadscale (synoptic) atmospheric condition, the type of local terrain and the modulating effect of regional meteorological phenomena.

Over the past decade theoretical, numerical, laboratory and field studies have been directed to understanding the relevant processes in the convective boundary layer and the effect of plume buoyancy. Simple models have been developed of buoyant plume dispersion under convective conditions in an attempt to provide a generalised approach which is applicable to most practical situations. In Australia the structure of the boundary layer has been intensively studied, partly because of its role in affecting the hydrological cycle in our water-deficient continent. Also, the country has a sparse population and, even in the more densely settled areas, is characterised by relatively discrete areas of industrial development. This provides opportunities to study plumes under stable conditions in which they often remain identifiable over long distances. (A notable example is the Mount Isa plume, emitted from two closely located tall stacks at an inland site in a trade wind region (see Fig. 5 inset for location). This plume can often be traced for over 1000 kilometres.) A third characteristic of our continent is that, notwithstanding the above example, most population centres are near the coast. Hence there is particular interest in the fate of waste emissions under sea-breeze conditions. For all these reasons much scientific effort has been devoted to studying mechanisms affecting atmospheric emissions from point sources into the lower atmosphere.

While field studies of the real system are essential for understanding the behaviour of plumes, one major problem is that the atmosphere cannot be controlled. Accordingly, because an enhanced observing network can usually be established only for a limited time, the vagaries of the weather mean that the situations sampled are not always what is needed in order to describe fully the gamut of conditions or to test a theory. For this reason surrogates are essential and, for atmospheric transport and dispersion, both laboratory and numerical models provide the means whereby experimental techniques can be used to probe the sensitivities of the system to variations in input parameters. The more complete numerical models have an equally important value in providing the means to synthesize quantitatively the

**Introduction**

Significant advances have occurred over the past decade in understanding and simulating transport and dispersion in the planetary boundary layer over complex terrain. These have enabled realistic estimates to be made of the impact of existing and projected future emission sources on regional air quality.

Because the continuing development of these methodologies involves the solution of relatively new scientific problems, or at least the application of techniques to the complexities of real situations, it is clearly desirable for applied research to be carried out with strong links to a multi-disciplinary research effort. This enables the rapid deployment of state-of-the-art scientific knowledge to such practical problems. Within CSIRO the elements of such a widely based air quality research program are in the process of being coordinated. One general objective is to minimise the normal engineering tendency to use very conservative assumptions and worst-case estimates as a safety factor. This is being done by achieving greater confidence in an ability to simulate accurately the controlling physical processes.
processes at work, yielding simulations of the full performance of the real system.

The purpose of this paper is to describe briefly some results from a field study, a laboratory facility and a numerical atmospheric transport and dispersion model. The field study has provided a new set of measurements of buoyant plume dispersion under convective conditions, relevant to near-field ground-level concentrations. The laboratory facility provides a means of carrying out controlled surrogate investigations of plume rise and dispersion and plume penetration of the inversion capping the boundary layer. These techniques of study are applicable to short-range (0–10 kilometre) problems. The numerical model is particularly useful in longer range (1–100 kilometre) problems for which it simulates the plume track and particle dispersion under synoptic and sea-breeze conditions in an area of complex terrain. In conclusion, examples are given of the way in which knowledge gained from such studies is used to solve practical problems.

Short-range problems (0–10 km downstream)

Parameters and concepts
A particularly important class of events concerns the emission of buoyant plumes into a strongly convective boundary layer. In these circumstances the ground-level concentrations of pollutant fairly close to the source, the so-called near-field levels, are often high. This occurs because heating at the earth’s surface causes vertical circulations between the ground and the top of the boundary layer. These circulations are responsible for the characteristic intermittent looping behaviour of the plume, often bringing it down to the surface relatively undiluted within a few kilometres of the source.

Within a distance of 10 kilometres or so downstream from an emission site, the transport and dispersion of the emitted pollutant is influenced by six principal factors:

- the prevailing wind speed and direction;
- the height of the inversion capping the boundary layer;
- the intensity of convective turbulence within the boundary layer which, in turn, depends on solar heating of the earth’s surface;
- the height above the surface of the emission point (the stack height);
- the initial buoyancy flux of the plume;
- the influence of local terrain on the mean flow and turbulence of the wind field.

The first five of these factors are represented schematically in Fig. 3.

The downwind distance $x$, height $z$, and buoyancy flux $F$, are usually expressed in a non-dimensional form so that field observing experiments involving different stack heights, inversion heights, wind speeds and turbulence intensities can be compared amongst themselves and with laboratory results. Non-dimensional parameters are:

For distance downwind $x^* = \frac{x}{z_i} \cdot \frac{W_*}{U}$

For height $z^* = \frac{z}{z_i}$

For buoyancy flux $F^* = \frac{F}{w^2 \cdot U (z_i - z_j)^2}$

(Symbols are defined in legend to Fig. 3.)

A field study
While theoretical and laboratory studies have contributed significantly to a quantitative understanding of the processes at work under these conditions, there is a notable deficiency in well-documented field data covering a range of the critical parameters listed above. Accordingly a suitable collaborative study was devised and

At Tarong, Queensland, in northeast Australia (see Fig. 5 insert for location), there is a large modern power station with a capacity of 1400 MW. The plume from this station was studied intensively for the eleven days 29 August–9 September 1989 when strong convection occurred in the boundary layer under clear sky conditions. The terrain surrounding the power station is rolling country with height variations of about 60 m, clad in light forest and cleared farmland. Air quality and meteorological measurements were made and in addition a unique observing facility was deployed — the Lidar (light detection and ranging) equipment, based on a ruby laser operating at a wavelength of 0.69 μm. This instrument fires a pulse of light 40 ns in duration (about 12 m long) which is scattered and absorbed by air molecules and particles in the atmosphere. Scattering is most effective when particle size is about the same size as the wavelength of the laser beam. Particle concentration along the beam can be measured from the intensity and timing of the back-scattered signal collected at the lidar site. In practice, when aligned at a fixed azimuth, some 50 shots at fixed increments of elevation were required to resolve the plume section (Fig. 4).

Five azimuths were chosen to sample the plume out to about 5 km downwind from the stack (Fig. 5). Frequent vertical shots were also made to determine the top of the convective boundary layer; this is identified by a marked reduction in particles scattering back light (Fig. 6). Between 1000 LST and 1600 LST each day, some passes of the electrostatic precipitators were shut down thus increasing the particle loading and so providing a strong signal from the lidar. Many of the data collected are still being analysed but one result for a two-hour period has yielded information on

centre line plume rise shown in Fig. 7. This result is compared with laboratory water tank model results reported by Willis and Deardorff (1974, 1983) and a field experiment using oil fog and radar chaff as pollutants carried out in Boulder, Colorado (Eberhard et al. 1988). Both these latter results were for non-buoyant plumes, and indicate the way in which the plume behaves purely due to mixing by turbulence. In the laboratory experiments the time-averaged plume reaches \( z_* = 0.5 \) at about \( x_* \approx 1.5 \) for both very tall and medium height stacks. Although widely scattered, the field results for a stack midway between these heights are consistent with these laboratory results.

The Tarong result for a very buoyant plume (from a somewhat short stack) indicates that, as might be expected intuitively, the plume reaches the \( z_* = 0.5 \) centre line level fairly quickly, at \( x_* \approx 0.3 \) which corresponds to a distance of about 1 km downstream. It then appears to first overshoot and then undershoot before stabilising; by this stage it is well mixed throughout the boundary layer at about the same distance downwind as the non-buoyant plumes. The overshoot/undershoot of this buoyant plume result may be due to a scatter in the data, with the buoyancy effect becoming negligible beyond about 1 km downwind. Further analyses of results will establish this and the vertical and lateral spread of the plume. Other concerns will include statistics on the ground strike of the plume. Willis and Deardorff (1983)
Fig. 6 Profiles in the boundary layer at Tarong at 1300 local time on 29 August 1989 of dry-bulb temperature ($T_D$), wet-bulb temperature ($T_W$), potential virtual temperature ($\theta_v$) and lidar backscatter coefficient ($B$). (From Sawford et al. 1990.)

Results show an average general strike at about 3 km from the source but intuitive reasoning, visual impressions at Tarong and more recent laboratory results (see below) suggest that under strong convection ground strikes closer than 1 km from the stack are not unusual even in moderate winds.

In summary, while this particular study comprised two intensive observing periods, each of two weeks duration in late winter, the conditions in 1988 were not representative of the convective situations required but those in 1989 were nearly ideal. From this latter period a substantial set of dispersion and concurrent meteorological and air quality data were collected over a range of plume buoyancies and a range of distances downstream that spans the point of maximum downstream concentration.

A laboratory facility

One of the difficulties in setting up a field experiment to measure in detail the behaviour of the atmosphere under certain ambient circumstances is the natural variability of these circumstances. An example of this is the two calendar weeks, chosen well in advance, for the Tarong study which, as explained above, provided poor conditions in 1988 but very good conditions in 1989. An associated difficulty is our inability to carry out controlled experiments in the parameter ranges of interest. For these reasons surrogates are necessary. Of course, analytical theory is itself a surrogate for the real system but often the nonlinearities involved are not tractable, and simplifications are of limited value. Both numerical and laboratory models, on the other hand, can provide a useful means to undertake controlled experiments, provided a suitable degree of verisimilitude can be achieved.

Some two decades ago Willis and Deardorff (1974) pioneered the study of the convective boundary layer in the laboratory, using heated water to provide the density variations for stratification and limited vertical convection. (This laboratory is no longer in existence.) Saline concentration, however, has advantages over heat; it allows greater density variation, a larger experimental volume and also permits repeated consecutive experiments. In the late 1980s a saline laboratory water tank was set up by Hibberd and Sawford (1990) for studying plume behaviour under a variety of ambient conditions.

Laboratory measurements in controlled situations provide data which bridge the gap between idealised conditions amenable to theoretical treatment and the complex and poorly sampled cases encountered in the field.

The tank is $3.2 \text{ m} \times 1.6 \text{ m} \times 0.8 \text{ m}$ deep. Initially it is set up with a $15 \text{ cm}$ deep constant density layer, the initial (mixed) boundary layer, and a $55 \text{ cm}$ linear density gradient below that.
Convective turbulence is generated by allowing very salty water to diffuse downward from a porous tray at the top of the tank; thus the convection proceeds 'upside down' compared with the atmosphere. Plume emission is undertaken by drawing a jet source of dyed salty water across the top of the tank at a speed representing horizontal wind speed (Fig. 8). Careful consideration is given to aspect ratios and scaling so that experiments can be regarded as simulations of realistic conditions in the atmosphere. Various techniques of measurement are used, including laser-induced fluorescence in a plane sheet at the effective ground level to map ground-level concentrations of the coloured fluid emitted from the source.

An important precursor to controlled experimentation with this facility is a careful study of the similarity between the convective turbulence generated in the tank and that in the atmosphere. One important feature is the profile of vertical velocity variance, $\sigma_w^2$, throughout the boundary layer. Figure 9 shows the results obtained, non-dimensionalised by the square of the convective velocity, $\sigma_w^2 / W^2$ (Hibberd 1990). In this figure the saline tank results are compared with earlier heated water tank data and field measurements from three experimental sites in the United States. The dimensionless vertical velocity variance can be seen to increase from small values near the surface to a peak of about 0.5 near the middle of the layer, then it decreases through 0.15 at the top of the layer to about 0.02 in the stable region above. This small non-zero value up to 1.4 $z_i$ is associated with entrainment processes. An indication of the low sampling errors is given by the average vertical velocity (not shown) at each level. This should be zero for unbiased sampling: it is always below 0.08 $w_\ast$ and generally below 0.04 $w_\ast$. An excellent correspondence can be seen between the saline tank profile and the field data, where the scatter reflects the difficulties in measuring vertical velocity in the real atmosphere. This result is only one of many which demonstrate the verisimilitude of the saline water surrogate.

The saline tank is being used to study many phenomena: plume rise and penetration of the inversion, the interaction between two plumes, the downstream distance of maximum ground-level concentration, etc. One result, shown in Fig. 10, concerns cross-wind integrated ground-level concentration as a function of (non-dimensional) distance downwind from a plume of fairly weak buoyancy flux. This is compared with non-buoyant source results from the heated water tank experiments, for various stack emission heights. It can be seen from the non-buoyant profile $z_i/z_L = 0.24$ and the approximate buoyant profile for $z_b/z_L = 0.22$ that even this low degree of plume buoyancy gives maximum ground-level concentrations twice as far downstream as in the non-buoyant case.
A numerical model
In the next section the application of numerical modelling techniques to study plume track and vertical dispersion on time-scales of hours and length scales of tens of kilometres is described. However, a numerical modelling approach can and has been used to study processes such as morning fumigation events and associated ground-level concentrations within a few kilometres of stack emitters. This phenomenon occurs when the shallow nocturnal inversion is replaced by a growing mixing layer as the morning sun heats the surface. As the mixing layer grows to encompass the complete stack height, the turbulence within the layer mixes the plumes to the ground. For a few hours, high ground-level concentrations may occur close to the stack while the plume caught in the downdraughts is narrow and undiluted. Later, as the mixing layer grows to several times the stack height and convection increases in intensity, the plume brought down is already to some extent diluted. The new particle component of the Lagrangian Atmospheric Dispersion Model (LADM) (Hurley and Physick 1989, 1990) overcomes practically all the identified problems of an earlier modelling procedure (Turner 1970) which strongly overestimates ground-level concentrations, and the Deardorff and Willis (1982) procedure which does not adequately treat the problem of the vertically developing boundary layer and associated wind shear. A mesoscale wind field module is used to give a detailed description of the changing temperature, wind field and turbulence characteristics of the morning atmosphere. A plume dynamics module, based on Briggs (1975), is used to specify the rise and initial dispersion of a pollutant plume and the Lagrangian particle flow module (LPFM) follows the dispersion of particles released regularly from the location of the plume at its final rise height. A comparison of model results under very simple conditions is given in Table 1; it shows good agreement with the Deardorff and Willis (D & W) technique and gives confidence in its application to much more complex and realistic conditions.

Longer-range problems (1–100 km)
For distances further downstream, of order 100 km, and times in excess of one hour after emission, regional and diurnal meteorological influences must be taken into account. A particularly useful way of doing this has been to use state-of-the-art numerical models that describe explicitly such influences.

The model described here is not statistical in the sense of making Gaussian plume assumptions and empirically deriving parameters to scale isolated observed concentration measurements. Instead it uses deterministic simulations of atmospheric flow pattern developments from an initial (observed) state to predict wind speed and direction at different heights and at high spatial resolution during the course of a normal diurnal cycle. Particles are then inserted at specific locations and allowed to be transported by these winds, and also allowed to diffuse according to turbulence theory (Physick and Abb 1988). The modelling system used consists of a Lagrangian particle dispersion model and a detailed mesoscale (wind field and temperature) model (McGregor 1987). The dispersion component moves particles from multiple sources according to wind and turbulent statistics in the immediate vicinity of each particle, provided every ten minutes on a three-dimensional grid. This LADM is thus an air dispersion system that accurately models the transport and diffusion of emissions to air from discrete sources for impact distances ranging from hundreds of metres to a few hundred kilometres. It is applicable to air quality studies that involve simple or very rugged terrain, time varying conditions such as sea-breezes, and the interaction of complex wind flows such as drainage winds.

The system is most useful for worst-case simulations for environmental impact assessment studies. It appears to be the only system currently capable of accurately predicting the impact of morning fumigation — the usual cause of highest ground-level concentrations in the far-field. Sea-breeze fumigation and convective mixing are equally well modelled in both flat and complex terrain. The increased accuracy of the system over more common, usually very conservative, approaches means that industry can avoid unnecessary expense in designing a facility to meet unrealisable air pollution predictions. Alternatively, industry can be more confident that later expense in retrofitting emissions controls due to inappropriate initial design data will not occur.

The example chosen for display here concerns emissions from a group of power stations in the Hunter Valley of New South Wales (see Fig. 5 inset for location). The broadscale meteorological situation selected was a typical springtime synoptic situation. The snapshot shown in Figs 11 and

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(From Physick et al. 1990)
Fig. 11 Numerical model simulation of particle distribution from continuously emitting sources: three sources are located in the coastal region and two in the upper valley region. Each represents an active power station source. This distribution applies to time 1500 LST, 13 hours after model emissions commenced. (From W.L. Physick, personal communication.)

12 represents the particle positions and ground-level concentrations at time 1500 LST, after continuous emissions from all stacks since 0400 LST, with 40 particles being released from each stack every 20-second time step. The model is run with 20-second time steps but wind data are kept for only each ten minutes. Thus advection and dispersion occur every twenty seconds although the wind and turbulence fields change only every ten minutes. Virtually no accuracy is lost by using this procedure for computational convenience.

These figures show that by mid-afternoon the three coastal plumes are being transported inland by the sea-breeze, whose leading edge is delineated by particle distribution. By contrast, plumes from the three inland stations are still drifting towards the coast in light northwesterly winds. The non-dispersive nature of the coastal plumes out to a few kilometres from the source indicates that the effective stack heights are above the thermal internal boundary layer (TIBL). The largest surface concentrations are found further inland where the plumes intersect the growing TIBL and are convectively mixed to the ground. Note that not all particles are at low levels; for example, those near the coastline are actually moving out to sea in the return flow of the sea-breeze.

Fig. 12 Ground-level concentrations for the situation depicted in Fig. 11. In practice particles at and below 25 km are included for a one-hour period. A test calculation for all particles below 50 km was undertaken and, because the atmosphere is well mixed at other levels and times, the results were very similar. (From W.L. Physick, personal communication.)

Applications

Near-field morning fumigation

About two years ago an environmental study was required to assess the impact of a new power station which would be within 10 to 15 km of an existing power station, a township and an aluminium smelter. Predictions of the maximum ground-level concentrations of SO₂ due to morning fumigation were required at various distances from the sites in estimated worst-case situations. The result shown here (Fig. 13) is for the worst-case situation when the wind blows directly from the existing to the proposed power station.

The conclusions of the study (Physick et al. 1990) illustrate the information to be derived from this technique:
(a) the maximum impact of the proposed power station is estimated to be about 1100 µg m⁻³ (one-hour average) at a distance of 2 km downwind;
(b) the maximum impact of this power station on the local township (about 9 km away) may be around 360 µg m⁻³ (one-hour average);
(c) under adverse conditions the present power station can enhance the proposed power station impact by approximately 60 per cent close to the ground.

The second example shows the way in which prognostic wind field models are capable of representing plume dispersion in complex terrain, with regional meteorological influences controlling the
flow. In this case the location is the Latrobe Valley in southeast Victoria (see Fig. 5 inset for location) where sea-breezes are a prominent feature, particularly in summer, and local topography is a significant influence.

The atmospheric model was used in two identical wind field experiments, each with a nil superimposed synoptic wind; subsequent winds are generated only by the complexities of diurnal heating and cooling.

On the first occasion, particles were released in the model at 2200 LST, 22 hours after the model run was commenced, at the rate of one particle per minute from each of the two elevated sources. The particle dispersion at 0400 LST, six hours later and well before sunrise, is shown in Fig. 14. The first source, labelled 'A', represents the Morwell Power Station, with an effective emission height of 550 metres above ground level. The second source, labelled 'B', represents the Australian Paper Mills with an effective emission height of 100 metres above ground level. The lower-level plume 'B' is strongly channelled whereas the higher plume 'A' is advected by the remaining sea-breeze flow which is, by this time, from the northeast as it rotates clockwise. The wind directions are in agreement with data from an acoustic sounder, 8 km east of source B.

When the model was re-run, particle emissions were not commenced until 0600 LST on the second day. By 1200 LST the valley winds had become predominantly westerly due to the mixing downwards of the return flow of the previous day's sea-breeze at higher levels when the rising convective boundary layer reached these levels. Effective emission heights still influenced, however, the detailed plume distributions (Figs 15 and 16).
Fig. 15  Particle distribution at 1200 LST for the APM source. (From Physick and Abb's 1991.)

Fig. 16  Particle distribution at 1200 LST for the MPS source. (From Physick and Abb's 1991.)

Fig. 17  Distribution of particles from the MPS source at 1800 LST. The particles have been released continuously since 0600 LST. In this plan view the vector arrows denote observed 10 m winds at 1800 LST (on 8 March 1985) and the dashed line indicates an observed line of confluence between south and east coast sea-breezes. (From Physick and Abb's 1991.)

Fig. 18  East-west vertical cross-section in which all particles are shown. The topography corresponds to a cross-section through the Latrobe Valley shown as XY in Figure 17. (From Physick and Abb's 1991.)

In the plan view of the distribution of particles at time 1800 LST (Fig. 17), the influence of the boundary between south and east coast sea-breezes can easily be seen. There is a tendency for the particles to collect at the line of convergence (AB) as well as at the leading edge of the east coast sea-breeze (BC). The vertical cross-section (Fig. 18; along X–Y in Fig. 17) shows the clean air
brought in at lower layers by the sea-breeze; it also reveals that all particles east of the sea-breeze front are at upper levels, taken there by the return flow towards the sea. In the afternoon a southeastern sea-breeze moves up the valley (see observed vector winds superimposed on Fig. 17) in agreement with an analysis of observed surface winds (Physick and Abbas 1991).

While the research described above is recent, results from earlier studies have already been included in air pollution regulatory models used to license emitters. The third example, therefore, refers to Kwinana, Western Australia (see Fig. 5 inset for location), where much industry is within 500 m of the coast (DCE 1982). In this case a special sea-breeze dispersion model was used.

Figure 19 gives maximum ground-level concentrations of sulphur dioxide measured at a residential area, Wattleup, for different averaging times. It is evident that, in 1981 before control procedures were put into place, high pollution episodes occurred due to industry emissions located on the coastal strip.

The conceptual approach used to model ground-level concentrations and show their dependence on emissions required a specification of plume rise, inshore flow, growth of the boundary layer, the contribution of different sources and the way in which pollution is mixed to the ground. All these are features that have benefited from air pollution meteorology studies using field work, laboratory models and numerical simulation.

Figure 20 represents the calculated frequency of very high-level pollution before the control strategy was designed and implemented. In practice the control strategy was dictated by model simulations such as those described above, which showed the way in which industrial emissions on the coast caused pollution at the inland residential areas. The effectiveness of the strategies designed and implemented can be seen from more recent 1989–90 measured values of SO₂ concentration.

**Conclusion**

This paper has used selected examples to illustrate the strategic research program on air pollution meteorology currently under way at the CSIRO Division of Atmospheric Research. This has enabled a concomitant and rapidly expanding applied research program to be developed in the Environmental Consulting and Research Unit at the Division. The direct access the latter group has to the former has enabled improved techniques to be used to simulate ground-level concentrations of pollutants emitted from present and planned future emission sites. Also cited is an example of how such research can influence control strategies that significantly reduce pollution levels.
It is clear that, for the responsible siting and operation of industrial complexes generally, and those emitting toxic material into the atmosphere in particular, careful meteorological studies using up-to-date techniques are essential. These can predict the fate of hazardous emissions into the atmosphere, and also can be of use in determining optimum locations and relevant operating control procedures. The science has advanced to the stage where quite complicated meteorological conditions can now be satisfactorily modelled.

Acknowledgments

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