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Modelling Wind Fields in MAQS

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Abstract MAQS is the Metropolitan Air Quality Study, a multi-million dollar scientific investigation of photochemical smog and fine particle pollution in the major urban and industrial area of New South Wales on the east coast of Australia, extending from Newcastle-Hunter Valley/Central Coast/Sydney/Illawarra-Wollongong. As part of a consultancy for MAQS, we have extended and applied the detailed prognostic numerical air pollution transport and dispersion model, LADM, to several simulations of local and inter-regional air pollution events for the region. The investigation has highlighted (i) the large uncertainty in specifying surface synoptic meteorological data on high pollution days, (ii) the ability of LADM to predict well the local winds and temperatures, even without assimilation of observational data, (iii) the need to incorporate observations of surface and upper air winds to give accurate air *trajectories*, (iv) that days conducive to sea-breeze conditions are the key to the meteorology of high pollution in the MAQS region, and (v) that poor dispersion in the Sydney basin also implies inter-regional transport: from the Newcastle and Hunter Valley region to parts of Sydney, or from much of Sydney to the Illawarra.

1. INTRODUCTION

Exacerbated by the recirculation of air in sea breezes, Australia's large coastal cities with sunny climates experience the most intractable form of air pollution—photochemical smog characterised by the presence in the air of excessive concentrations of ozone gas, a respiratory irritant (Manins *et al.*, 1994). Figure 1 shows that there has been some success in reducing the problem in the largest cities of Sydney and Melbourne, but that there is no cause for complacency.

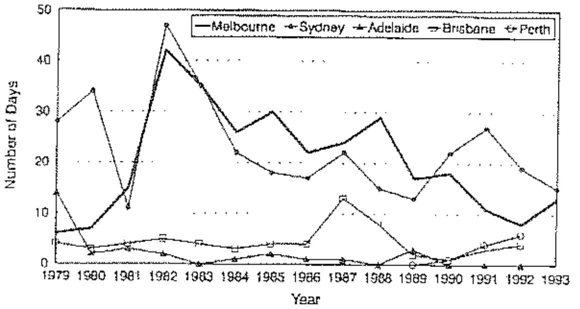


Figure 1. Number of days when peak 1-hour ozone concentrations exceeded 80 ppb in selected Australian cities, 1979-93 (courtesy S. Ahmet).

In 1993 the Environment Protection Authority (EPAN) of New South Wales (NSW) initiated the Metropolitan Air Quality Study (MAQS). EPAN was anticipating a big population growth in the major urban and industrial area of NSW, *viz* Newcastle-Hunter Valley/Central Coast/Sydney/Illawarra-Wollongong (shown in Figure 2), cognisant of predictions that an expansion in the western part of the Sydney basin could lead to a deterioration of air quality (Hyde and Johnson, 1990). MAQS is a multi-million dollar study of the present and expected future air quality in the region. The study has involved the enhancement of existing air quality measurement sites, establishment of additional sites, funding of health studies, and scientific studies of pollution mechanisms including numerical modelling. This last component of the study was contracted out to a consultancy team managed by Coffey Partners International. The tasks were to develop and validate an emissions inventory and a set of modelling tools for the region. These tools would be passed on to EPAN at the end of the study to assist in future assessment of urban and industrial planning issues.

The MAQS consultancy consisted of four major tasks:

1. Air Emissions Inventory (done by EPA of Victoria);
2. Meteorology - Air Movements (Macquarie University and CSIRO Division of Atmospheric Research);
3. Air Chemistry (CSIRO Coal & Energy Technology);
4. Development of Airshed Models (EPA of Victoria).

Here we describe the meteorological modelling component of the Meteorology - Air Movements task. The Environmental Consulting and Research Unit of the CSIRO Division of Atmospheric Research conducted selected numerical meteorological simulations for the MAQS region based on high pollution days categorised by Macquarie University using historical data. The meteorological predictions were used as input to other MAQS tasks: Air Chemistry, and Development of Airshed Models simulating smog formation and dispersion. In Section 2 we describe the modelling system used for the study, the configuration of the model for MAQS, and some results. Section 3 focuses on a detailed case study day for Sydney, and Section 4 summarises the results from various types of high pollution scenarios identified in the study.

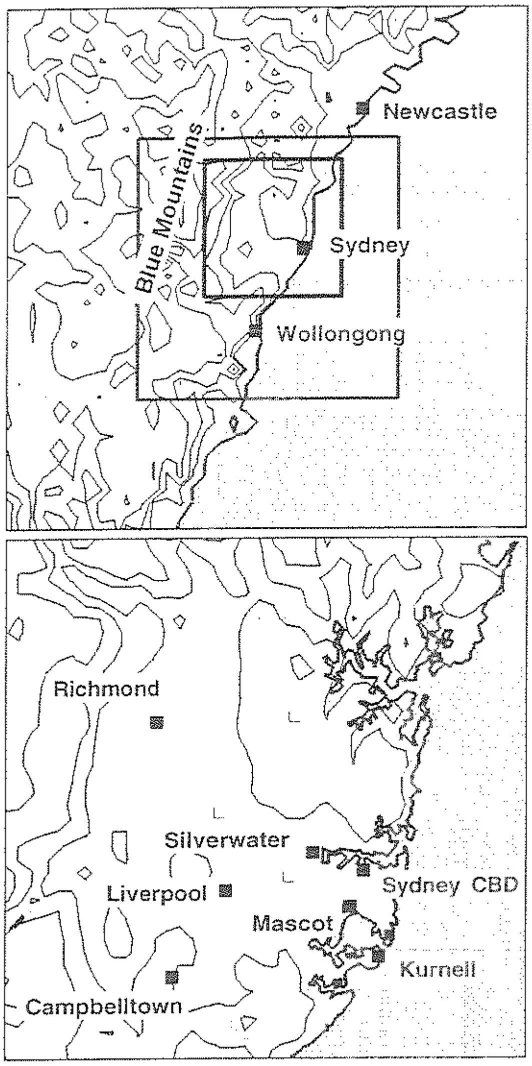


Figure 2. (Top) One of the 10 km spaced grid domains used by LADM (5.0, 2.5 km grid domains are marked inside it), showing the extent of the MAQS region (400 km across). (Bottom) A 2.5 km spaced grid domain for the Sydney Basin (100 km across).

2. MAQS METEOROLOGICAL MODELLING

While extensive surface wind and temperature data are available in MAQS from 20 or more stations throughout the region, the only upper air data are from the airports on the coast at Mascot and north of Newcastle (Figure 2). For airshed modelling of inter-region transport and smog dispersion to be successful, it is essential to have detailed data on the upper-air winds, the height of turbulent mixing in the atmosphere, and on the winds between the population centres. The approach adopted for the meteorological modelling for MAQS was the only one possible in the circumstances—we used the Lagrangian Atmospheric Dispersion Model (LADM), a complete air pollution modelling system described by Physick *et al.*, (1994) and Physick (1993).

LADM has taken over 10 years to develop and has been applied to numerous air pollution studies across Australia.

2.1 LADM

LADM is a two-part prognostic model:

1. The first part is a mesoscale meteorological model which solves the primitive equations for fluid flow, predicting the three-dimensional local winds, turbulence, temperature and mixing heights on a grid in a complex geographic region using terrain data from Hutchinson *et al.* (1991). This semi-implicit model uses Lagrangian techniques; it is a fast (hydrostatic assumption) weather-forecasting model with long- and short-wave radiation schemes and a full vegetated surface scheme. The modelled region must be so large as to include all relevant terrain that causes the local wind to deviate from the large-scale (synoptic) wind. The predicted winds and turbulence parameters for every grid point are saved at frequent intervals for analysis or use by the second component of LADM.
2. The second part is a Lagrangian particle dispersion model. This predicts the transport and diffusion (including plume rise for hot emissions) from the pollutant sources using the wind data and turbulence characteristics predicted by the meteorological model. A stream of particles is released from each source at a rate proportional to the specified emissions. Each particle is tracked as it is moved in the wind and by random perturbations simulating the turbulence. To predict ground level concentrations the number of particles in surface-located boxes is counted over an averaging time.

2.2 Running LADM in MAQS

For MAQS two sets of nested grids were used: one set covering the Sydney and Illawarra sub-regions, and one set covering the Sydney and Newcastle sub-regions. The grids had horizontal dimensions of 40×40 points and 20 points in the vertical. The horizontal grid spacing was 40 km, 20 km, 10 km, 5km, and 2.5 km. Figure 2 shows 10 km, 5 km and 2.5 km spaced grid domains. Note that 40 km and 20 km spaced grids were run merely to set up realistic boundary conditions for the 10 km grid, thereby reducing the effects of imposed boundary conditions on the outer nest.

The model was generally started at 0300 hr on simulation day 1 and run for 63 hours through to 1800 hr on simulation day 3. Results from simulation days 2 and 3 are taken to correspond to a 48 hour period of interest. Two kinds of investigations were performed in MAQS:

- '*Generic*' modelling imposes the large-scale ('geostrophic') winds to drive the simulation without much concern with accuracy in reproducing local observations. This is done to help identify the mechanisms which characterise the type of days being modelled (*eg*: summer poor dispersion days in Sydney). The results are used to enhance understanding of available data and the general characteristics of the category of day being considered.

- '*Case study*' modelling is performed in order to describe as much detail about a particular day as possible. It involves first using the generic modelling approach, and then refining the imposed conditions (usually to a much greater degree than the accuracy of the available geostrophic wind measurements), until good agreement is obtained in detailed comparisons between predicted and locally observed meteorological variables.

2.3 A Summertime Pollution Day in Sydney: 13 Feb '93

A common summer pollution situation in the western region of Sydney has a broad area of high pressure off the east coast leading to large-scale northerly winds. Nighttime drainage flows in the Sydney basin and from the high slopes move cold air to the north towards Richmond (Figure 2) in the lee of the Blue Mountains and to the east towards the centre of Sydney. As the air travels over densely settled and industrial areas in the inner western suburbs, it accumulates pollutants. The air then flows out to sea during the morning. With the onset of the sea breeze the same air is frequently returned, travelling westward and reaching the western Basin near Penrith or Campbelltown in the afternoon.

To simulate these conditions, LADM was run by imposing a steady $5\ \mathrm{m\,s^{-1}}$ northerly geostrophic wind at the surface, backing to westerly by 2,500 m above sea level. All the features discussed above are shown in Figure 3 and compare well with observed data: the 1500 hr surface wind arrows show the presence of the sea breeze; the heavy lines show the paths followed by selected air parcels—the numbers indicate the parcel positions at the marked times. One path line shows that overnight there is a light northward drift in the western basin. Further to the east, the other path line shows polluted air that flows offshore in the early morning is returned in the sea breeze to the western suburbs, by then transformed in the sunlight to photochemical smog.

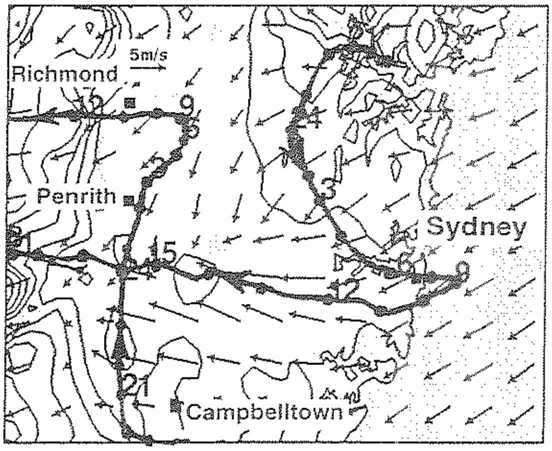


Figure 3. LADM predictions for a common summertime pollution day in the Sydney region (100 km east-west): 1500 hr on 13 February 1991. Also: selected air parcel trajectories with time marks.

2.4 Extensions of LADM for MAQS

The data from the predicted windfields were required for the airshed smog modelling of days with extensive surface observations, necessitating the following important capabilities of LADM being completed during MAQS:

- incorporation of time varying synoptic winds;
- accounting for cloud cover effects on surface radiation;
- assimilation of wind observations.

2.4.1 Time-Varying Synoptic Winds

To account for the variation of synoptic conditions over the three day simulation periods used for MAQS, LADM was modified to incorporate time-varying synoptic winds, potentially allowing a more accurate solution to be generated. Usually, synoptic conditions change on time scales of the order of several hours: for MAQS the imposed geostrophic conditions were changed approximately every six hours. Note that the model cannot presently account for horizontal variations of the synoptic conditions across the modelling domain, such as occurs during the passage of a cold front.

An example of the effect of the variation of synoptic winds with time is given in Figure 4: it shows the predicted movement at 0600 hr on 3 and 4 January 1993 of tracer particles from elevated point sources in the Upper Hunter Valley west of Newcastle, as well as from sources on the coast. These days were similar to that discussed in Section 2.3 but the modelled synoptic winds were stronger ($10\ \mathrm{m\,s^{-1}}$) and were at first from 30°, backing to be from 0° by 0000 hr on 4 January.

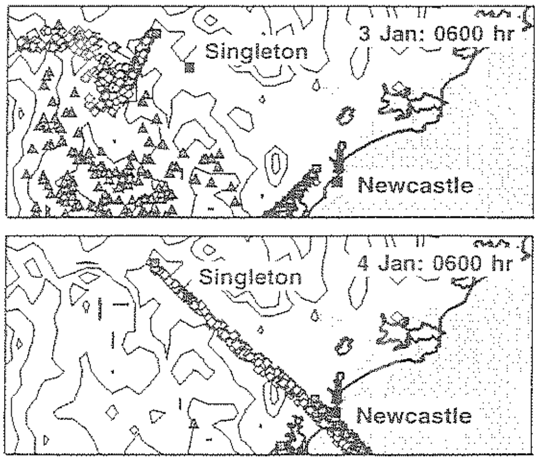


Figure 4. Predicted particle positions for two 500 m high point source releases from the Upper Hunter ◇, and Central Coast □, and a 200 m high release from near Newcastle Δ at 0600 hr on 3 January (top) and 4 January (bottom) 1993.

With a change of only 30° in synoptic wind direction over the period, the winds channelled by the Hunter Valley have changed from being up-valley (towards the west) to being down-valley (out to sea). Indeed, investigation showed that as little as a 10° change in synoptic forcing could give the same result on these kinds of days—so long as the synoptic forcing has no easterly component, the predicted winds in a deep layer in the Hunter are down-valley, otherwise they are up-valley. The prediction is supported by qualitative analyses of data on surface winds, but these are too subject to channelling for this to be a definitive test of wind directions at upper levels.

2.4.2 Cloud Cover Effects of Surface Radiation

Some of the days studied in MAQS were characterised by the presence of clouds. Regional predictive models generally either cannot account for effects of cloud at all, or treat them in such great detail that the model performance is compromised. In LADM the effect of cloud cover has been included only insofar as it affects surface radiation. This was done by fitting simple formulae to predictions from a detailed radiation model (Boers and Mitchell, 1994) for two cloud types and three height levels. The formulae account for the increase in net longwave radiation and decrease in net shortwave radiation at the ground due to cloud cover. The fitted data were obtained from Australian observer information at nine airports averaged over seven years.

As demonstration of the effect of using the new formulae, a test using LADM for three specific cases of cloud cover was performed:

1. No cloud cover
2. Full cover of mixed cumulus/stratus
3. Full cover of stratus cloud

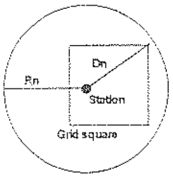
The results show that for both cases 2 and 3 the near-surface temperature minima at night are up to +3.4 K greater than in the no-cloud case. The daytime temperature maximum for case 2 (mixed cumulus/stratus) was minimally affected (due to increased longwave but decreased shortwave of approximately the same order). However, for the case of stratus cloud, the difference in daytime maximum temperature was as much as -4.4 K. These changes could significantly affect predictions of three-dimensional local winds in complex terrain, including a reduction in the speed of drainage winds overnight in valleys, and a reduction of sea-breeze strength during the day for coastal sites. Further details are given in Hurley and Boers (1995).

2.4.3 Data Nudging

Since an extensive network of wind observation stations was available in MAQS, a four-dimensional data assimilation method was employed to improve the predictions from LADM. One way is to assimilate measurements as an extra forcing term in the horizontal momentum equations. The model solution near these sites is thereby 'nudged' towards the measured winds. This technique has been used in various forms in the past, particularly for synoptic scale predictions by weather forecasting models. For the MAQS case study, we implemented in LADM an assimilation technique used by Stauffer and Seaman (1994). The approach was applied to the horizontal velocity variables (u, v), but not to temperature due to the detrimental effect it can have on the structure of the convective boundary layer (Stauffer *et al.*, 1991). An example of the method in operation is given in Section 3.

For a variable u at grid point (i,j,k) the prognostic momentum equation takes the form:

$$\frac{\partial u}{\partial t} = F + G_u \left(\frac{\sum_{n=1}^{N} W_n^2 \gamma_n (u_n - \hat{u}_n)}{\sum_{n=1}^{N} W_n} \right)$$



where the first term (F) on the right hand side of the equation is the normal forcing term for u, and the second term is an additional data nudging acceleration term, where:

$W_n = w_{Hn} w_{\sigma n} w_{tn}$
= weighting function made up of horizontal (w_{Hn}), vertical $(w_{\sigma n})$, and time (w_{tn}) weights;

$$w_{Hn} = \begin{cases} \dfrac{R_n^2 - D_n^2}{R_n^2 + D_n^2} & \text{for } D_n \le R_n ; \\ 0 & \text{for } D_n > R_n . \end{cases}$$

$w_{\sigma n}$ = decreases linearly with height from a value of 1 at the observation height to a value of 0 at another height (eg: 50 m);
w_{tn} = piecewise linear function within a specified time window (eg : ± 30 min), ranging from a maximum of 1 in the middle of the window to 0 outside;
$\hat{u}_n$ = model value of u interpolated to observation point;
u_n = measured station value of variable u;
G_u = nudging coefficient (s^{-1});
γ_n = data confidence factor [0,...,1];
R_n = station horizontal radius of influence (m);
D_n = distance from grid point to station location (m),
N = the number of station observations.

3. MAQS CASE STUDY DAY (9-10 FEBRUARY 1994)

The period 9-10 February 1994 was selected as a case study 'day' because of the observations of high ozone levels in the southwest of the Sydney Basin and the completeness of monitoring data. The days were characterised by a high pressure system off the NSW coast directing northerly gradient winds over the Sydney region. Profiles of wind at Mascot show that north-northeasterly flow occurred in the lowest 1,000 m throughout the period, backing with height to be westerly by 2,000-3,000 m. In the period, the high drifted slowly eastward but for modelling purposes, was considered to be stationary.

Overnight surface winds were light, and increased during the day with the passage of the sea breeze across the region. Winds at the coast were stronger than at inland sites, particularly overnight. Wind direction at the coast remained north-northeasterly throughout the day, while a light southerly flow was apparent in the western half of the basin overnight, with northeasterly to easterly winds in the afternoon sea breeze.

3.1 The Geostrophic Winds and Initial Conditions

Initial conditions and the geostrophic wind forcing are given in Table 1. Sea surface temperature was specified as 295 K, and the mean sea level pressure was 1,015 hPa. A surface roughness length of 1 m was used, and a soil moisture content of 0.20 was taken, based on an analysis of rainfall data for the previous 12 months at Mascot Airport.

Table 1. Profiles of geostrophic (and initial) wind speed and direction, and initial potential temperature and mixing ratio for 9-10 February 1994.

Height (m)	Wind Speed ($m\ s^{-1}$)	Wind Direction (°)	Potential Temperature (K)	Mixing Ratio ($g\ kg^{-1}$)
0	13	15	298	15.0
500	13	20	303	13.0
1,000	13	20	306	5.5
1,500	13	330	309	5.5
3,000	13	240	313	4.0
5,000	13	210	325	0.1

3.2 Data for Nudging

Surface (10 m) anemometers provided wind speed and direction throughout the study area: data from 17 sites were used. Temperature and solar radiation measurements were also available from eight sites.

The simulation with data nudging required the input of the hourly average measured wind data and associated variables. The other main inputs were a 10 km radius of influence (R_n), a nudging coefficient (G_u) of 0.002 s^{-1}, and an assumed data confidence factor (γ_n) of 1. Only surface winds were nudged, due to the lack of detailed wind profiles in the region.

3.3 Predictions of Winds and Temperatures at Sites

Scatter plots of predicted *vs* observed u- and v-components of the wind and temperature (T) for the final case study run, without and with data nudging were prepared. The results without nudging give R^2 correlation measures of 0.48, 0.39, and 0.89 for u, v, and T respectively: there is an over-prediction of low wind speeds, an under-prediction of high wind speeds, and an under-prediction of minimum temperatures. As would be expected, the changes in the solution due to nudging were most pronounced at the observation sites. The results, shown in Figure 5, give improved R^2 values of 0.73 and 0.68 for u and v respectively, and a slight deterioration in the temperatures with an R^2 value of 0.79.

If the constraint of exact time matching was relaxed (allowing the predictions to be shifted by one hour from the measurements), the degree of scatter reduced, resulting in R^2 values of 0.65, 0.55, and 0.93 without nudging, and 0.84, 0.75, and 0.91 with nudging, for u, v, and T respectively.

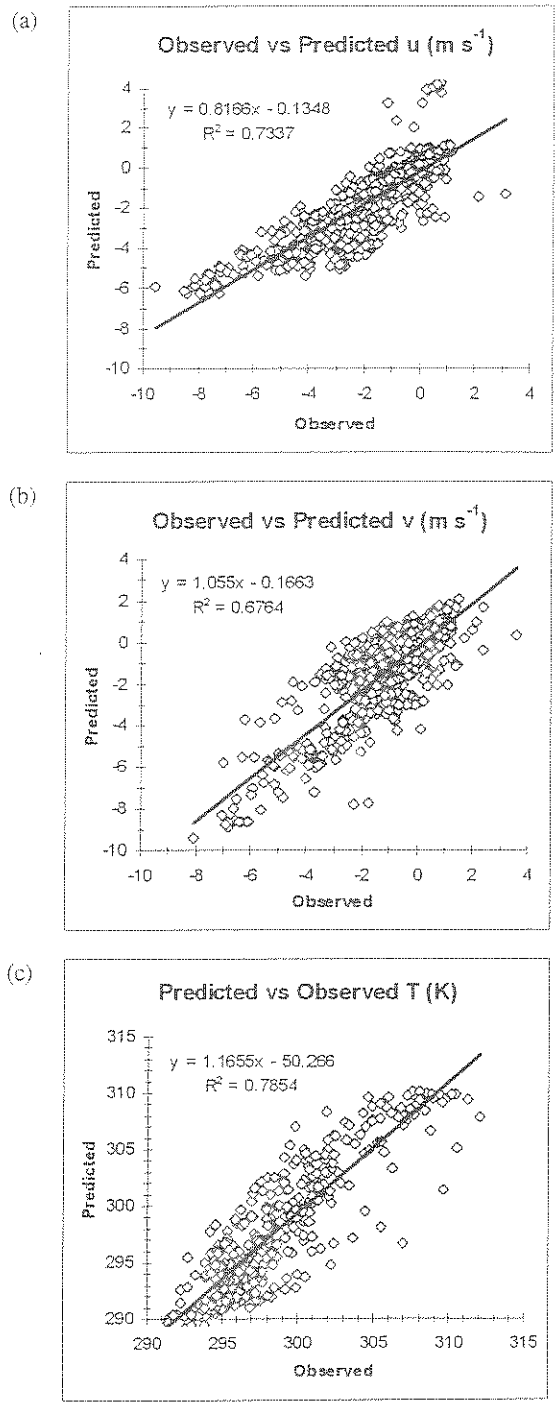


Figure 5. Scatter plots of (a) u-component, (b) v-component and (c) temperature at 17 monitoring sites in the Sydney Basin nudged for every hour of 9 and 10 February 1994.

Figure 6 shows a comparison of predicted versus measured wind speeds and directions for the case study without and with data nudging for the inland site of Liverpool. Generally, results on a site-by-site basis show a trend of light winds overnight and stronger northeasterly to easterly sea breeze flow during the afternoon. The strengths of the winds were predicted well at nearly all sites except for an overnight over-prediction on the western slopes of the basin, and a daytime overprediction at some central basin sites. The wind direction was generally predicted well when the wind speed was significant. Some of the differences may be explained by examining site locations and determining the importance of local effects not resolved by the model, such as channelling by small scale local terrain, and building effects.

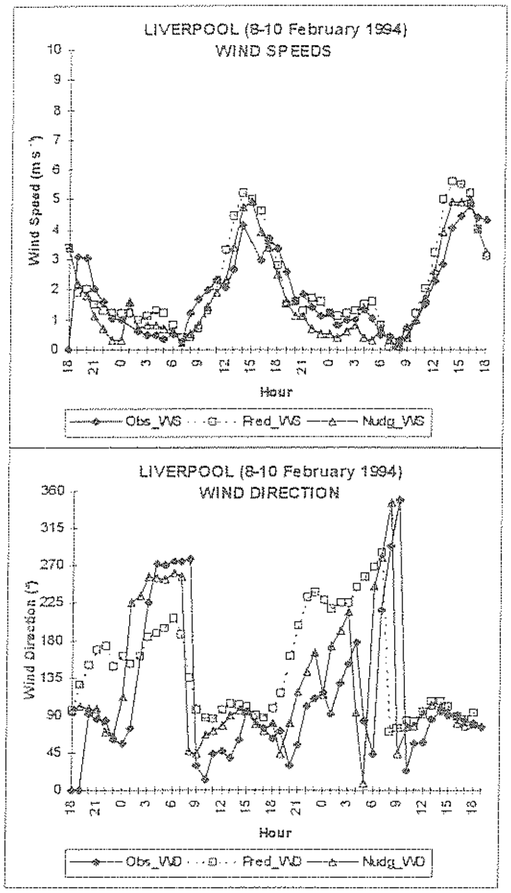


Figure 6. Comparison of observed wind speed and direction at the Liverpool air monitor with predictions from LADM.

3.4 Wind and Trajectory Predictions

Figure 7 shows an example of the predictions of winds at 1500 hr for the whole Sydney basin. By this time the sea breeze, which had formed at the coast by mid-morning, has travelled across much of the grid area producing northeasterlies at the coast and easterlies inland. The lighter north-easterly winds in the north of the western basin and the stronger easterlies to the south are a consistent feature of the predictions on many of the modelled days.

Three-dimensional dispersion calculations were performed for notional sources for the case study day to assist the interpretation of wind flow patterns and indicate pollutant trajectories from these sources. Trajectories were calculated using data from the nudged run with the Lagrangian particle model component of LADM.

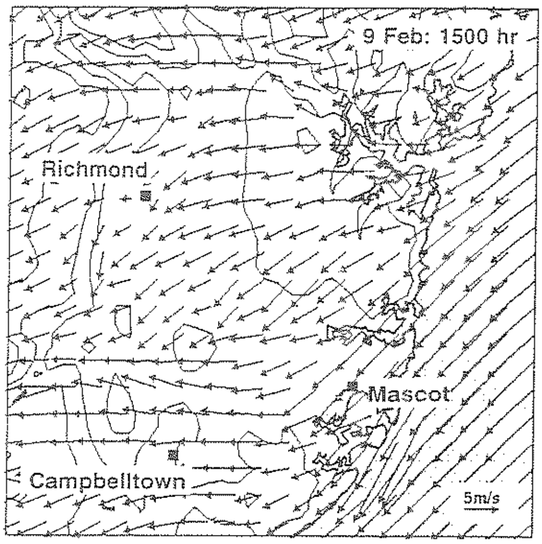


Figure 7. Predicted 10 m winds at 1500 hr in a simulation of 9 February 1994 in the Sydney Basin.

For the Sydney study region, particle releases from three notional sources were made (locations shown in Figure 2):

- Sydney central business district (CBD) area source;
- Inland Silverwater 200 m high point source;
- Southern Kurnell 200 m high point source.

Predictions of particle positions at 0600 hr on 9 February 1994 are shown in Figure 8. Overnight surface emissions from the CBD were caught in light northeasterly flow near the coast, travelled inland in an easterly flow, and then in light southerly flow in the western part of the basin: a consequence of terrain blocking of the winds (see *eg* Manins

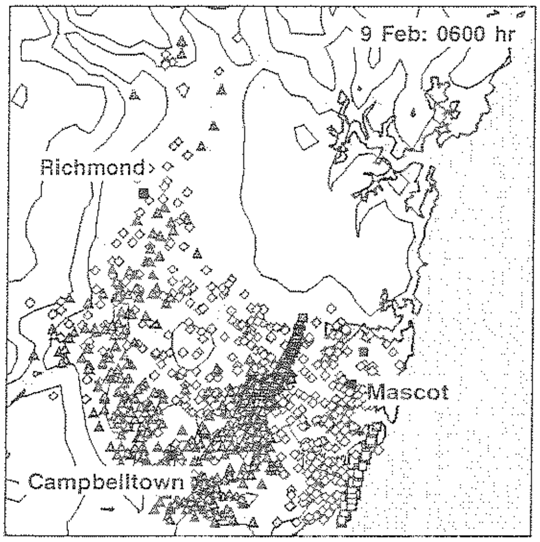


Figure 8. Predicted particle positions for an area source release from Sydney CBD ◊, and 200 m high point source releases from Silverwater □ and Kurnell Δ at 0600 hr in a simulation of 9 February 1994.

and Sawford, 1982). By sunrise, CBD pollutants are spread over most of the Sydney basin floor, covering the south-north extent of the grid domain and the west-east extent in southern Sydney; a broad L-shape pattern was formed. Even so, the majority of the particles are in the southern half of the basin. Pollutants from the notional source at Silverwater followed a similar path to the surface CBD emissions throughout the period. Particles from the source located at Kurnell travelled down the coast throughout the simulation.

Particles released from elevated sources on the Central Coast are predicted also to have entered the basin on 10 February. Overnight particles drifted over Sydney CBD and then followed the Silverwater particles northward in the western basin to Richmond and beyond. Later in the day they were predicted to have taken a more direct route to Richmond. The presence of emissions from either source could be the explanation of elevated sulfur dioxide readings recorded at Richmond at different times on that day.

3.5 Sensitivity of results

The specification of initial profiles of synoptic winds is only accurate to within approximately 2 m s^{-1} and 25°. This is due to the difficulty in interpreting synoptic pressure charts in slack gradient situations, and the need to eliminate any mesoscale effects from available measurements. The case study simulation was the result of a multitude of model runs, made in order to refine the initial and geostrophic conditions to produce model predictions in line with the detailed structure of the observed flow conditions. Geostrophic and initial wind directions below 1,000 m were varied between 10 and 30° with wind speeds varying between 7 and 15 m s^{-1}—final values used were 13 m s^{-1} and 15-20° in the lowest 1,000 m.

A major reason for choosing the selected run over the rest of the sensitivity runs was that the slightly more northerly wind direction in the lowest 500 m produced more northerly drift at around sunrise. This was a critical feature for the positioning of the urban plume to the south of the CBD. This enabled the sea breeze to transport the plume to the observed southern region by mid-afternoon. Aircraft ascent data from Mascot confirmed that the winds between the surface and 500 m showed significant north-northwesterly to northerly components. Such observations were more consistent with the selected run. These westerly component winds were not seen in the north-northeasterly surface winds both measured and predicted at the coast.

4. MECHANISMS LEADING TO HIGH POLLUTION

The following describes some of the major findings from the Meteorology - Air Movements task, determined by a combination of LADM modelling and data analysis.

4.1 Inter-regional transport

Poor dispersion days in Sydney also tend to be conducive to inter-regional transport, either to Sydney from the Newcastle region, or from Sydney to the Illawarra.

Southward transport of Newcastle and Sydney emissions

- During the afternoon, surface and elevated emissions within north-northeasterly synoptic winds and north-easterly sea breezes can travel overland from Newcastle and the Central Coast into the Sydney region. Pollutants could be trapped in stable layers over the basin overnight and be fumigated to the surface next morning.
- Under north-northwesterly synoptic flow conditions elevated emissions from Newcastle and the Central Coast, transported out to sea in offshore drainage flows, can be carried onshore over Sydney in the sea breeze.
- Elevated releases in the Upper Hunter Valley can travel to Newcastle under northerly synoptic winds if there is a westerly component to the synoptic flow (but not when there is an easterly component to the synoptic flow). Pollutants can be then carried into the Sydney basin within a northeasterly sea breeze. Or they can be transported directly to Sydney overnight, fumigating to the surface on the following morning.
- If there is a westerly component to the synoptic wind, Sydney surface and upper level emissions can be transported out to sea overnight and in the morning. Carried down the coast as a wide plume, the emissions can arrive off the Illawarra coast throughout the morning and afternoon. The sea breeze then brings this broad plume of pollutants ashore over several hours.

Northward transport of Sydney and Illawarra emissions

- Surface and elevated pollutant releases can travel from the Illawarra to the Sydney basin under nighttime conditions when synoptic winds have a southerly component.
- Surface and elevated pollutant releases can travel overnight from Sydney to Newcastle under southwesterly synoptic winds, and can be brought into Newcastle by the daytime sea breeze.
- Southerly synoptic change conditions can also transport Sydney or Illawarra emissions northward.

4.2 Locally poor dispersion

Sydney summertime conditions

- The movement of the sea breeze across the Sydney basin is consistent with the afternoon peaks of ozone observed in the sea-breeze front in the west and southwest parts of the Sydney basin.
- If there is no westerly component to the synoptic winds, Sydney emissions stay within the basin, spreading out from the coast to the western edge of the basin where they can be caught in southerly drainage flows and contribute to the observed morning build-up of ozone.
- The combined effect of overnight southerly drainage flows in western Sydney and northerly synoptic winds aloft, can induce a closed north-south vertical rotor

circulation. Sydney emissions caught in this circulation could be fumigated to the surface in the morning.

- In north-northeasterly synoptic winds, overnight blocking of stable flow by the topography of the Sydney basin leads to a clockwise circulation. The result is southerly flow up to 1,000 m deep in the western half of the basin. However, there are no upper level measurements available in the western region to confirm this effect, and winds at the coast give no indication, showing northeasterly flow at the coast.

Sydney wintertime conditions

- Winter poor dispersion days in Sydney with light westerly synoptic winds were shown to be prone to the accumulation of fine haze particles as a result of overnight trapping within light synoptic winds, late afternoon sea breezes, and cold-air drainage flow overnight.

Illawarra in poor dispersion conditions

- The observation of high readings of sulfur dioxide around Wollongong are consistent with Port Kembla emissions fumigating to the ground there in the late morning, as south-southwesterly offshore winds are displaced by an onshore southeasterly sea breeze.

Newcastle in poor dispersion conditions

- When northwesterly synoptic winds change to a southerly direction, emissions from Newcastle can be returned onshore as a result of the combined effect of southerly synoptic flow and a northeasterly sea breeze.

5. CONCLUSIONS ON PROGNOSTIC MODELLING

- The uncertainty in specifying surface synoptic meteorological data on high pollution days is very large (no better that approximately 2 m s^{-1} and 25°)—it is even larger aloft.

- While verification of LADM performance has been possible, absence of upper air data in key regions has left major predictions unvalidated.

- Even without assimilation of observational data, the ability of LADM to predict local winds and temperatures must be rated as very good.

- For smog modelling, where prediction of trajectories is required, it may well be that the necessary accuracy can only be achieved by incorporating observed surface and upper-air winds.

6. ACKNOWLEDGMENTS

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