Evaluation of The Air Pollution Model (TAPM): Comparison of Meteorological Predictions with Observations in Sydney.

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Abstract: The Air Pollution Model (TAPM) is a user-friendly, PC-based, prognostic meteorological and air pollution model which can be used to predict hourly meteorological parameters required to simulate air pollution episodes. For a selected day, meteorological observations from two air quality monitoring stations within the Sydney airshed were compared with predictions from the model. Overall, the local meteorological parameters predicted by TAPM correlated closely with the observed values.

1 Introduction

Ground-level ozone is formed as result of complex photochemical reactions that take place when reactive organic compounds (ROCs) and nitrogen oxides (NO_x) react in sunlight. Large amounts of these ozone precursors are emitted every day from anthropogenic and biogenic sources. Both urban and rural areas can have high ozone levels, depending on emissions, meteorological conditions and topography.

Meteorological conditions favourable to the formation of ozone usually occur during summer. Solar radiation, which together with high ambient air temperatures is an important factor in ozone formation, is highest during cloudless, summer days. Low wind speeds lead to poorer dispersion and generally result in increased concentrations of ozone. However, areas affected by the inland transport of emissions within sea breezes, or areas affected by long-range transport, can experience high ozone concentrations during periods of moderate winds. Strong temperature inversions aloft can cause low mixing heights and result in increased ozone concentrations.

Photochemical smog models require detailed, three-dimensional meteorological predictions to reproduce smog events accurately. Recent studies of smog formation have tended to use output from atmospheric numerical models. One such model, newly developed at CSIRO, is The Air Pollution Model (TAPM) (Hurley, 1998, 1999), which is used in this paper to predict meteorological parameters for a given day. These predictions have been compared with observations made at the New South Wales Environment Protection Authority (NSWEPA) air quality monitoring stations at Woolooware and Bringelly shown in Figure 1.

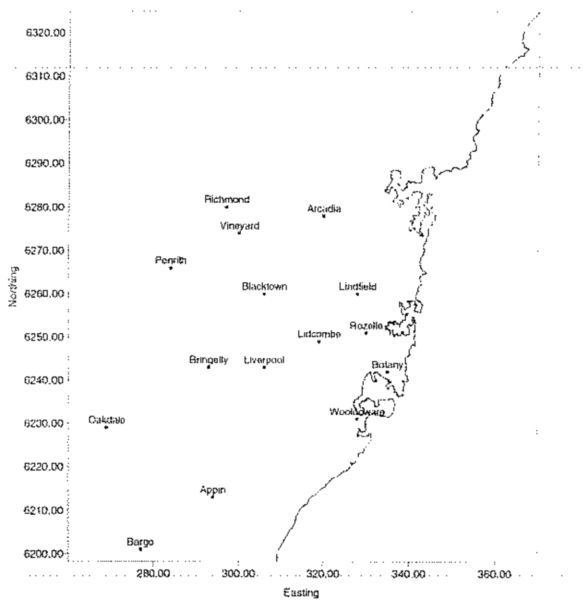

Figure 1: Map of Sydney Region showing locations of some air quality stations.

2 The Air Pollution Model (TAPM) Description

TAPM is a fast, PC-based, prognostic, three-dimensional meteorological and air pollution model that requires no local meteorological data (Hurley, 1998). The model is configured and run through a Graphical User Interface (GUI) connected to Australia-wide databases of surface characteristics and synoptic weather analyses. The model predicts three-dimensional time-varying fields of winds, temperature, humidity, cloud, mixing height, turbulence and air pollutant concentrations for a range of species.

The meteorological module included in TAPM solves the three-dimensional, terrain-following, incompressible, non-hydrostatic, primitive equations. Prognostic equations include the momentum equations for horizontal wind components, scalar equations for virtual potential temperature, the specific humidity of water vapour, cloud and rain water, and the equations for turbulent kinetic energy and rate of eddy dissipation. Diagnostic solution methods are used to determine the terrain-following vertical velocity and the Exner pressure function.

The air pollution module solves prognostic equations for concentration and for counter-gradient fluxes using predicted meteorological and turbulence fields from the meteorological module. Wet and dry deposition of pollutants are determined from the meteorological and air pollution predictions.

Gas phase photochemistry is based on the semi-empirical Generic Reaction Set (GRS) model (Azzi *et al.* 1992). The GRS model has been modified to include gas- and aqueous-phase reactions of sulfur dioxide and particles.

3 Example Simulation for Sydney

A model simulation of meteorology for 8th February 1997 is presented. The pattern of ozone occurrence across the Sydney region on this day is typical of many ozone events in Sydney (Hyde *et al.* 1997). On these days, ozone usually increases in the central and western regions to reach moderate levels within light northerly to north-easterly winds during the morning and early afternoon, increases abruptly with the onset of the sea breeze then decreases steadily during the afternoon and evening. On 8th February, hourly ozone concentrations reached 6 pphm during the morning, then increased to 10 pphm within the sea breeze. Maximum ozone concentrations were measured at Appin and Bargo in the southwest of the Sydney Basin (11.2 and 12.5 pphm respectively), in the late afternoon.

The simulation was carried out using TAPM with grids centred approximately 25 km north of Richmond, and using two nested grids with 10 and 5 km horizontal grid spacing. The model used a stretched vertical grid containing 20 levels, with a 10 m lower model level and 8000 m upper model level. The simulation used surface information automatically extracted from Australian databases (through the GUI), including synoptic information determined from the six hourly Limited Area Prediction System (LAPS) (Puri *et al.*, 1997) analyses for NSW.

An example of winds predicted by TAPM at the lowest model level of 10 m is shown in Figure 1. Three main regions of wind flow can be identified: a northerly synoptic wind in the west of the region, up-slope anabatic winds that result in the northerly synoptic winds turning north-north-easterly in the centre of the domain and increasingly north-easterly in the south, and an easterly to north-easterly sea breeze at the coast.

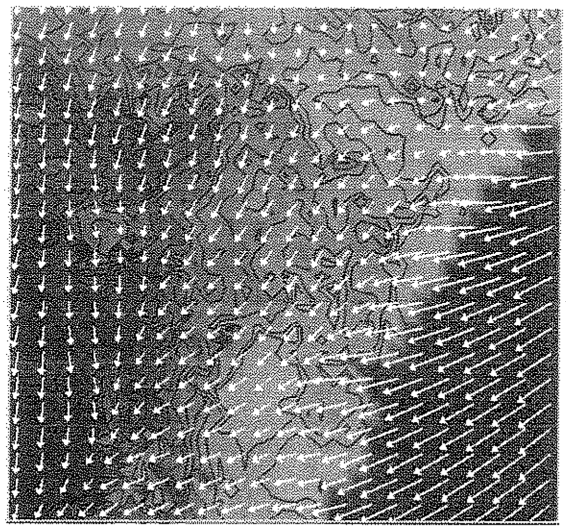

Figure 2: Sydney 5 km spaced inner grid domain showing predicted winds at 10 m model level at 1400 hours on 8 February 1997.

To illustrate the performance of the model, surface winds, temperatures and mixing heights predicted by the model on the 8th February have been compared with surface observations at Bringelly (in the west of the region) and Woolooware (near the coast on the southwest shore of Botany Bay). The only information about the variation of temperature with height in the lower atmosphere are radiosonde ascents measured at 0500 and 1400 hours Eastern Standard Time (EST) by the Bureau of Meteorology at Sydney Airport (approximately two kilometres west of Botany), and profiles measured by some commercial aircraft during take-off and landing.

3.1 Simulation of Meteorology at Bringelly

Comparisons between predicted and observed values of wind direction, wind speed and temperature are plotted in Figures 3, 4 and 5. Predicted and estimated values of mixing heights at Bringelly are plotted in Figure 6.

The observed wind direction and speed in Figures 3 and 4 show a light south-south-westerly drainage flow between midnight and 0600 hours, followed by northerly to north-easterly synoptic winds between 0700 and 1400 hours, and the onset of an easterly sea breeze between 1500 and 1600 hours. Model predictions of wind speed were mostly within 1 m/s of the observed values, except between 1800 and 2000 hours, when the predicted values were up to 2 m/s higher than the observations.

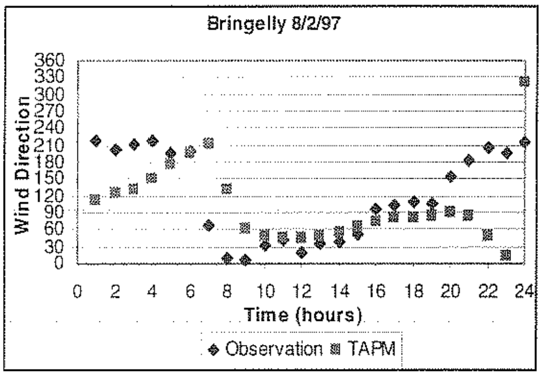

Figure 3 : Predicted and observed hourly wind Direction at Bringelly on 8 February 1997.

Between 1000 and 1900 hours, wind directions predicted by the model were close to the observed values. The model also predicted the drainage flow from the south-south-west between 0400 and 0600 hours. However, for the period between midnight and 0400 hours, the predicted wind directions were significantly different from those observed at Bringelly, but were similar to those observed west of a shallow topographic ridge that runs southward from Blacktown and between Liverpool and Bringelly. For this early morning period up until 0400 hours, it appears that the model was not predicting undercutting of the onshore flow by cold air drainage flow in the vicinity of Bringelly.

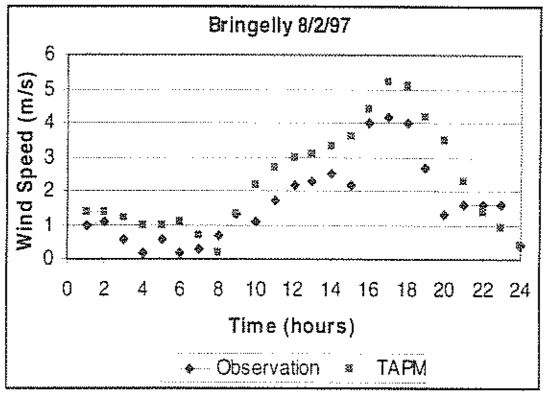

Figure 4 : Predicted and observed hourly wind Speed at Bringelly on 8 February 1997.

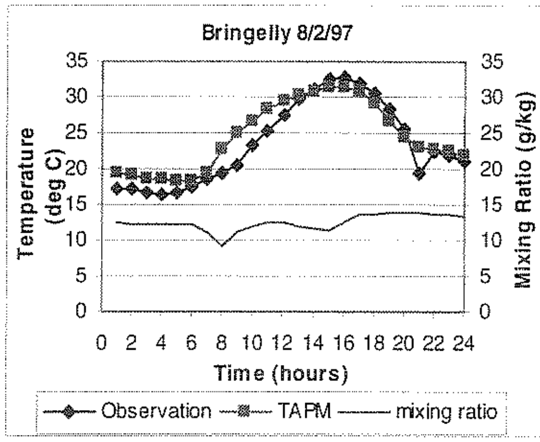

Figure 5 : Predicted and observed hourly temperature and calculated mixing ratio at Bringelly on 8 February 1997.

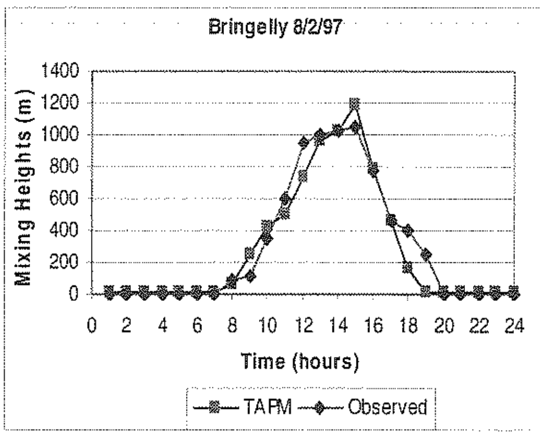

Figure 6 : Predicted and estimated hourly mixing height at Bringelly on 8 February 1997.

As it is shown in Figure 5, temperatures predicted by the model were in close agreement with the observed values, except for the period between 0800 and 1100 hours when predictions were 1°C to 5°C higher.

Predicted mixing heights in western Sydney on the basis of observations is extremely difficult because the only vertical temperature profiles are those observed at Sydney Airport, which is about 40 kilometres to the east. However, on the basis of the wind and temperature profiles at the coast and observed values of 2-minute average temperatures and mixing ratios at a number of locations across the region, it is possible to obtain an estimate of mixing heights away from the coast.

Predicted and estimated mixing heights at Bringelly were comparable between 0700 and 1300 hours. By 1500 hours the mixing height predicted by the model was approximately 180 metres higher than that estimated using both the temperature profiles at the coast and the 2-minute average values of mixing ratio and temperature at Bringelly. However, the mixing height predicted by the model for 1500 hours does, in fact, correlate reasonably well with the estimate obtained by using mixing ratio and temperatures measured at Penrith close to the lower Blue Mountains escarpment.

Estimated mixing heights following the onset of the sea breeze between 1400 and 1500 hours are similar to those predicted by the model. However, following the onset of a second sea breeze front at 1700 hours the estimated mixing heights are slightly greater than those predicted by the model.

It is worth noting, however, that estimating the depth of the mixing height across the Sydney Basin on the afternoon of 8th February is complicated by the inland movement of at least two separate sea breeze fronts across the southern half of the region, and a significant increase in the speed of sea breeze front between Bringelly and Oakdale. The first sea breeze front arrived at Bringelly around 1430 and the second at 1700 hours. It is difficult, therefore, to be confident about the estimated values of mixing height within the sea breeze at Bringelly.

3.2 Simulation of Meteorology at Woolooware

On occasions, the area around Woolooware is subject to high concentrations of ozone, but on most generic ozone event days, the ozone concentrations at the coast are low. This was the situation on 8th February 1997.

The predicted and observed values of wind direction, wind speed and temperature are plotted in Figures 7, 8 and 9, while predicted and estimated mixing heights are plotted in Figure 10. Overall, wind directions within the sea breeze predicted by the model were good, but at other times predictions differed from observations by between 30 and 40 degrees. Between midnight and 1100 hours the model predicted north-easterly winds. Over the same period, the observed wind directions were north-north-easterly between midnight and 0500 hours, followed by a period of northerly winds mixing down to the surface between 0500 hours and the onset of the sea breeze at 1030 hours. Wind speeds predicted by the model compared favourably with the observations between 0600 and 1800 hours, but under-predicted speeds by up to 1 m/s for a few hours after midnight, and over-predicted wind speeds after 1800 hours.

Temperatures predicted by the model were in close agreement with the observed values between midnight and 1100 hours but then diverged from the observations by up to 4°C within the sea breeze.

The most significant differences between the model predictions and observations were the values of mixing height plotted in Figure 10 from 0600 hours until the onset of the sea breeze between 1000 and 1100 hours.

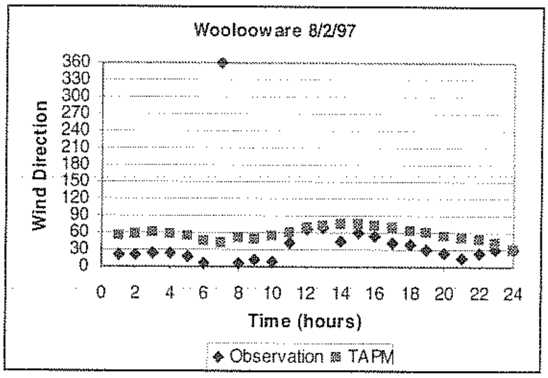

Figure 6 : Predicted and observed hourly wind Direction at Woolooware on 8 February 1997.

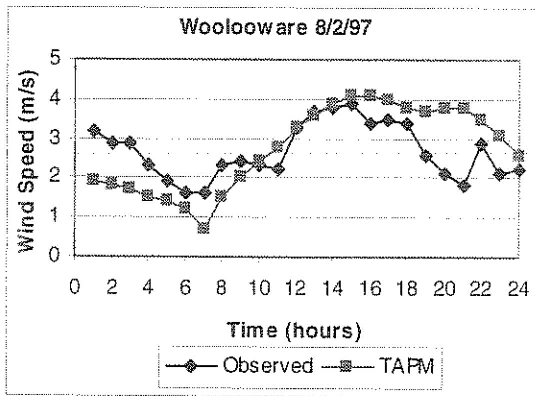

Figure 7 : Predicted and observed hourly wind Speed at Woolooware on 8 February 1997.

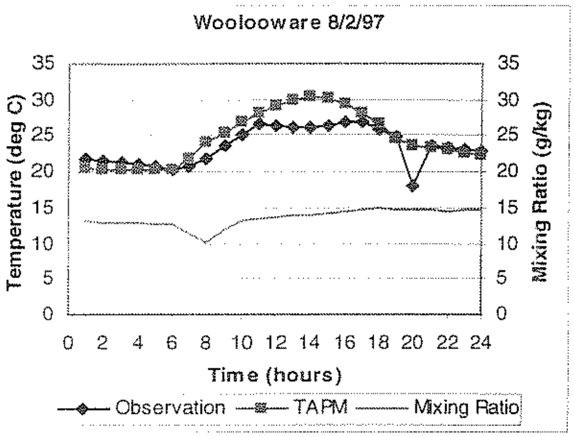

Figure 8 : Predicted and observed hourly Temperature and calculated mixing ratio at Woolooware on 8 February 1997.

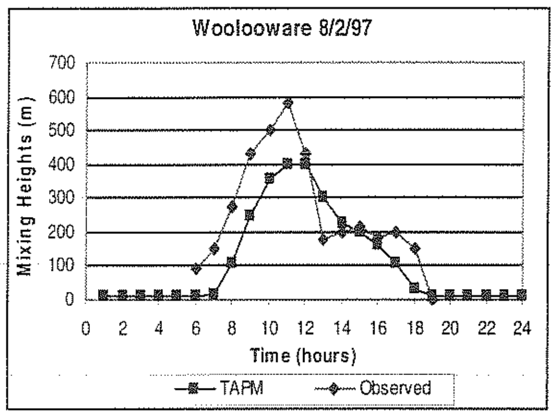

Figure 9 : Predicted and estimated hourly mixing height at Bringelly on 8 February 1997.

Woolooware is a similar distance away from the coast as Sydney Airport, so mixing heights estimated on the basis of the morning and afternoon radiosonde ascents at the Airport, and temperature and wind profiles measured by aircraft landing and taking off, are considered representative of conditions at Woolooware.

Because of its coastal location, the mixing height at Woolooware will be influenced by the direction of the wind direction and the time that the air has been moving over the heated land surface. Between 0600 and 1000/1100 hours the model predicted north-easterly flow off the ocean, while the 2-minute and hourly observations of wind direction showed northerly winds. It is this difference in wind directions that accounts for the difference between the predicted and estimated mixing heights. For example, between 0600 and 1000/1100 hours the model predicted onshore north-easterly flow.

Therefore, because of the proximity of Woolooware to the coast, the growth of the mixing layer as the cooler air moved onshore from the ocean across the heated land surface resulted in a fairly shallow mixing height being predicted. In contrast, the observed wind directions at Woolooware in this period were from the north, which would have carried the air over the heated land surface for a longer period of time and resulted in a deeper mixing height. Thus, the inaccuracy of the model in predicting mixing height was directly related to the difficulty in accurately predicting wind direction before the onset of the sea breeze.

4 Conclusions

This paper discusses the ability of TAPM to predict local meteorological parameters at two sites, one inland (Bringelly) and one at the coast (Woolooware), on a generic ozone event day in Sydney. For the day selected, 8th February 1997, the results predicted by the model were, in general, comparable with those measured at the two locations. The main exceptions were the inability of the model to correctly predict cold air drainage flow in the early hours of the morning at Bringelly, and the model predicting onshore north-easterly flow from the ocean at Woolooware before the onset of the sea breeze, when the observations, in fact, showed a period of several hours of northerly wind mixing down to the surface after sunrise. This resulted in a significant over-prediction of the mixing height during the morning because the actual trajectory of the air arriving at Woolooware during this period was over a heated land surface, whereas the model was predicting a trajectory that carried maritime air onshore.

5 References

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