TAPM V3 – Model Description and Verification

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ABSTRACT

Since the release of TAPM V2 (The Air Pollution Model Version 2) in April 2002, several improvements and enhancements have been made to the model. This paper outlines the changes in this enhanced version of the TAPM package (TAPM V3 – released in May 2005), which includes general enhancements to the GUI (Graphical User Interface), as well as changes to both meteorological and pollution aspects of the model. The major changes include: an optional offline-pollution mode; an update of microphysics and moisture processes; addition of a dust mode; an extension of the building wake algorithms to allow wake effects on all source types; an option to calculate pollution concentration variances; and a peak-to-mean ratio parameterisation. The performance of TAPM V3 will be summarised for several verification datasets, including Kincaid and Indianapolis tracer datasets in flat terrain, Bowline building downwash annual dataset, Lovett and Westvaco annual datasets in complex terrain, Anglesea and Kwinana annual datasets in coastal terrain, and Melbourne photochemical smog annual dataset in coastal and complex terrain. The results show that TAPM performs well for predictions of extreme (high) concentrations, and the consistently good performance of TAPM across a range of studies gives confidence in the use of the model for air pollution modelling applications, even when no local meteorological data is used for annual simulations.

Keywords: Meteorological modelling, Air pollution modelling, Verification studies, TAPM.

INTRODUCTION

Air pollution models that can be used to predict hourly pollution concentrations for periods of up to a year, as often required for regulatory purposes, are generally semi-empirical/analytic approaches based on Gaussian plumes or puffs, and usually either ignore chemistry or treat it very simply. They typically use either a simple surface-based meteorological file or a diagnostic wind field model based on available observations (e.g. ISC3 (EPA, 1995); AUSPLUME (EPA, 2000); CALPUFF (Scire *et al.*, 2000)), however the required meteorological information is not always available or not available in sufficient detail, which can make application of these models difficult. Moreover, for short-range dispersion under complex flow and diffusion conditions (e.g. in coastal regions or complex terrain), these types of models are either not applicable or the simple assumptions and extensions used therein lack generality. An alternative approach is to use airshed models and/or dispersion models coupled to prognostic meteorology from a mesoscale model (e.g. studies by: Physick and Noonan, 2000, using MM5; Moussiopoulos *et al.*, 2004, using MEMO) – for a summary of these types of models see Seaman (2000) and Russell and Dennis (2000).

The model presented in this paper, TAPM, is prognostic and uses the complete equations governing the behaviour of the atmosphere and the dispersion of pollutants. Until recently, the prognostic approach has been impracticable for use in regulatory modelling on PCs because of the time and computing resources required. But advances in computing power now make this approach realistic for simulations of extended periods at high resolution. TAPM uses large-scale weather information (synoptic analyses or forecasts) typically available at a horizontal grid spacing of 100km, as boundary conditions for the model outer grid. TAPM then 'zooms-in' to model local scales at a finer resolution using a nested approach, predicting local-scale meteorology such as sea breezes and terrain-induced flows. A prognostic approach eliminates the need to have site-specific meteorological data to drive the dispersion model, but allows assimilation of observations if desired. With TAPM, all input data sets, except emissions, accompany the model and are easily transferred through a graphical user interface to nested grids for the region of interest.

This paper presents an overview of the science behind the model, summarises the major changes in going from TAPM V2 to V3, and summarises model performance for a number of air pollution verification studies, including Kincaid and Indianapolis tracer datasets in flat terrain, Bowline annual dispersion dataset with building downwash, Lovett and Westvaco annual datasets of plume impact on complex terrain, Anglesea and Kwinana annual datasets in coastal terrain, and Melbourne urban photochemical smog dataset in coastal and complex terrain.

TAPM OVERVIEW

TAPM is a PC-based, nestable, prognostic meteorological and air pollution model driven by a Graphical User Interface (GUI). It was designed to be easy to use and fast to run, but also to be based on comprehensive science. Datasets of the important inputs needed for meteorological simulations accompany the model, allowing model set-up for any region, although user-defined databases can be connected to the model if desired. The only user-supplied data required for air pollution applications are emission information. The model outputs can be examined easily and quickly, with various types of output processing options provided.

TAPM uses the fundamental equations of atmospheric flow, thermodynamics, moisture conservation, turbulence and dispersion, wherever practical. For computational efficiency, it includes a nested approach for meteorology and air pollution, with the pollution grids optionally able to be configured for a sub-region and/or at finer grid spacing than the meteorological grid, which allows a user to zoom-in to a local region of interest quite rapidly. The meteorological component of the model is nested within synoptic-scale analyses/forecasts that drive the model at the boundaries of the outer grid. The coupled approach taken in the model, whereby mean meteorological and turbulence fields are passed to the air pollution module every five minutes, allows pollution modelling to be done accurately during rapidly changing conditions such as those that occur in sea-breeze or frontal situations. The use of integrated plume rise, Lagrangian particle, building wake, and Eulerian grid modules, allows industrial plumes to be modelled accurately at fine resolution for long simulations. Similarly, the use of a condensed chemistry scheme also allows nitrogen dioxide, ozone, and particulate mass to be modelled for long periods.

TAPM V2

TAPM V2 is a prognostic meteorological and air pollution model developed by CSIRO Atmospheric Research (Australia) (Hurley *et al.*, 2005a). Recent verification studies in published journal papers are for Kwinana (Hurley *et al.*, 2001) and Melbourne (Hurley *et al.*, 2003a) regions, and for Kincaid and Indianapolis international model inter-comparison datasets (Luhar and Hurley, 2003). Other recent verification studies published in conference proceedings are the dispersion studies in the Pilbara (Hurley *et al.*, 2003b) and Anglesea (Hill and Hurley, 2003). Two evaluation studies of predicted vertical profiles of winds against sodar observations

Table 1. Observed and Predicted RHC (Robust Highest Concentration) and MAX (Maximum Concentration) for each study. For Kincaid and Indianapolis, RHC and MAX are calculated for the arc-wise maximum concentrations (scaled by the emission rate) at several distances downwind of the source for all hours, with corresponding RMSE (root mean square error) over all distances/hours. For all other (annual) datasets, the monitoring site concentrations of annual RHC and MAX are averaged over all monitoring sites, with corresponding RMSE over all sites.

Extreme Statistics		RHC			MAX		
	#Sites	OBS	TAPM	RMSE	OBS	TAPM	RMSE
Kincaid Q2&3 SF_6 (scaled)	n/a	275	246	-	319	269	50
Indianapolis Q2 SF_6 (scaled)	n/a	1,248	1,367	-	1,154	1,289	262
Indianapolis Q2&3 SF_6 (scaled)	n/a	1,175	1,345	-	1,068	1,289	302
Bowline SO_2 ($\mu g\ m^{-3}$)	4	439	325	192	441	299	224
Lovett SO_2 ($\mu g\ m^{-3}$)	9	228	191	74	244	246	76
Westvaco SO_2 ($\mu g\ m^{-3}$)	11	1,852	1,455	691	1,735	1,762	426
Anglesea SO_2 ($\mu g\ m^{-3}$)	4	595	625	103	525	610	136
Anglesea 5-min SO_2 ($\mu g\ m^{-3}$)	4	-	-	-	1,232	1,306	270
Kwinana SO_2 ($\mu g\ m^{-3}$)	6	139	137	43	137	143	28
Kwinana 10-min SO_2 ($\mu g\ m^{-3}$)	6	-	-	-	241	231	57
Melbourne NOX (ppb)	8	483	408	156	480	407	151
Melbourne NO_2 (ppb)	8	75	77	13	76	76	8
Melbourne O_3 (ppb)	9	97	88	17	93	90	15
Melbourne 24-hr PM10 ($\mu g\ m^{-3}$)	5	49	45	8	48	44	7
Melbourne 24-hr PM2.5 ($\mu g\ m^{-3}$)	3	34	29	6	34	30	7

have also recently been published in journal papers for Kalgoorlie (Edwards *et al.*, 2004) and for the Pilbara (Physick *et al.*, 2004). A number of verification studies have also been conducted by TAPM users – see Hurley *et al.* (2005a) for references to some of these papers. Results from these studies have shown good model performance for both meteorology and air pollution predictions, particularly for the study of annual extreme (high) concentrations.

TAPM V3 enhancements

TAPM V3 was released in May 2005. A complete technical description of the model equations, parameterisations, and numerical methods are described by Hurley (2005), and a summary of some verification studies is given in more detail by Hurley *et al.* (2005c). TAPM has been enhanced in the following ways to produce TAPM V3:

- Inclusion of an optional offline-pollution mode to allow pollution to be run from saved meteorology, either for all grids (nested) or for only the inner-most grid;
- an update of microphysics and prognostic equations for cloud water/ice and rain/snow;
- addition of a dust mode for particle sizes PM2.5, PM10, PM20 and PM30;
- an extension of the building wake algorithms to allow wake effects on line, area/volume, and gridded emission sources;
- an option to calculate pollution concentration variances;
- a peak-to-mean ratio parameterisation to allow peak short-term averages to be estimated from hourly concentration mean and variance;
- changes to the minimum roughness length, synoptic scale moisture, turbulence in the top-half of the convective boundary layer, and the use of a more realistic minimum level of horizontal turbulence;
- an option to generate and post-process three-dimensional pollution output files;
- an option to provide an hourly-varying concentration file to the model as input boundary conditions;
- inclusion of an option to configure and run case studies with TAPM meteorology driving the CSIRO Chemical Transport Model (CTM) for urban airshed applications that may require more complex chemistry (e.g. Carbon Bond);
- numerous changes and enhancements to the GUI and model output post-processing utilities.

Some of these changes are improvements to the model, while others such as the off-line meteorology mode, the dust mode, the calculation of concentration variance and peak-to-mean ratios for averaging periods less than one hour, and the ability to optionally call the CSIRO CTM, are new features that extend the applicability of TAPM V3.

As it will be used in Section 3 to calculate 5-minute and 10-minute averaged peak-to-mean ratios for the Anglesea and Kwinana datasets, the procedure to calculate these values in TAPM will be described in some more detail (for full details see Hurley, 2005). TAPM V3 has an option to calculate concentration variance as well as the usual mean concentration fields, using a prognostic approach. Like the equation for mean concentration, this equation accounts for all stability regimes and all source types without the need to specifically parameterise for these conditions, unlike many current schemes. Peak concentrations are calculated using the commonly employed power-law relationship, but with an exponent that depends on concentration fluctuation intensity I_c (derived from the mean and variance of the concentration output from the model):

$$C_{MAX}(t) = C_{MAX}(3600)\left(\frac{3600}{t}\right)^{\min(0.1+0.25 I_C^{1/3},0.4)} \qquad (3)$$

with *t* the averaging period (s), and uses the general idea that the exponent should increase with increasing concentration fluctuation intensity. This new approach is consistent with the findings of Hibberd (1998), and it provides a general framework for predicting peak-to-mean values that does not explicitly depend on source type, distance from the source, or atmospheric stability – these dependencies are accounted for implicitly within the calculation of concentration mean and variance.

TAPM V3 evaluation

TAPM V3 has been assessed against some of the datasets used to verify earlier versions of TAPM (see below). TAPM V3 results are similar to, or in some cases better than, results from TAPM V2 (see Hurley *et al.*, 2005c, for more detail). Changes to the minimum roughness lengths used in the model have improved predicted wind speeds at 10m, while winds at higher levels and other mean meteorological variables are equally good for both versions. Turbulence in the upper half of the convective boundary layer, where some underestimation of turbulence was apparent in TAPM V2, has also been improved. The minimum level of horizontal diffusion has now been set to a more realistic value, which, in particular, allows a more realistic horizontal plume spread above the convective boundary layer and so better predictions of nocturnal inversion break-up fumigation.

TAPM V3 has also been re-run for a number of past verification studies including laboratory experiments of concentration mean and variance, and dispersion within building wakes, for Kalgoorlie sodar upper-level wind comparisons, for the Kincaid and Indianapolis international tracer studies (SF6), and for the following annual meteorological and air pollution evaluation studies: Anglesea 2002 and 2003 (SO_2); Kwinana

1997 (SO_2); Pilbara 1999 (NO_X, NO_2, O_3); and Melbourne (urban) July 1997 to June 1998 (NO_X, NO_2, O_3, PM10, PM2.5). Results from TAPM V3 were similar to, or in some cases better than, results from TAPM V2 – see Hurley *et al.* (2005c) for more detail. Since the release of TAPM V3, the model has been evaluated against a building downwash dataset (Bowline), and two complex terrain datasets (Lovett and Westvaco). Results from most of these studies are shown in the following sub-sections.

A model evaluation and inter-comparison of the latest versions of AUSPLUME, CALPUFF and TAPM has also recently been made by Hurley and Luhar (2005) for the Kincaid and Indianapolis datasets, and by Hurley *et al.* (2005b) for the Anglesea and Kwinana datasets.

Note that data assimilation of local wind observations has been used only for Kincaid and Indianapolis tracer studies, as they are not annual datasets. Results for these two studies, with and without data assimilation, (Luhar and Hurley 2003; Hurley *et al.*, 2005b) show that TAPM performs well for both options, but that results are slightly better when assimilation is used. Data assimilation has not been used for the annual datasets, as generally we have shown that the use of assimilation of local wind observations is not necessary for annual simulations (e.g. see Hurley *et al.*, 2003a), but that it can become more important when modelling shorter periods (particularly case studies). This idea is amply supported by the good results obtained for the annual datasets shown in Section 3.2 onwards, without using data assimilation.

Kincaid and Indianapolis tracer datasets in flat terrain

The Kincaid and Indianapolis point source dispersion datasets were collected in the 1980s in the US in relatively flat and horizontally homogeneous rural and urban locations respectively. For each study, monitors were set up in arcs surrounding isolated buoyant point sources to determine ground level concentrations. A quality indicator was assigned to each value, and the recommendation was that only data with quality indicator 2 (maxima identified) and 3 (maxima well defined) be used for model comparison. Out of a total of 1,284 arc-hours of Kincaid data, 585 are quality 2 and 3, and 338 are quality 3. Out of a total of 1,511 arc-hours of Indianapolis data, 1,216 are quality 2 and 3, and 469 are quality 3. Winds from a meteorological tower (for heights up to 100m) were assimilated into the model.

TAPM V2 has previously been evaluated against these datasets as described in Luhar and Hurley (2003), and here (Table 1) we show a sample of TAPM V3 results of arc-wise maximum ground level concentration extreme statistics for each study (see Hurley *et al.*, 2005c for more detail).

Results show that TAPM performs well for both Kincaid and Indianapolis studies with good prediction of the RHC (Robust Highest Concentration) and MAX (Maximum Concentration) – note that some minor over-prediction is expected for these data, as the finite spacing between monitors on each arc cannot determine the exact observed arc-wise maximum value. The RMSE (Root Mean Square Error) is also low compared to the magnitude of MAX. TAPM generally performs slightly better for the highest quality data (Quality 2&3). Other statistics of model performance including mean, normalised mean square error, correlation, and Index of Agreement (IOA) have also been calculated with good results (see Hurley *et al.*, 2005c, for more detail).

Bowline annual dataset in flat terrain with building downwash

The Bowline 1981 annual dataset consists of SO_2 measurements at four monitoring sites situated to the south of a power station in a river valley in New York (US) (Schulman and Hanna, 1986). The plant consists of two 87m high stacks, separated by a distance of 90m, and situated about 27m to the east of the main building, which is about 66m high, 140m wide and 76m deep. Peak concentrations due to building downwash effects occurred mainly at the two monitoring sites situated to the southeast of the plant.

TAPM was configured for the Bowline dataset using nested grids of 25 x 25 x 25 points down to a resolution of 1,000m for meteorology, and using nested grids of 21 x 21 x 21 points down to a resolution of 100m for pollution, using default model settings and databases, with the exception of the NCEP synoptic reanalyses data. The Lagrangian particle module was used to represent near-source dispersion. Building dimensions and characteristics for the standard five building blocks of this dataset were used. TAPM was run without using local meteorological observations (i.e. meteorological data assimilation was not used).

Table 1 summarises the extreme concentrations (RHC and MAX) for the average and RMSE over all monitoring sites, for observations (OBS) versus TAPM. It is clear from these results that TAPM performs acceptably with good average and reasonably low RMSE for each of the statistics, although there is a slight under-prediction of the RHC and MAX overall. As indicated by the RMSE, model performance has more variability between sites than for most of the other studies considered, which is probably an indication of the uncertainty in building downwash parameterisations used in all air pollution models.

Lovett and Westvaco annual datasets in complex terrain

TAPM was run for the Lovett and Westvaco datasets using nested grids of 25 x 25 x 25 points down to a resolution of 300m for both meteorology and pollution, using default model settings and databases, with the exception of three-second resolution USGS terrain data and NCEP synoptic reanalysis data. The Lagrangian particle module was used to represent near-source dispersion. Note that the simulation of these datasets was performed without using local meteorological observations (i.e. meteorological data assimilation was not used).

Lovett

The Lovett 1988 annual dataset consists of SO_2 measurements at a number of monitoring sites situated mainly on Dunderberg Mountain to the north of the Lovett power station in southeastern New York state (US) (Paumier *et al.*, 1992). The difference in terrain height between the base of the Lovett stack and the highest sites on the mountain was approximately 300m, and the monitoring sites range in distance from 2–4km from the stack. Peak concentrations at the monitoring sites occur under southerly winds and mainly during stable conditions at night, although some daytime events were also observed.

Table 1 summarises the extreme concentrations (RHC and MAX) for the average and RMSE over all monitoring sites, for observations (OBS) versus TAPM. The results show that TAPM performs well with good average and small RMSE for each of the statistics, although there is a slight under-prediction of the RHC overall.

Westvaco

The Westvaco December 1980 – November 1981 annual dataset consists of SO_2 measurements at a number of monitoring sites situated mainly on a mountain range to the southeast of the Westvaco power station in Maryland state (US) (Strimaitis *et al.*, 1987). The difference in terrain height between the base of the Westvaco stack and the highest sites on the mountain was approximately 350m, and these monitoring sites range in distance from 0.8–1.6km from the stack. Peak concentrations at the monitoring sites occur under northwesterly winds and stable conditions at night. There were three other monitoring sites that were at varying distances to the north, northeast and northwest of the power station, respectively.

Table 1 summarises the extreme concentrations (RHC and MAX) for the average and RMSE over all monitoring sites, for observations (OBS) versus TAPM. The results show that TAPM performs acceptably with good average and small RMSE for each of the statistics, although (as for Lovett) there is a slight under-prediction of the RHC overall. Model performance has more variability between sites than for other studies, which is an indication of the complexity of the region.

Anglesea and Kwinana annual datasets in coastal regions

Anglesea

TAPM V3 has been re-run (see Hill and Hurley, 2003, for TAPM V2 results) for the Anglesea 2002 and 2003 annual datasets which have two monitoring sites to the south of the Anglesea power station. One site (School) is located on the northern edge of the Anglesea township, and the other site (Ingoldsby) is located to the west of the township and further away from the source. The coastline also lies at the southern edge of the township, however dispersion affecting the two monitoring sites only occurs under northerly winds so that concentrations at these two sites occur for neutral or convective dispersion conditions, rather than under sea breeze flow. Note that the simulation of this dataset was done without using local meteorological observations (i.e. meteorological data assimilation was not used).

Table 1 summarises the extreme concentrations (RHC and MAX) for the average and RMSE over all monitoring sites and the two years, for observations (OBS) versus TAPM. TAPM performs well with very good average and small RMSE for each of the statistics. TAPM over-predicts the MAX to some extent, however MAX is usually a more volatile statistic to predict.

Table 1 also shows the performance of the model when estimating maximum concentration for five minute-averaged concentration. The results show that the peak 5-minute averaged predictions perform as well as the predictions for the hourly-averaged results. The predicted peak-to-mean power-law exponent, averaged over the two sites for 2002 and 2003, was 0.31, compared to the average observed exponent of 0.34 – in better agreement with the data than the more commonly used generic exponent of 0.20 (see Hibberd, 1998, for more discussion).

Kwinana

TAPM V3 has been re-run (see Hurley *et al.*, 2005a, for TAPM V2 results) for the Kwinana 1997 annual dataset. The dataset includes data from six monitoring sites situated mostly inland to the east of the Kwinana Industrial Complex – the Complex has twenty point sources spread along the Kwinana coastline. Pollution impact at the monitoring sites is dominated by shoreline fumigation processes. Note that the simulation of this dataset was done without using local meteorological observations (i.e. meteorological data assimilation was not used).

Table 1 summarises the extreme concentrations (RHC and MAX) for the average and RMSE over all monitoring sites, for observations (OBS) versus TAPM. Once again, TAPM performs well with very good average and small RMSE for each of the statistics. Some over-prediction is apparent at Abercrombie Rd, however the maximum observed concentration at this site was unusually large in 1997 compared to other years.

Table 1 also shows the performance of the model when estimating maximum concentration for 10 minute-averaged concentration, using the new concentration variance and peak-to-mean concentration options. The results show that the peak 10-minute averaged predictions perform as well as the predictions for the hourly-averaged results. The site-averaged peak-to-mean power-law exponent predicted by the new procedure was 0.27, compared to the observed exponent of 0.31 – in better agreement with the data than the more commonly used generic exponent of 0.20 (see Hibberd, 1998, for more discussion).

Melbourne urban photochemical annual dataset

Melbourne is a coastal city in the southern part of Victoria, with ocean to the south and mountains to the north. The EPA Victoria operates an air monitoring network covering the urban region of Melbourne, and measures both near-surface meteorology and air pollution. Here we summarise the results from TAPM V3 modelling of year-long (July 1997 to June 1998) meteorology and photochemical air pollution in Melbourne (Hurley *et al.*, 2003a, 2005c), which was an update/extension of the verification component of the work performed as part of the EPA Victoria Air Quality Improvement Plan.

The emissions inventory covered Melbourne and Geelong, as well as major point sources in the Latrobe Valley about 100km east of Melbourne. It represents emissions for all pollutants on approximately a 1km spaced grid for vehicle, commercial and domestic emissions, as well as a point-source inventory, and a biogenic-emission inventory on a 3km spaced grid (nitrogen oxides and hydrocarbons only). The emission inventory was developed for the Melbourne region by EPA Victoria for both general EPA use, and for use by the Australian Air Quality Forecasting System (AAQFS). Non-zero background concentrations were used for ozone (15ppb), smog reactivity (Rsmog = 0.7ppb) and particles (10 $\mu g\ m^{-3}$ for PM10 and 5 $\mu g\ m^{-3}$ for PM2.5, to account for dust and sea salt emissions not in the inventory), and the standard reactivity coefficient for Rsmog of 0.0067 was used for all VOC emissions.

Ground-level pollution results for hourly average NO_2 and O_3, and for daily average PM10 and PM2.5, were extracted from the nearest grid point to each of the monitoring sites on the inner grid (1.5km spacing), and are summarised for site-averaged RHC and MAX in Table 1. The results show that TAPM simulations of the RHC and MAX are good for all species, with low RMSE indicating good site-by-site prediction as well. In particular, the NO_2 and O_3 extreme annual statistics are predicted very well, giving confidence in the (highly condensed) GRS photochemical mechanism and the emission inventory for this study.

SUMMARY AND CONCLUSIONS

The update of TAPM from V2 to V3 has led to some improvements to various aspects of the modelling system, and has extended the types of applications for which TAPM can be used to include faster multiple scenario pollution modelling using the off-line meteorology mode, dust modelling, peak-to-mean estimation for averaging times less than one hour, and episodic urban airshed modelling with more complex chemistry (via the CTM).

It has been illustrated here that TAPM V3 performs well for a number of model evaluation and inter-comparison studies, using quality datasets where both hourly-varying emission rates and air quality monitoring data are well known (e.g. Kincaid and Indianapolis flat terrain datasets; Bowline building downwash annual dataset; Lovett and Westvaco annual complex terrain datasets; Anglesea and Kwinana annual coastal datasets; Melbourne photochemical smog annual dataset). Other datasets have also been re-run with TAPM V3 with good results (e.g. wind tunnel datasets, the Kalgoorlie sodar dataset and the Pilbara photochemical smog dataset – see Hurley *et al.*, 2005c, and associated references).

The results from these studies show that TAPM exhibits consistently good performance across multiple studies, even when local meteorological data are not assimilated into annual simulations. The results show that TAPM performs well in coastal, inland, and complex terrain, and for a range of important phenomena such as general dispersion in convective, neutral and stable conditions, nocturnal inversion break-up fumigation, shoreline fumigation, plume impact on hills, dispersion within building wakes, and for general dispersion in complex rural and urban conditions. In particular, TAPM performance is very good for the prediction of extreme pollution statistics, important for environmental impact assessments, for both non-reactive (tracer) and reactive (nitrogen dioxide, ozone and particulate) pollutants for a variety of sources (e.g. industrial stacks and surface or urban emissions).

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REFERENCES

Edwards M., Hurley P.J, and Physick W.L. (2004). Verification of TAPM meteorological predictions using sodar data in the Kalgoorlie region. Australian Meteorology Magazine, 53, 29–37.

EPA (1995). Users guide for the Industrial Source Complex (ISC3) dispersion models. Volume 1 – User instructions. US Environmental Protection Agency, EPA–454/B–95–003a.

EPA (2000). AUSPLUME Gaussian Plume Dispersion Model: Technical User Manual. Environment Protection Authority of Victoria, Australia.

Hibberd M. (1998). Peak-to-mean ratios for isolated tall stacks (for averaging times from minutes to hours). *Proceedings of the 14th International Clean Air and Environment Conference of CASANZ, Melbourne*, Australia, 19-22 October 1998.

Hill J. and Hurley, P. (2003). The use of TAPM at Anglesea. *Proceedings of the National Clean Air Conference of CASANZ, Newcastle*, Australia, 23-27 November 2003.

Hurley P. (2005). The Air Pollution Model (TAPM) Version 3. Part 1: Technical Description. CSIRO Atmospheric Research Technical Paper No.71.

Hurley P., Blockley A. and Rayner K. (2001). Verification of a prognostic meteorological and air pollution model for year-long predictions in the Kwinana region of Western Australia. Atmospheric Environment, **35**, 1871–1880.

Hurley P., Manins P., Lee S.,'Boyle R., Ng Y. and Dewundege P. (2003a). Year-long, high-resolution, urban airshed modelling: Verification of TAPM predictions of smog and particles in Melbourne, Australia. Atmospheric Environment, **37**, 1899-1910.

Hurley P., Physick W., Cope M., Borgas M., and Brace P. (2003b). An evaluation of TAPM for photochemical smog applications in the Pilbara region of WA. *Proceedings of the National Clean Air Conference of CASANZ, Newcastle*, Australia, 23-27 November 2003.

Hurley P.J., and Luhar A.K. (2005). An evaluation and inter-comparison of AUSPLUME, CALPUFF and TAPM. Part I: The Kincaid and Indianapolis field datasets. *Clean Air and Environmental Quality*, **39**, 39-45.

Hurley P., Physick W., and Luhar A. (2005a). TAPM – A practical approach to prognostic meteorological and air pollution modelling. Environ. Modelling and Software, 20, 737-752.

Hurley P., Hill J., and Blockley A. (2005b). An evaluation and inter-comparison of AUSPLUME, CALPUFF and TAPM. Part II: Anglesea and Kwinana annual datasets. *Clean Air and Environmental Quality*, 39, 46-51.

Hurley P., Physick W., Luhar A. and Edwards M. (2005c). The Air Pollution Model (TAPM) Version 3. Part 2: Summary of some verification studies. CSIRO Atmospheric Research Technical Paper No.72.

Luhar A.K. and Hurley P.J. (2003). Evaluation of TAPM, a prognostic meteorological and air pollution model, using urban and rural point-source data. *Atmospheric Environment*, **37**, 2795-2810.

Moussiopoulos N., Helmis C.G., Flocas H.A., Louka P., Assimakopoulos V.D., Naneris C. and Sahm P. (2004). A modelling method for estimating transboundary air pollution in southeastern Europe. *Environmental Modelling & Software*, **19**, 549-558.

Paumier J.O., Perry S.G. and Burns D.J. (1992). CTDMPLUS: A dispersion model for sources near complex topography. Part II: Performance characteristics. *Journal of Applied Meteorology*, **31**, 646-660.

Physick W.L. and Noonan J.A. (2000). Mesoscale Modelling with MM5 for the PATH study (pollutants in the atmosphere and their transport over Hong Kong). *Proceedings of the 11th joint conference on the applications of air pollution meteorology with the A&WMA*, Long Beach, California, USA, 90-95.

Physick W.L., Rayner K.N., Mountford P., and Edwards M. (2004). Observations and modelling of dispersion meteorology in the Pilbara region. *Australian Meteorological Magazine*, 53, 175-187.

Physick W.L., Noonan J.A., McGregor J.L., Hurley P.J., Abbs D.J., and Manins P.C. (1994). LADM: A Lagrangian Atmospheric Dispersion Model. CSIRO Atmospheric Research Technical Paper No.24. 137 pp.

Russell A. and Dennis R. (2000). NARSTO critical review of photochemical models and modelling. *Atmospheric Environment*, **34**, 2283–2324.

Scire J., Strimaitis D. and Yamartino R. (2000). A users guide for the CALPUFF dispersion model (version 5). Earth Tech, Inc., Concord MA.

Seaman N. (2000). Meteorological modelling for air-quality assessments. *Atmospheric Environment*, **34**, 2231–2259.

Strimaitis D.G., Paine R.J., Egan B.A., and Yamartino R.J. (1987). EPA complex terrain model development: Final report. US EPA Report No. EPA/600/3-88/006, 486 pp.

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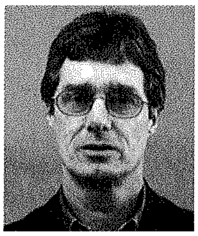

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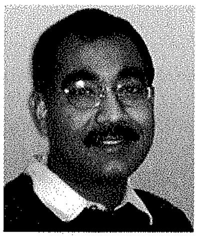

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