DEVELOPMENT OF THE AUSTRALIAN AIR QUALITY FORECASTING SYSTEM: CURRENT STATUS

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ABSTRACT
The Australian Air Quality Forecasting System (AAQFS) is currently under development. The numerical system will produce high-resolution, meteorological and air quality forecasts for the major urban areas of Australia, and will initially be tested in Melbourne and then demonstrated in Sydney during the 2000 Olympics. The AAQFS will be used to generate twice daily, 24-36 hour air quality forecasts at an effective resolution of a few kilometres. A range of air pollutants will be forecast, including photochemical smog, fine particulate matter and air toxics. The air quality forecasts will be provided to the EPAs, greatly enhancing their ability to provide relevant air quality information to the public. Here, we provide a brief description of the design and current status of AAQFS development, and present examples of system operation for the Sydney region.

INTRODUCTION
The Australian Air Quality Forecasting System (AAQFS; 1) is being developed with funding from the *Air Pollution in Major Cities Program*. The AAQFS project was formally launched in May 1998 by the Federal Minister of the Environment. Its short-term goal is to develop, validate and trial an accurate, next-day (24-36 hour) numerical air quality forecasting system for a three-month demonstration period in Sydney, which includes the 2000 Olympics. Trialing of the system in Melbourne is being undertaken during the development period. In the longer term, the AAQFS will be available for forecasting health- and visibility-related air quality metrics in the other major population centres of Australia. Principal project partners are the Bureau of Meteorology (BoM), CSIRO, Environment Protection Authority of Victoria (EPA-VIC) and the Environment Protection Authority of New South Wales (EPA-NSW).

The project has a number of specific goals: to provide the ability to generate 24-36 hour air quality forecasts twice per day (available 9 am and 3 pm); provide forecasts for a range of air pollutants including oxides of nitrogen (NO_x), ozone (O_3), sulfur dioxide (SO_2), benzene, formaldehyde and particulate matter (PM10 and PM2.5); provide forecasts at a resolution sufficient to consider sub-urban variations in air quality; and to provide the ability to generate simultaneous forecasts for a ‘business-as-usual’ emissions scenario and a ‘green emissions’ forecast. The latter may correspond to a minimal motor vehicle-usage scenario and will be used to indicate the reduction in population exposure that could result from a concerted public response to a forecast of poor air quality for the next day.

In this paper, we provide a brief description of the AAQFS and indicate how the system is evolving from the pilot status, through to the final demonstration system that will be used during the Sydney 2000-Olympics. A description of the forecasting methodology is given in the next section, and is followed by some indicative comparisons of Sydney-based air quality observations and preliminary forecasts.

METHODOLOGY
The AAQFS consists of five major components (Figure 1): a numerical weather prediction system (NWPS), an emissions inventory module, a chemical transport model (CTM), an evaluation module, and a data archiving and dissemination module. The development of the AAQFS is proceeding in two phases: 1) the construction and operation of a pilot system using components that were available at the time of study inception; and 2) the development of a demonstration system, through the enhancement of components in the pilot system, and where necessary, through the construction of new modules. We note that resources were allocated to first implement a pilot system in order to provide a preliminary indication of system performance. This has enabled important areas of development to be identified prior to the design and construction of the demonstration system.

As indicated in Figure 1 the principal difference between the pilot and demonstration systems (see also Table 1) is the number of processes that are run online (i.e. as modules that are called directly by the NWPS). For example, in the demonstration system (Figure 1b), a large component of the emissions modelling, and all of the chemical transport modelling, is conducted online. This contrasts with the pilot system (Figure 1a), where a meteorological forecast is first completed, stored and post processed prior to the execution of the chemical transport model.

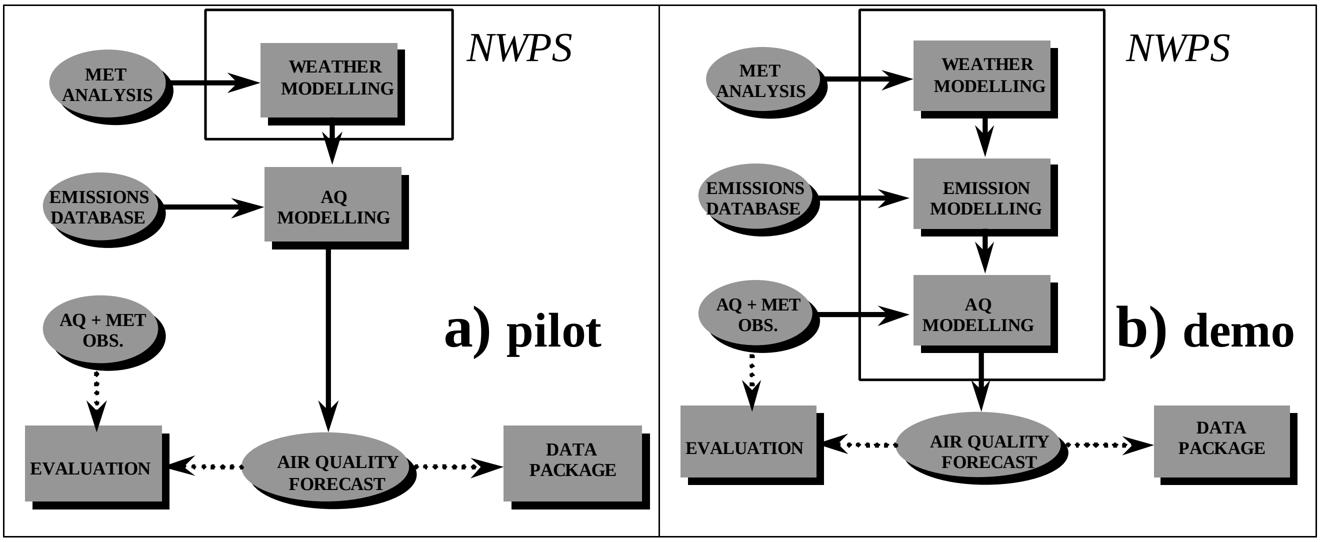

Figure 1: Schematic of pilot (a) and demonstration (b) forecasting systems. Note that modules located within the bounding-box labeled 'NWPS' correspond to components that are run online during a meteorological forecast.

The Bureau of Meteorology Limited Area Prediction System (LAPS; (2)) constitutes the NWPS in both the pilot and demonstration systems. LAPS is a hydrostatic model with state-of-the-art numerics and physics packages, and has been used by BoM to generate operational meteorological forecasts since July 1996. Meteorological forecasts will be provided at a horizontal resolution of 0.05° (LAPS05; 0.05° is approximately 5 km). A list of enhancements that are likely to be made to LAPS during the project is given in Table 1. Note that these enhancements are part of an on-going development program that is conducted by BoM's research arm (BMRC). From Table 1 it can be seen that the resolution and treatment of surface processes will be substantially enhanced by the time the demonstration system is in operation. Such enhancements may be expected to lead to improved representations of local and mesoscale flows and boundary-layer growth. Accurate representations of these processes are crucial for realistic, high-resolution forecasting of air pollution dynamics.

EPA-VIC and CSIRO, with support from EPA-NSW, are undertaking emission inventory development. As noted in Table 1, the pilot system uses a cut-down version of the Metropolitan Air Quality Study (MAQS) 1992 3-km emissions inventory (3) that has been lumped to 6-km resolution. All emissions processing for the pilot system is undertaken offline with no allowance made for week/weekend or seasonal/local meteorological dependencies. The demonstration system will use size-fractionated and speciated particle emissions (the MAQS inventory has a single lumped TSP species), 0.01° (approximately 1-km) gridded area sources over the densely population regions and meteorologically dependant emissions that are generated online during NWPS operation (see Figure 1b). A power-based vehicle emissions model, being developed at CSIRO, will be used to generate road-specific vehicle emission fluxes for the purpose of near-road impact modelling.

The Carnegie Mellon, California Institute of Technology (CIT) photochemical airshed model (4) comprises the pilot CTM. This model was adapted and applied to the prediction of photochemical smog production over the Newcastle/Sydney/Wollongong region for MAQS (5). A notable modification is the implementation of the compact GRS photochemical mechanism (6), which enables rapid turn-around times for the CTM modelling. For NSW forecasting, the pilot system CTM domain covers the greater-MAQS region at a horizontal resolution of 6 km (see Figure 3). The domain is divided into 10 non-uniform levels in the vertical (extending to 2000 m above ground level). The pilot system has been used to generate 24-hour air quality forecasts (NO_x, ozone and SO_2) using the 1100 UTC (2100 EST) LAPS05 forecasts. In the demonstration system, the CTM modelling will be conducted online using LAPS05 transport fields that are updated at 5-10 minute intervals. Note that the CTM simulations for NSW will use a 0.05° outer grid, with nested inner 0.01° grids for Newcastle, Sydney and Wollongong. Photochemical smog production will be simulated using an enhanced version of the GRS mechanism and particle transformation will be modelled using a modal-based particle scheme. A more comprehensive treatment of both processes will also be available in an offline version of the CTM.

Both the meteorological and air quality forecasts are the subject of on-going and case-specific validation. This has already commenced for the pilot system through comparison of LAPS meteorological fields with METAR/SYNOP (near-surface) and AMDAR (vertical profile) data and meteorological observations from the EPA monitoring networks. Air quality forecasts are compared against 1-hour EPA observations for NO_x (both as nitric oxide and nitrogen dioxide) and ozone. This will be expanded for the demonstration system to include SO_2, PM10, PM2.5, CO and (where available) non-methanic hydrocarbons. Critical to the validation process has been the availability of EPA data sets by the end of each forecast period, enabling the on-going validation to be substantially automated.

Data archiving will evolve from use of native system formats in the case of the pilot system (already NetCDF in the case of LAPS) to unified NetCDF data packets, which will be accessible via GUI-driven Q&A software. Sufficient information will be available in a data packet to enable the CTM to be run offline at a later time. The EPAs will have access to the daily forecasts via the AAQFS Web Site and will control the dissemination of the forecast data.

Table 1: Important components of the Pilot and Demonstration forecasting systems.

Pilot System	Demonstration System
Meteorological Modelling *LAPS05 (2)* *Simple local turbulent mixing scheme.* *Parameterised surface flux scheme.* *No vegetation.* *Uniform soil properties.* *Same roughness length for momentum, heat and moisture.* *Smoothed topography (interpolated from 0.10^o grid).* *Interpolated initialisation from analysis at 0.75^o resolution.* *0.05^o horizontal computational grid with 19 vertical levels.*	*LAPS05 (2)* *Non-local turbulent mixing scheme for convective conditions.* *Direct calculation of surface fluxes.* *Vegetative effects included (32 vegetation/land use categories at 0.05^o resolution).* *Horizontal variation in soil (8 soil texture/hydraulic categories at 0.05^o resolution).* *Separate roughness lengths for momentum, heat and moisture.* *High resolution topography (based on 0.008^o data).* *Improved initialisation scheme and boundary conditions.* *0.05^o horizontal computational grid with 29 vertical levels (higher resolution experimental, offline meteorological model, resources permitting).* *Online emissions and air quality modelling code.*
Emissions Modelling *MAQS 1992 emissions inventory (3).* *Modelled species- NO_x, ROC, SO_2 and TSP.* *6-km grid spacing for area sources.* *No discrimination between weekday/weekend.* *No seasonal variability.* *Biogenic emissions calculated using 'typical' summer time temperatures and radiation fluxes.*	*MAQS 1992 extrapolated to year 2000.* *NO_x, ROC, SO_2, size-fractionated PM10, CO, NH_3, some air toxics.* *0.05 °and 0.01 °grid spacing for area sources.* *Weekday/weekend; seasonal; public holidays.* *Weak[1] meteorological dependency (wood-burning; motor vehicle-evaporatives).* *Strong[2] meteorological dependency (biogenics; wind blown dust; sea-salt).* *Prescribed burning.* *Power-based vehicle road-scale emission modelling.* *Biogenic emission factors from CSIRO measurement program for EPA NSW.*
Chemical Transport Modelling *CIT photochemical airshed model (4).* *GRS photochemical mechanism (6).* *Other enhancements as described in (5).* *Scalar transport for PM10 and SO_2.* *MAQS domain at 6-km resolution (10 levels).* *24-hour forecast using 1100 UTC LAPS meteorology.*	*CTM modules to run online in LAPS, offline option also available.* *Extended GRS mechanism online, CBIV (6) offline.* *Size fractionated particle scheme (modal-online; sectional- offline).* *Some air toxics (e.g. benzene) also simulated.* *Nested horizontal domains (0.05° and 0.01°).* *Sub-grid scale module for near-road impacts.*
Validation *Model evaluation done for specific case studies.* *Comparison of peak-daily air pollutant concentrations.* *Some 1-hour observed and modelled time series analysis.* *Limited comparisons of LAPS winds with observations.*	*Daily and monthly verification. METAR/SYNOP surface observations, rawindsondes, pilot balloons, vertical profilers, AMDAR and EPA meteorological and air quality data sets.* *Detailed case studies conducted as required.* *Statistical analysis tools to look at long-term performance trends.* *Cluster analysis used to test match between observed and modelled 1-hour air quality time series.*
Data Dissemination *Data archived in native formats of current models (LAPS- NetCDF; CIT- ASCII and Fortran binary).*	*Data archived in unified NetCDF data packets.* *Packets distributed via ftp or CD-ROM.* *Offline CTM simulation possible from archived set.* *Graphics of daily forecasts available on the EPAs' Web Sites.*

[1]Emissions will be calculated online and updated at hourly or higher frequencies in accordance with local, time-varying meteorological conditions.
[2]Emissions are determined using forecast daily temperature variation, as provided by an Australian regional forecast.

RESULTS

Examples of typical outputs from the pilot forecasting system are given in Figure 2 and Figure 3. In Figure 2 the computed near-surface wind field is compared with observations of the wind field obtained from the METAR/SYNOP measurement network for various hours of the day. The first thing we notice, for the day shown, is the complexity of the wind field, with synoptic-scale forcing (by the progression of depressions and anticyclones), topographical forcing (by the presence of mountains near the coast) and temperature/moisture forcing (by the temperature and moisture contrast between the land and the sea).

The forecast is initialised at 9 pm EST (local time) on 4 June 1999. The panels show the evolution of the wind field at 4-hourly intervals. The wind is mainly northwesterly to northerly ahead of a change, then turns more westerly over the land; later the wind becomes light and variable in direction, and finally it becomes northeasterly. In general there is reasonably good correspondence between the predicted and observed winds, even in a difficult situation like this one. However, as we move to higher resolution air quality forecasting (i. e. as we move from airshed-scale to suburb-scale forecasting) the demand for accuracy in the meteorological modelling increases. The demands on monitoring networks to provide complete and representative data for model initialisation and verification also increases. The development of the modelling system must go hand-in-hand with maintaining an adequate observational system.

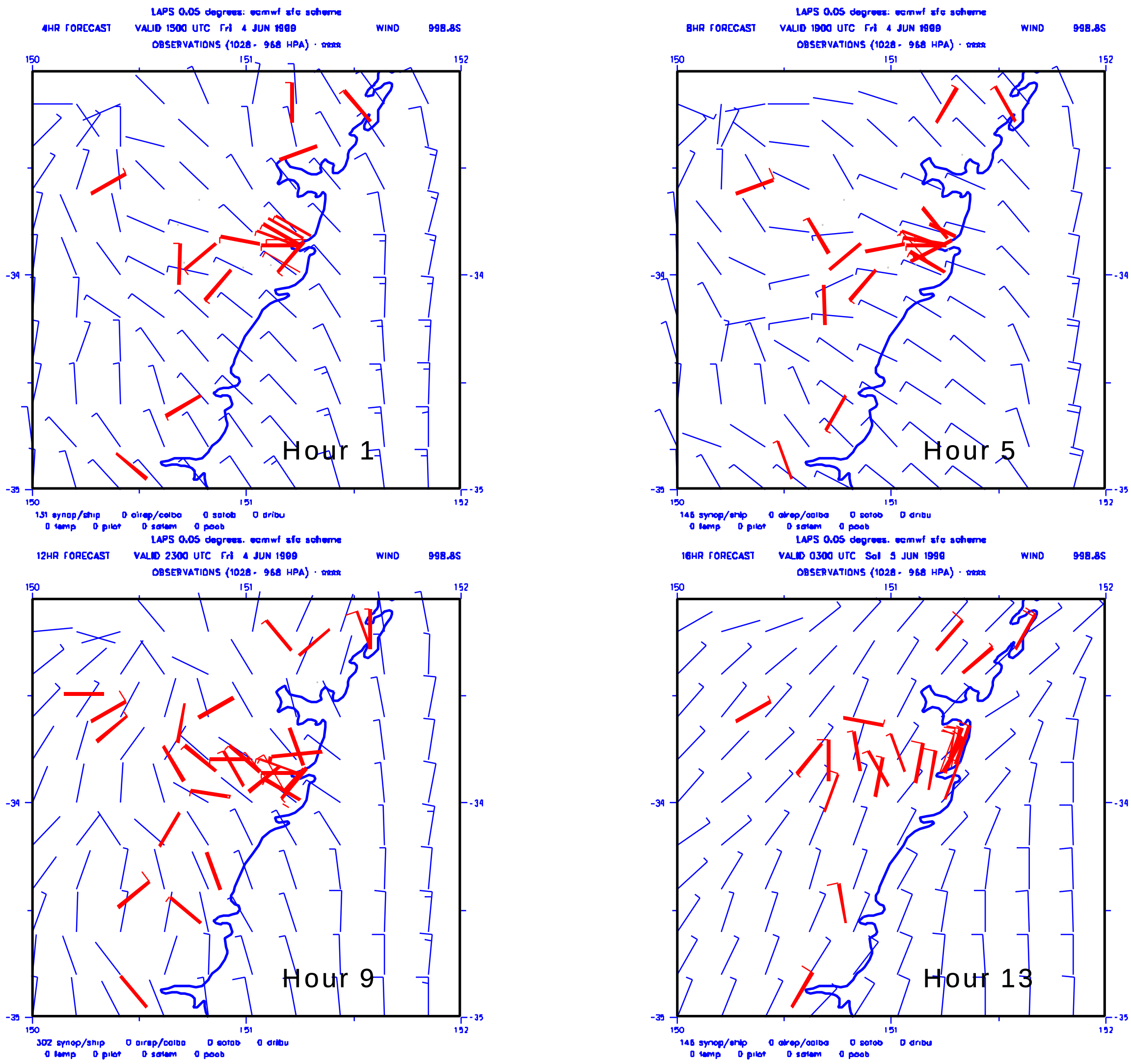

Figure 2: Comparison of near-surface wind field observations with LAPS05 forecast initialised at 1100 UTC 4 June 1999. The wind vectors are shown at every fourth point on the meteorological grid. The observations are indicated in bold. (full barb = 10 kts; half barb = 5 kts; no barb » 2 kts; 1 kt » 0.5 m s^{-1}).

As another example, some time series of observed versus forecast daily peak 1-hour concentrations of ozone and oxides of nitrogen are shown in Figure 3. The time series have been compiled for October to December 1998 inclusive. Forecast daily 1-hour peaks have been generated by the pilot system, as described in the Methodology section. Note that the observed and forecast ozone concentrations are unpaired in space. Modelled and observed NO_x time series have been developed for monitoring stations and grid points that fall within three prescribed sub-domains of the CTM grid (Newcastle, Sydney East and Wollongong-see Figure 3).

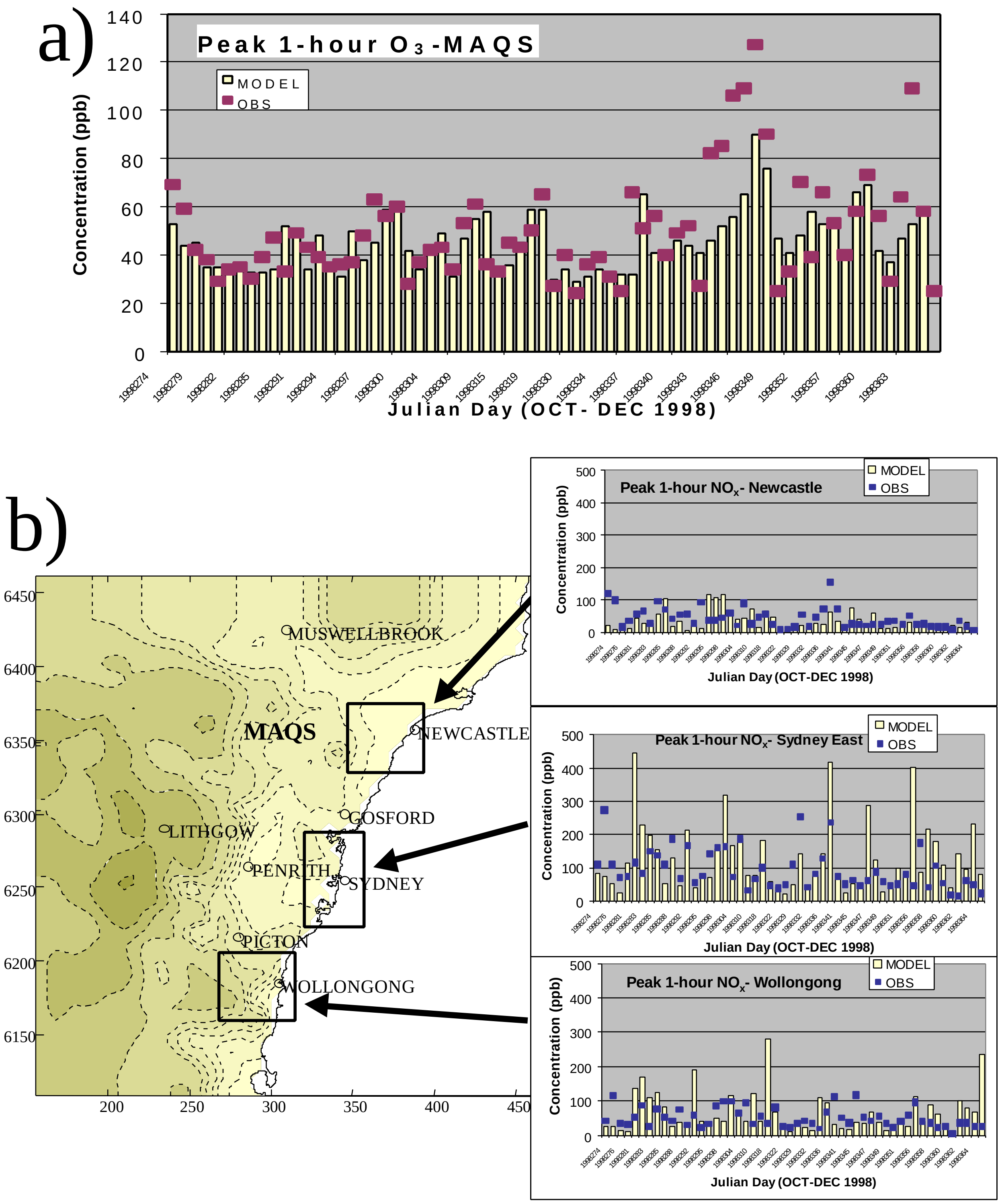

Figure 3: Observed and forecast (Pilot System) daily peak 1-hour ozone (a) and NO_x (b) concentrations for MAQS region, October to December 1998. Forecast peaks are denoted by the bar plots (MODEL) and observed peaks by the squares (OBS).

With respect to Figure 3, it should be noted that the plots have been filtered to remove days for which an air quality forecast was unavailable. In fact, all components of the pilot system ran successfully on 79 of the 92 days or 75% of occasions. While this outcome is considerably less than the projected performance goal of > 95%, the simplified computational architecture of the online demonstration system will result in a significantly enhanced level of reliability.

The pilot system has been able to capture a majority of the day-to-day variability in peak ozone concentration (Figure 3a). However, while the low- and mid-range ozone concentrations (30-60 ppb) have been estimated with good skill, there is a tendency for peak observed concentrations to be underestimated. For example, the observed and modelled 50^{th} percentile concentrations are 43 ppb and 45 ppb respectively. The observed and modelled 75^{th}

percentiles are 58 ppb and 55 ppb. The 90th percentile concentrations are 70 ppb and 65 ppb and the observed and modelled 95th percentiles are 90 ppb and 66 ppb respectively. Thus, it can be seen that a good match exists between the range of observed and forecast peak ozone concentrations up to and including the 90th percentile. This result is consistent with the hypothesis that lowest peaks correspond to clean air, onshore synoptic flow conditions and the mid-range peaks to elevated continental background under large-scale offshore flow conditions. However, the most extreme ozone concentrations are generally strongly controlled by local-scale flows (8), which may not be fully resolved by the pilot system (but will be better resolved by the demonstration system).

It is pleasing to note that the day of highest forecast ozone concentration corresponded to the day of highest observed concentration (13 December 1998; Julian day 347). The pilot system has also done reasonably well at reproducing the observed inter-regional variability (as represented by data for Newcastle, Sydney East and Wollongong) in daily maximum 1-hour NO_x concentration (Figure 3b). For example, the 50th, 75th and 90th percentiles of NO_x concentrations observed at Wollongong scale as 54%, 50% and 55% of the 50th, 75th and 90th percentiles observed at Sydney East. The ratios of the forecast percentiles are in good agreement, with the predicted 50th, 75th and 90th percentiles for Wollongong being 47%, 53% and 54% respectively of the values predicted for Sydney East.

The pilot system has overestimated peak NO_x concentrations (particularly for Sydney East) on a number of occasions. The observed 50th, 75th and 90th percentile concentrations are 79 ppb, 137 ppb and 175 ppb respectively while the equivalent modelled percentiles were 87 ppb, 168 ppb and 231 ppb. Clearly, it is important to reduce the incidence of such overestimates, particularly given that they could lead to erroneous forecasts of impending poor air quality. However, it is anticipated that the improvements documented in Table 1 (particularly the NWPS modelling of surface characteristics) will lead to improved prediction of urban dispersion conditions, particularly during nighttime.

CONCLUSIONS

Significant progress has been made on the AAQFS since it was first announced in May 1998. The pilot system has produced forecasts for Sydney and Melbourne for more than a year. These forecasts have been used to evaluate the pilot system and assist in the development of the demonstration system. Although the pilot system has a number of shortcomings, results support the premise that a numerical forecasting system will be able to provide outputs that are useful for short-term air quality management by the EPAs. Work on the demonstration system is well underway. For example, the high-resolution data sets are undergoing testing in LAPS05; a 0.05° emissions inventory for Victoria has been completed and has been incorporated into the pilot system for Victoria; construction of the online emissions inventory and CTM software is in progress; and the daily forecasts and validation outcomes are available to members of the team via an internal AAQFS Web Site.

Implementation of the online emission modules is expected to occur in time for testing during the 1999/2000 photochemical smog seasons in Sydney and Melbourne. Additional on-going and case-specific testing and validation of the completed demonstration system will then continue until June 2000, prior to the showcasing of the system at the Sydney 2000 Olympics.

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