Department of the Environment and Heritage

Air Quality Forecasting

for Australia's Major Cities

1st Progress Report

Prepared by Project Management Committee
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25 October 1999 CAR: SB / 1 / 407

Reference: SB / 1 / 407
25 October 1999

The Director
Air Quality Section
Environment Protection Group
Environment Australia
The Administrative Building
King Edward Terrace, Parks ACT 2600

Attention Ms Chris Schweizer

Dear Ms Schweizer,

Re: Air Quality Forecasting for Australia's Major Cities — First Progress Report

We are pleased to present the first progress report for the Australian Air Quality Forecasting System. The report is a compilation of progress reports for each of the four collaborating organisations for the project and managed by CSIRO Atmospheric Research. The project team comprises:

Environment Protection Authority (Victoria)
Environment Protection Authority of NSW
Bureau of Meteorology Research Centre
CSIRO Energy Technology and
CSIRO Atmospheric Research

Introduction

The primary objective of the *Air Quality Forecasting System for Australia's Major Cities Project* is to set up, validate, and trial for a four month demonstration period, a real time software system capable of providing accurate air quality forecasts to the public for the purpose of "*preventing, combating, or rectifying*" the level of air pollution, particularly on forecast high pollution days.

After the Australian Air Quality Forecasting System (AAQFS) is demonstrated in Sydney and Melbourne, the Commonwealth shall have the exclusive right to use to System in Australia for Air Quality Forecasting and will have a non-exclusive right to use the System overseas for the same purpose.

The System will be completed and demonstrated to the public in Sydney in time to provide air quality forecasts for the 2000 Olympic Games. The demonstrations in Sydney and Melbourne need not necessarily be run simultaneously.

The AAQFS comprises the following components:

(i) The "access system" which manipulates
- emissions data based on traffic and industry activity for a particular region from pollution inventories,
- meteorological data from the Limited Area Prediction System (LAPS), being a system developed by the Bureau of Meteorology,
- other materials necessary for the development of the System,

(ii) The "customised airshed system" being the consolidated airshed model which will be customised for a particular region or city,

(iii) A "visual graphics modelling system" which offers a visual graphics representation of the forecasts suitable for the world wide web.

Management Structure and Responsibilities

The AAQFS is being developed with funding from the *Air Pollution in Major Cities Program*, and was approved by the Minister for the Environment as one of the *Clear the Air* projects on 15 May 1998. The Project is legally organised as a contract between the Commonwealth and CSIRO Atmospheric Research, with subcontracts to other participants. However, the actual conduct of the Project is by a collaborative arrangement as follows:

> Bureau of Meteorology Research Centre (BMRC) is responsible for the preparation of the LAPS model for the Project and for the consolidation of various air pollution emissions and chemical transport components to make up the full System. BMRC is providing the resources of the Bureau to access verification data, trialing the System in its various forms and is working with the EPAs to set up information streams to the EPAs from the System. BMRC also is working with CSIRO and the EPAs to develop the visualisation systems.
>
> Environment Protection Authority (Victoria) is providing expertise in developing a real-time emissions inventory system in collaboration with CSIRO, is working with EPA NSW to prepare the Sydney emissions inventory for the Project, and is providing an extended

emissions inventory for Victoria. EPA (Victoria) is also providing data for validation purposes from the Melbourne monitoring network.

Environment Protection Authority of NSW is providing data for validation purposes from the Sydney monitoring network, is working with EPA (Victoria) in preparing the Sydney emissions inventory for the System, and is facilitating the introduction of the System into Sydney.

CSIRO Energy Technology is underpinning CSIRO Atmospheric Research in the Project by contributing to extensions of the air pollution modelling components, is developing an advanced version of their chemical reaction scheme for high speed smog forecasts, and is developing and providing advanced algorithms for the real-time calculation of vehicle emissions in that depend on power requirements which in turn depend on hilly terrain — a characteristic of many cities, particularly Sydney.

CSIRO Atmospheric Research is assisting and advising EPA (Victoria) in the development of the real-time emissions inventory, is developing, extending and customising the air pollution modelling component, is working with BMRC to incorporate the air pollution components into the LAPS model, and is participating with the EPAs and BMRC in the development of graphical outputs.

The Project is managed by Dr Peter Manins of CSIRO Atmospheric Research. He chairs the Steering Committee which meets every two months or more often as necessary. The Steering Committee is made up of representatives of the collaborators.

Progress

As specified in the contract between the Commonwealth and CSIRO, the Project is in seven phases, with reporting required within 30 days of completion of the phase. The phases are described in the table below.

Phase	**Tasks**	**Date commenced**	**Date completed**
Phase 1	Trial a working test system in Melbourne, determine areas of concern and devise requirements for extension, verification measures, criteria	May 1999	Jun 1999
Phase 2	Recast latest emissions inventory for Melbourne (Mar 99) into form for the System. First pass at extending inventory to respond to weather, events. Trial full prototype system in Melbourne, test performance	Jun 1999	Jul 1999
Phase 3	Extend real-time emissions inventory methodologies to Sydney, incorporating the new power-based vehicle emissions application. Install full prototype System in Sydney and verify against measures and data.	May 1999	Dec 1999

Phase 4	Iterate on performance measures for forecasts for Sydney and Melbourne, finalise extensions to meteorology component, incorporate advanced GRS smog model, commence development of display systems and other products in consultation with users	Jul 1999	Apr 2000
Phase 5	Demonstration to EPAs of prototype System in Melbourne and Sydney over summer period. Fix problems and refine display products in consultation with users in Sydney and Melbourne	Jan 2000	Jun 2000
Phase 6	Demonstrate full System in Sydney and Melbourne with products to EPA NSW and EPA VIC for dissemination to media	Jun 2000	Sep 2000
Phase 7	Package outputs for EPAs in light of demonstrations. Document performance, validate against System performance measures and recommend extensions	Oct 2000	May 2001

Progress has been good. The following sections summarise this. Appended are copies of several publications that members of the Team have prepared and presented to various fora. It may be noted that some reports indicate progress against more than just Phase 1. This should be expected in a project where internal priorities change and allow some components to run faster than others. The important thing is that the critical path to delivery is well in hand.

The following highlights are especially interesting:

- A working base emissions inventory for the whole of Victoria has been completed and made available for the AAQFS. A more detailed and refined inventory is in preparation.
- Development of a real-time emissions inventory has commenced.
- Validation data from Melbourne and Sydney are being provided automatically to the Project from EPA networks.
- A project to determine biogenic emissions in the target airsheds has commenced, funded by EPA NSW.
- LAPS (the numerical weather prediction model) has been confirmed to run satisfactorily at approximately 5 km grid resolution, as required for the Project. It now runs routinely twice a day to produce 36 hour forecasts for Victoria and eastern NSW.
- The CTM chemical transport model based on the public domain CIT model has been modified to employ the high-speed Generic Reaction Set smog chemistry from CSIRO Energy Technology.
- Progress has been made in developing the power-based vehicle emissions component focussed on Sydney.
- A prototype data archiving and display system has been developed to handle the diverse data sources, including air quality observations and prediction fields.
- A trial of the AAQFS for March 1999 for Melbourne has been completed successfully, and this has indicated several areas of concern for the further development of the System:
    - the number of system failures of the working test system will need to be reduced;
    - planned improvements to the weather prediction system are essential;

    - some overpredictions of NOx and occasional incorrect spatial distributions of O_3 concentrations point to the need for better weather and emissions determinations;
- The requirements for a suite of model performance and verification measures have been developed to judge the AAQFS as further progress is made.

Communication between the four Organisations has been excellent. There is clearly a lot of good will to develop this important system to be of great use to the agencies and the public.

We are practically finished the scheduled progress targets for Phase 2 and these will be reported upon in the second Progress Report due by the end of August.

Project Developments

A closed web site for the AAQFS should be running by early September. It will be an important source of information on the development of the project, will hold forecast fields as they are developed and will show a variety of kinds of presentations. We will be seeking feedback about the development and the best ways to present information.

The Management Committee will be considering what access restrictions will be imposed on the web site. Our initial expectations are that only Management Team plus EA Air Studies Section members will have full access via a password. The public may be given access to a selection of materials on the web site, including non-confidential components of the Progress Reports to the Commonwealth.

Also in hand is a review of comparable systems around the world. This review will feature in a future Progress Report.

Issues of Note

No subcontracts have been signed off as yet.

For and on behalf of
AAQFS Steering Committee

P. Manins

(Dr) **Peter Manins** PSM, FTSE, CCM, QEP

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Environment Protection Authority (Victoria).

1st PROGRESS REPORT

Progress has been made on the majority of the deliverables as outlined below. A draft agreement between EPA Victoria and CSIRO to cover this project is currently being negotiated.

Emissions Inventory

Phase 1 - Initial Victorian Inventory

The first phase of extending the current Melbourne emissions inventory to cover the whole of Victoria has been completed. This extended draft inventory is being used as a working draft inventory to assist with model development and testing.

The diffuse source allocation (emissions from the domestic / commercial sector) for Victoria was based on scaling of emissions from the metropolitan region using population as a scaling factor. The emissions data sets developed show regional differences in emissions such as domestic incinerator burning varying from rural to urban areas.

The mobile source allocation was carried out based on predicted VKT and emission factors used in the metropolitan areas. The motor vehicles emissions respond to variations in temperature (eg for evaporative emissions).

The biogenic emissions were based on available land use data and emission factors. The biogenic emissions respond to changes in temperature and solar radiation. The industrial inventory was based on the work conducted in the Melbourne inventory.

Phase 2 –Detailed Victorian Inventory

The detailed Victorian inventory is progressing well and is expected to be finished on time.

The major industrial sites have been identified and the data collection completed. The emissions estimation is 70% complete. Emissions from all power stations across the state have been estimated and only several other major point sources are left to finish this task.

The biogenic inventory has been completed. A detailed examination of the available vegetation data and emission factors for Victoria was undertaken for this task.

The detailed diffuse inventory is progressing. The ammonia inventory and solid fuel inventory have been completed. The wildfire / prescribed burning data collection has started. The Department of Natural Resources and Environment (DNRE) manages the prescribe burning that takes place in Victoria. EPAV is currently liaising with DNRE about the data that is required for the forecasting system.

The detailed mobile inventory has begun. The available data for the whole of Victoria (mainly traffic count data from VicRoads) has been reviewed and methods to integrate this data into the inventory have been scoped out.

Phase 3 –Run Time System Development and Sydney Inventory

The development of the run time system is progressing. The detailed work program has been scoped and system documentation has been developed including program descriptions and a data dictionary. The model has been broken into six modules;

- Point source
- Area source
- Biogenic source
- Motor vehicle
- Wildfire and prescribed burning
- Speciation

Each of the source modules will produce the emissions data sets for the forecast days. In some cases, the emissions sources respond to data supplied from the LAPS model such as temperature. The point source model software development has been completed. Work on the motor vehicle module has started.

A meeting with the NSW EPA has taken place in which discussions focussed on the format of the MAQS inventory. It was important to do this early on in the project so there would be no delay on starting on the Sydney inventory after the Victorian inventory had been finished. A list detailing the data requirements for the forecasting system has been forwarded to the NSW EPA.

Meteorological Data

Automated programs have been developed by EPA Victoria which provide Bureau of Meteorology with 1-hourly ambient data (first level validation) on a daily basis from all stations within the Port Phillip Control Region. The data is being used to validate LAPS modelling.

Air Quality Data

EPA Victoria is also providing CSIRO with first level validated 1-hourly ambient data (first level validation) on a daily basis from all stations within the Port Phillip Control Region. The data is being used for preliminary validation of air quality forecasts.

Historical air quality data has also been supplied for validation purposes of air quality forecasts on selected event days identified by CSIRO.

Vertical Profiling for Melbourne

The Acoustic sounder has been relocated to the RAAF Williams Air Base and Laverton (west of the city). The instrument has been commissioned, but is currently running intermittently due to operational problems. These will be rectified in over the next two months, and data provided to the BOM and CSIRO.

Facilitation for progress of the Project

EPA Victoria has been represented at meetings of the AAQFS Management team.

Environment Protection Authority of NSW

1st Progress Report

Environment Protection Authority of NSW

1st PROGRESS REPORT

INTRODUCTION

The Australian Air Quality Forecasting System (AAQFS) is being developed as a collaborative project between CSIRO, Bureau of Meteorology (BoM), Environmental Protection Authority of New South Wales (EPANSW) and Environmental Protection Authority of Victoria.

EPA NSW’s principal responsibilities are to facilitate the implementation of the forecasting system in Sydney and to provide support to implement the demonstration of the system in time for the 2000 Olympics. The specific deliverables include:

- Providing access to the 1992 emissions inventory with updates for MAQS.
- Provision of routine meteorological data for inclusion in the LAPS analyses for NSW.
- Provision of routine ambient air quality data and additional meteorological data for validation of model performance.
- Vertical profiling data from western Sydney if a sounder can be funded outside of AAQFS.
- Funding for a complementing biogenic emissions project.
- Facilitation for progress of the project, feedback on operational questions and ideas and guidance in the development of forecast presentations.
- Officer time for operational use.

PROGRESS REPORT

Progress has been made on the majority of the deliverables as outlined below.

Emissions Inventory

The contract allowing provision of emissions inventory data to CSIRO is currently being prepared subject to commercial-in-confidence requirements.

Meteorological Data

Automated programs have been developed by NSWEPA which provide Bureau of Meteorology with 1-hourly ambient data (first level validation) on a daily basis from all stations within the Sydney Basin except Rozelle and Westmead. The data is being used to validate LAPS modeling.

Air Quality Data

NSWEPA is also providing CSIRO with first level validated 1-hourly ambient data (first level validation) on a daily basis from all stations within the Sydney Basin. The data is being used for preliminary validation of air quality forecasts.

Historical air quality data has also been supplied for validation purposes of air quality forecasts on selected event days identified by CSIRO.

Biogenic Emissions

Biogenic emissions have been identified as a significant source of uncertainty in emissions inventories (Carnovale et al 1996, Pierce et al 1998, Roselle 1994, Anstasi et al, 1991). The MAQS emissions inventory estimated that vegetation makes a substantial contribution to VOC emissions in the Sydney Region. These emission rates were based on literature values and may not be applicable to Australian conditions.

CSIRO Energy Technology (CET), in collaboration with CSIRO Atmospheric Research (CAR), has been commissioned by NSWEPA to carry out preliminary measurements of biogenic emissions from trees and grasses.

CET is determining emissions from trees based on both canopy sampling and dynamic chamber measurements. These results will enable further validation of the algorithms used in MAQS for biogenic emissions estimates. CAR is measuring grass emissions and, based on the results, will produce algorithms to be used for modelling purposes.

To date, one progress report has been received. Two dynamic chamber experiments have been completed during the 98/99 summer period. Initial emission measurements were carried out on a small eucalypt species and these results have yet to be analysed. The second measurement was carried out on a protuding branch of a 20-22m high Forest Red Gum *(Eucalyptus Tereticornis)* using a flexible chamber. The diurnal variation of volatile organic compounds emitted from the test branch has been measured, however identification of all detected emitted species has not been completed.

Data on emissions from grasses has yet to be collected.

It is anticipated that work will continue over the 99/00 summer season.

Vertical Profiling for Western Sydney

It is anticipated that vertical profiling for western Sydney will commence sometime in 2000. As part of an independent program, limited meteorological data were collected at Bringelly during early 1999. The data consists of continuous profiles of wind speed and direction for a period late February to early April 1998. Following some analysis, EPANSW can make available to CSIRO data for days of interest to the AAQFS project (where data exists) for the purpose of model validation.

Facilitation for progress of the Project

EPANSW has been represented at meetings of the AAQFS Management team.

CONCLUSION

- Contracts for the supply of the emissions inventory data are currently being reviewed.
- Ambient air quality data and meteorological data is now supplied to CSIRO Atmospheric Research and Bureau of Meteorology on a routine basis.
- A project aimed at determining biogenic emissions from trees and grasses has commenced.

References

Anastasi, C., Hopkinson, L. and Simpson, V.J. 1991. "Natural Hydrocarbon Emissions in the United Kingdom". Atmospheric Environment, 25A(7), pp.1403-1408.

Carnovale, F., Tilly, K., Stuart, A., Carvalho, C., Summers M. and Eriksen, P. 1996. "Metropolitan Air Quality Study: Air Emissions Inventory", *Final Report to New South Wales Environment Protection Authority*. Bankstown, NSW, Australia.

Pierce, T., Geron, C., Bender, L., Dennis, R., Tonnesen, G. and Guenther, A. 1998. "Influence of Increased Isoprene Emissions on Regional Ozone Modeling". Journal of Geophysical Research, 103(D19), pp.25,611-25,629.

Roselle, S.J. 1994. "Effects of Biogenic Emission Uncertainities on Regional Photochemical Modeling of Control Strategies". Atmospheric Environment, 28(10), pp. 1757-1772.

Bureau of Meteorology Research Centre and

CSIRO Atmospheric Research

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System Overview

The Australian Air Quality Forecasting System (AAQFS) is in the initial stages of a two-year program of development and testing. Following this period, the AAQFS will be used to operationally generate air quality forecasts for the Port Phillip Control Region (PPCR) and regional centres of Victoria (see **Figure 1**), and a region in NSW which includes the Metropolitan Air Quality Study Region (MAQSR; see **Figure 1**). It is planned that the AAQFS will have the following features:

- Air quality forecasts will be made twice per day, and will be for a period of 24-36 hours.
- The forecasting system will operate at an effective maximum horizontal resolution of about 5 km, thus enabling the forecast to discriminate between different regions of a city.
- The AAQFS will simulate a wide range of air pollutants including photochemical smog, particulate matter (PM_{10}), air toxics, oxides of nitrogen (NO_x), carbon monoxide, sulfur dioxide and volatile organic compounds (VOCs).
- The AAQFS will provide the ability to generate air quality forecasts simultaneously for a 'business as usual' emissions base case, and for alternative cases in which emissions are perturbed to represent environmentally friendly scenarios such as increased patronage of public transport systems.
- An archive of forecasts will be available for a number of applications including the determination of long-term population exposure metrics, the development of an optimal network design, and regulatory planning.
- The system will go operational in time to provide air quality forecasts for the Sydney 2000 Olympics. Forecasts will be managed by the environment department of each state, and will be made available to the media and general public.

A schematic diagram of the forecast system in presented in **Figure 2**. Principal components of the system are the numerical weather prediction (NWP) system, the emissions inventory module (EIM), the initial and boundary condition module (BCM), the chemical transport model (CTM), the evaluation module (EVM), and the display and archiving module (DAM). A brief description of the status is now given for a number of the key system components.

Status

Numerical Weather Prediction (NWP) system

The purpose of the NWP is to provide accurate, high-resolution (both spatial and temporal) forecasts of the vector wind field, temperature, humidity and radiation fields, and surface-layer stability parameters. The meteorology forecasts are used by the CTM to drive the processes of pollutant transport and deposition, and to provide radiation, temperature and moisture fields for the simulation of chemical transformation processes.

Meteorological forecasts will be generated by the Bureau of Meteorology's Limited Area Prediction System (LAPS; Puri et al. 1998) a state-of-the-art numerical weather prediction model, which began operational forecasting at a horizontal resolution of 0.75 degrees in July 1996 (the system has also been generating operational forecasts at a resolution of 0.25 degrees over two smaller regions since May 1997). Higher resolution versions of LAPS (at 0.375 degrees and 0.125 degrees including the whole Australian region) have been handed over to the National Meteorological Operations Centre and are currently undergoing testing. It is expected that they will become operational in July 1999.

The LAPS model uses a latitude/longitude grid and solves the primitive equations of momentum, mass, temperature and moisture on a non-staggered Arakawa A grid. Physical processes in the model include: a parameterisation of the Monin Obukhov constant flux layer near the surface; stability dependent turbulent diffusion above the Monin Obukhov layer; a Tiedtke moist convective scheme (with an option for a Kuo scheme); and a Fels-Schwarzkopf radiation scheme. The model is initialised from a limited-area version of the global multi-variate statistical interpolation analysis, using data which comprise available surface pressure data, radiosondes, radar winds, cloud drift winds, AMDAR (commercial airline) winds and temperatures, and satellite temperatures and humidities.

LAPS has also been configured to run with a horizontal grid spacing of 0.05 degrees (approximately 5 km) with 29 vertical levels between the surface and the top of the atmosphere for Victoria and New South Wales. For convenience, we will denote this model as LAPS05.

The boundary conditions for the meteorological forecast are provided by output files from a LAPS run with a horizontal grid spacing of 0.375 degrees (approximately 37.5 km) with 29 vertical levels for a domain that includes all of Australia, New Zealand, Papua New Guinea, and Indonesia. This model is called LAPS375. Thus the LAPS05 model (used for the AAQFS) is nested within LAPS375, the new model for operational meteorological forecasting. The boundary conditions in LAPS05 are updated every three minutes (by interpolation LAPS375 three-hourly output files).

The initial conditions for the LAPS05 are derived from the analysis of meteorological data from a variety of sources. The procedure takes account of (1) the raw observations, their reliability (instrument error) and their representativeness; and (2) the state of the atmosphere (all the atmospheric variables must be mutually compatible and certain balance conditions must be satisfied). The input data are analysed onto a latitude-longitude grid with a resolution of 0.375 degrees. Analyses at 0.375 degrees at 1100 and 2300 UTC are then interpolated to 0.05 degrees to provide the initial conditions for the model runs.

LAPS05 now runs routinely twice a day (with forecasts commencing at 1100 and 2300 UTC) to produce 36 hour forecasts for Victoria and New South Wales. The output from these runs is used for input to run the Chemical Transport Model.

Chemical Transport Model

A modified version of the Carnegie Mellon, California Institute of Technology model (CIT; Harley et al. 1993) comprises the CTM. Originally developed in its basic form at the California Institute of Technology for the simulation of photochemical smog within the Los Angeles region, the model has since been applied to other airsheds in the Americas and in Europe.

The CIT model features a Cartesian grid in the horizontal and a non-uniform sigma-height coordinate system in the vertical. Subgrid scale transport is simulated using the gradient transfer approximation. Dry deposition at the surface is modelled using the multiple-path resistance analogue. Photochemical transformation proccesses in CIT are simulated using an extended version of the Lurmann, Carter, Coyner mechanism (LCC; Harley et al. 1993 and reference therein).

The model has been extensively modified and applied to the simulation of photochemical smog production in a number of major Australian airsheds (for example, see Cope and Ischtwan 1996). A significant modification for AAQFS is the replacement of LCC by the Generic Reaction Set (GRS; Azzi et al. 1992). The highly condensed GRS mechanism (7 reactions and 7 species) has the advantage of being computationally more efficient (the GRS version of CIT typically runs 5-10 times faster), yet can be configured to reproduce the predictions of the more detailed mechanism. In addition to the other enhancements documented in Cope and Ischtwan (1996), we have also modified CIT to simulate the transport and deposition of PM10 emissions.

Emissions Inventory Module

The EIM provides daily forecasts of emissions for a wide range of pollution species including, oxides of nitrogen, carbon monoxide, sulfur dioxide, PM_{10}, air toxics and a number of volatile organic compounds (VOCs). The pilot forecasting system uses the PPCR emissions inventory (Carnovale *et al.* 1991) for the Melbourne modelling. This inventory database provides hourly-varying emissions on a 3 km grid for a range of source categories (including motor vehicle, industrial, commercial, natural and biogenic).

In addition to the gridded emissions inventory, a more detailed motor vehicle emissions module is under development. This is based on the work at CSIRO-ET where motor vehicle emissions are modelled on the basis of power expended by individual vehicles rather than VKT and emission factors. The model predicts the source strength of CO_2, NO_x, CO and hydrocarbons (HC) resulting from individual vehicles as they traverse road links.

Emission rates for each pollutant, as well as the rate of fuel consumption, are derived from the instantaneous power expended by the vehicle in traversing a section of road. The total instantaneous power is the sum of the individual components required to overcome the power expended in the drive train and tyre rolling resistance, aerodynamic drag, uphill gradients and general accelerations. Emission rates are calculated for each of the four classes of vehicle type i.e. catalyst spark ignition, non-catalyst spark ignition, light duty diesel and heavy duty diesel vehicles.

The basic form of the model is being adapted to the Sydney major road network. Each of the major roads is being broken up into a series of links with characteristic road gradients. Traffic volume data along with the vehicle fleet mix are being used to provide the volume flow data for each class of vehicle for each link.

Vehicle emissions during the cruise mode, which occur on mid-link sections of road, are very different to the emissions during the acceleration, deceleration, and idle modes experienced at an intersection. The road network is being separated into mid-link segments and intersection segments. Cruise mode emissions are calculated from the average gradient of the link and knowledge of the total traffic flow, its average speed (with an allowance for the variability in the running speed) and the vehicle mix. Intersection emission rates are calculated in a similar fashion to the standard links but also account for emissions from the start and stop movements induced by traffic lights. The average number of vehicles using the intersection and the average number of vehicles delayed per cycle are used to calculate the effects of acceleration, deceleration, idle and cruise modes on the cumulative emission rate. Emissions for both cruise mode and intersections need to be summed to calculate the overall emissions from a road and for the 3 km grid required by the overall air quality model.

In addition to the modelling, field measurement campaigns have been planned to provide data on

- speed versus time curves for a number of key roads in the Sydney Metropolitan Region at different times of the day to obtain data on typical driver behaviour for these major routes.

- A number of major intersections to measure typical acceleration rates from the intersections and the formation of queues.

Display and Archiving Module

A prototype data archiving system has been developed for the pilot forecasting system. The Network Common Data Form (NetCDF) has been used in order to provide a system-independent storage format. The NetCDF is public domain software developed by the Unidata Program Centre. It has the advantage of being able to interface with FORTRAN, C, C++ or Perl.

An important stage in the development of the prototype archiving system was the replacement of 22- mixed format input and output data files by a single, more compact, system-independent NetCDF data set. A graphical display system has also been interfaced to the archiving system for the display of observed and modelled meteorological and air quality fields.

When completed, the system will archive a composite data set from the EIM, the NWP, the CTM, and validation data. The system will enable the following tasks to be undertaken.

- To re-run the CTM in offline mode at a later date.

- To evaluate the model output by comparison against observational data.

- To display output in a manner suitable for interpreting forecast meteorological and air quality fields

Evaluation

One of the milestones for the AAQFS is to trial a forecasting system for Melbourne. This trial has been carried out for March 1999.

During the month of March, the 1100 UTC LAPS05 model ran and the record was complete and successfully archived on 25 days; the CIT model ran and the record was complete and successfully archived on 22 days. In **Figure 3a,** a time series of peak 1-hour NO_x concentrations for the Melbourne region is given for the month of March 1999. Note that NO_x can be considered a semi-conserved primary species that is not a strong function of chemical transformation processes. The predicted concentrations are compared to the range of measured peak 1-hour concentrations of NO_x obtained from the Environmental Protection Authority of Victoria's monitoring stations located at Alphington, RMIT (Melbourne CBD), Box Hill, Brighton, Dandenong, Paisley, Footscray and Geelong South. Similar time series plots are presented in **Figure 4** for sub-regions of the air quality forecasting domain. It is apparent that the overall system (NWP, EIM, CTM) has had some success in correctly forecasting the day-to-day trend of increasing or decreasing peak NO_x. These trends correspond to the passage of high pressure systems over the study area, that is the large-scale synoptic meteorology pattern. It is also apparent that the system has, to some degree, been able to discriminate between different regions of the airshed. However, it can also be seen that the forecasting system has strongly overpredicted peak 1-hour NO_x concentrations on a couple of occasions.

Time series plots of peak observed and predicted daily 1-hour ozone concentrations are shown in **Figure 3b**. Note that ozone is a product of the reaction between volatile organic compounds (VOC's) and oxides of nitrogen. Ozone production rates are sensitive to the concentration of NO_x, the concentration and content of the VOC's, and to ambient temperature and solar radiation. It can be seen that the forecasting system has successfully been able to predict the day (1 March) on which the highest ozone concentrations of the month were observed. It is also apparent that none of the observed ozone peaks are strongly over predicted by the model (no false alarms).

Areas of Concern

Although the model performance for March is quite encouraging, the trial has illustrated a number of areas of weakness in the models/system performance.

- The incidence of successful, completed and archived runs of the CTM (and the LAPS) needs to be increased. It is clear from **Figure 3b** that a number of potentially significant ozone events were not included in the forecast record because of system failures.

Although the system appears to have performed reasonably well at forecasting daily maximum 1-hour concentrations of NO_x and O_3, further progress is required in order to achieve acceptable performance for region-specific 1-hour concentration time series. This is illustrated in **Figure 5** where observed and predicted 1-hour ozone concentrations are plotted for selected EPA monitoring sites for 1 March 1999. Also plotted in **Figure 5** is the spatial distribution of maximum 1-hour ozone concentration for 1 March. Although the system correctly predicted that 1 March 1999 would be a day of elevated ozone, it is clear from **Figure 5**, that the observed diurnal distribution of ozone has not been well modelled. Moreover, from a consideration of the spatial distribution of maximum ozone, it is apparent that the system has incorrectly predicted the location of the ozone plume on this day. Often this type of problem can be related to errors in the transport fields. Observed and forecast near-surface wind fields for selected hours of 1 March are plotted in **Figure 6**.

- It can be seen that the model has done a relatively good job at reproducing the broad scale flow patterns on this day. However, to achieve the ability to forecast the diurnally varying air pollutant concentrations at the suburb level, rather than at the airshed level, means that we demand a very high level of accuracy in forecasting the small scale meteorological features.

- The system has strongly overpredicted peak 1-hour NO_x concentrations on a couple of occasions. It will be important to ensure that the number and severity of false alarms 'is kept to a minimum.

In addition to model/system performance, there are a number of areas regarding model/system development that are of immediate concern:

- incorporation of the latest emissions inventory for Melbourne,

- incorporation of higher spatial and temporal resolution of physical and chemical processes,

- incorporation of routine daily verification.

Of concern in the longer term is improving the initialisation and boundary conditions procedures; carrying out sensitivity studies for particular episodes; carrying out verification studies for previous years during the September period in Sydney and during summer periods for Melbourne and Sydney; incorporating the new emissions inventory for Sydney; making the daily verification scheme comprehensive by including new data sources; improving the graphical display and archive system; possible modification of physical parameterisation schemes, especially in urban areas; possible backup prediction scheme in case of model or system failure.

Requirements for extension

Improvement in the forecasting skill for NO_x and other pollutants will require that attention be paid to modelling the higher resolution processes (on the meso- and microscale). This will include incorporation of the following within LAPS05:

- 5-km resolution of topography

- 5-km resolution surface roughness parameterisation

- 5-km resolution vegetation fraction

- 5-km resolution soil hydraulic properties

- nested areas with 1-km resolution of emissions inventory

- nested areas with 1-km resolution of chemical mixing
- modelling the emissions near major roads to 10's of m resolution

To achieve this, online code must be written, including some new physics and chemistry modules. With regard to the latter, the GRS mechanism will be extended to provided an improved simulation of rural/background photochemical production processes (such as O_3 production from methane and other background species under conditions of low NO_x). The GRS mechanism will also be modified to accommodate an explicit treatment of the key radical species (such as the hydroxyl radical and various peroxy radicals). This will also simplify the development of an improved treatment of secondary particle formation.

These changes need to be added before meaningful verification of the overall system can be conducted. However in the meantime additional data need to be added to the verification database, the retrieval needs to be automated and programs for statistical appraisal and for graphical display need to be written. In addition, the new emissions inventory needs to be added to the system.

Verification measures

Meteorological verification: primary variables of interest are the wind speed and direction, the screen temperature and dew point temperature, radiation and the height of the mixing layer. Data sources include the METAR and SYNOP data, additional EPA data, vertical profilers, rawinsonde and pibal data, and AMDAR (aircraft measurements) data.

Air quality verification: a range of air quality indicators is available for model performance evaluation including- oxides of nitrogen, nitric oxide, nitrogen dioxide, PM_{10}, carbon monoxide, non-methanic hydrocarbons, sulfur dioxide and ozone. Nephelometer (aerosol scattering) data are also available for future evaluation work when visibility will become an important variable.

Graphical display of predicted and measured values will indicate the patterns of coherence. Statistical analysis of bias, root mean square error, mean deviations, and averages and standard deviations will be performed to examine the performance of the model and of individual measuring stations. The diurnal variation of the performance and the differences with time of the model initialisation will be examined. Lagged correlations will allow determination of systematic lags in the simulation of meteorological systems. Simple schemes for statistical correction will be investigated.

Performance criteria

Two sets of measures will be used to assess the performance of the forecasting system.

Reliability measures quantify the performance of the software system in completing the task of providing twice-daily, 24-36 hour air quality forecasts. The following measures will be used to track system reliability:

- percentage of days where pollution forecasts were issued on time,
- percentage of days where verification measures were carried out,

- percentage of days where archiving of data was achieved,
- percentage of days where archiving of forecasts was achieved.

Accuracy measures pertain to the ability of the system to provide an accurate forecast of air quality. Accuracy will be ascertained using 2 × 2 contingency tables that tabulate the number of correct, missed and false alarm 'air quality forecasts.

Such tables can be applied to an entire forecast domain, and to smaller regions to determine geographical skill.

There are a number of ways to quantify the results of the contingency tables. Investigation needs to be done to determine the most appropriate methodology to adopt. A relative indication of system performance will be developed through comparison of the results from the empirical/statistical forecasting systems that are currently operated by the environmental authorities in Victoria and NSW.

CONCLUSIONS

A pilot air quality forecasting system has been developed and has been tested in Melbourne and Sydney for a number of months. Results presented for Melbourne for March 1999 are encouraging and support the basic premise that a high-resolution, numerical forecasting system can provide air pollution forecasts that are suitable for the purpose of short-term air quality management. It is anticipated that the skill and reliability of the forecasts will improve further over the coming months following the completion of enhancements to the meteorological model and the emission inventories, and the development and implementation of the online air quality modules.

References:

Azzi, M., Johnson, G. J., and Cope, M., 1992. An introduction to the Generic Reaction Set photochemical smog mechanism. Proceedings of the 11th International Clean Air and Environment Conference, Brisbane, 1992, Clean Air Society of Australia and New Zealand, Eastwood, NSW, pp. 451-462.

Carnovale F.C., Alviano P., Carvalho C., Deitch G., Jiang S., Macaulay D. & Summers M., 1991, 'Air emissions Inventory Port Phillip Control region: Planning for the Future', *SRS 91/001*, *Environment Protection Authority*, Melbourne, VIC, Australia.

Cope, M. E., and Ischtwan, J., 1996. Metropolitan air quality study: Airshed modelling, Final Report to the New South Wales Environment Protection Authority, Bankstown, NSW.

Harley, R. A., Russell, A. G., McRae, G. J., Cass, G. R., and Seinfeld, J. H., 1993. Photochemical modeling of the southern California air quality study, Environ. Sci. Technol., **27**, 378-388.

Puri, K., Dietachmayer, G. D., Mills, G. A., Davidson, N. E., Bowen, R. A. and Logan, L. W. 1998. The new BMRC Limited Area Prediction System (LAPS), Aust. Met. Mag., **47**, 203–223.

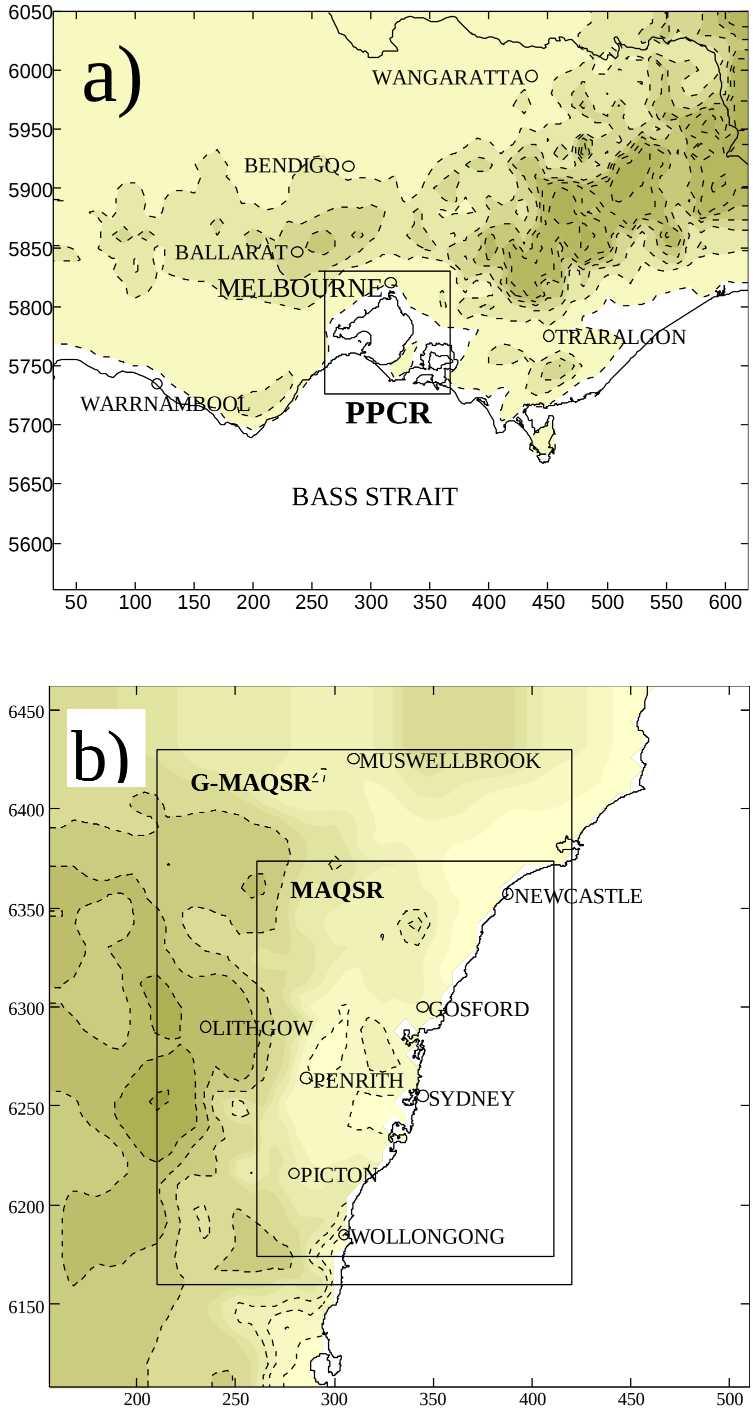


Figure 1. (a) Domain to be used for air quality forecasting in Victoria (domain of the PPCR is also indicated). (b) Domain to be used for air quality forecasting in NSW (GMAQSR- GREATER MAQS study region). Note that distances are given in units of kilometres.

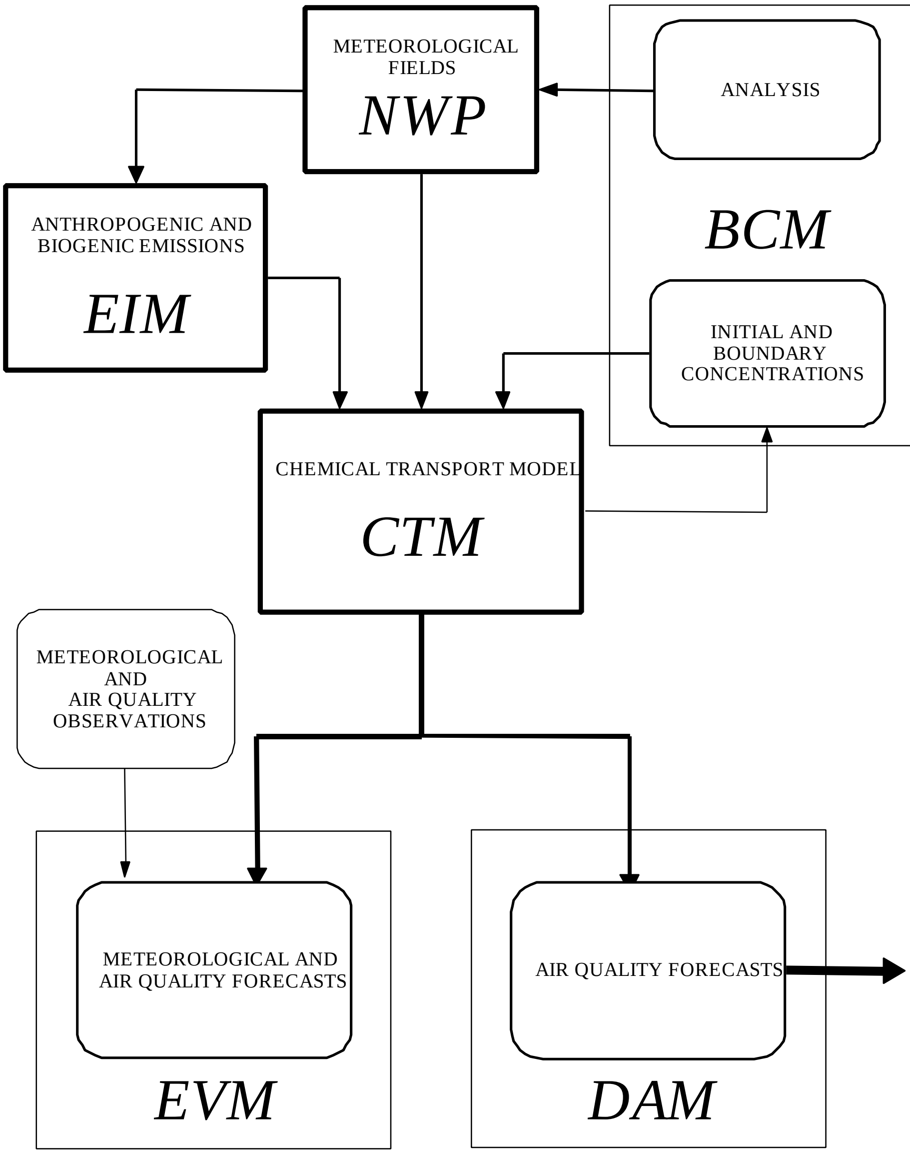
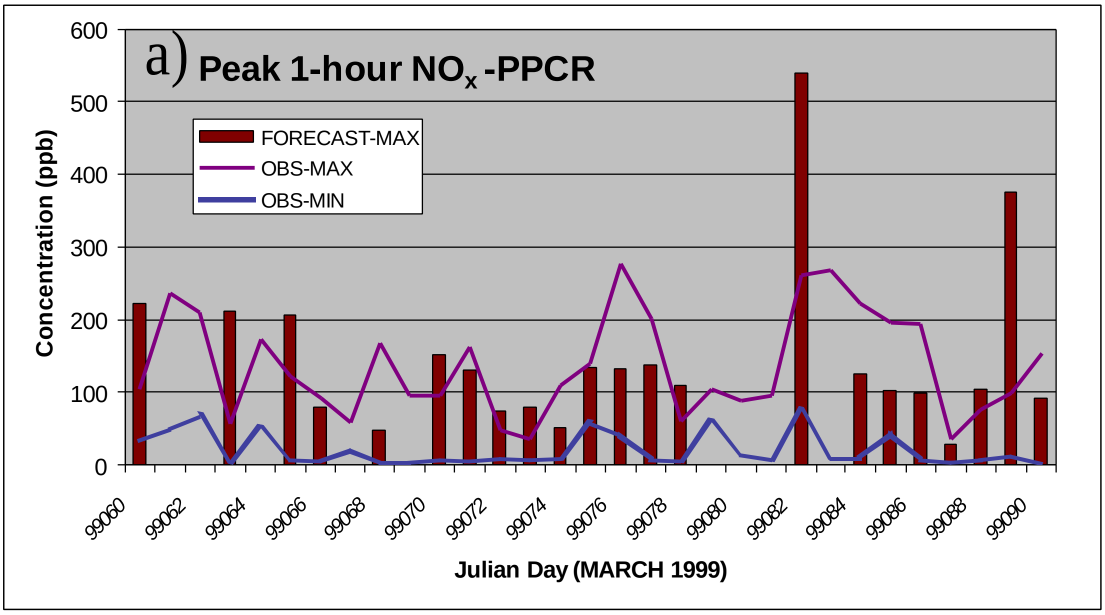


Figure 2. Schematic diagram of the Australian Air Quality Forecasting System.



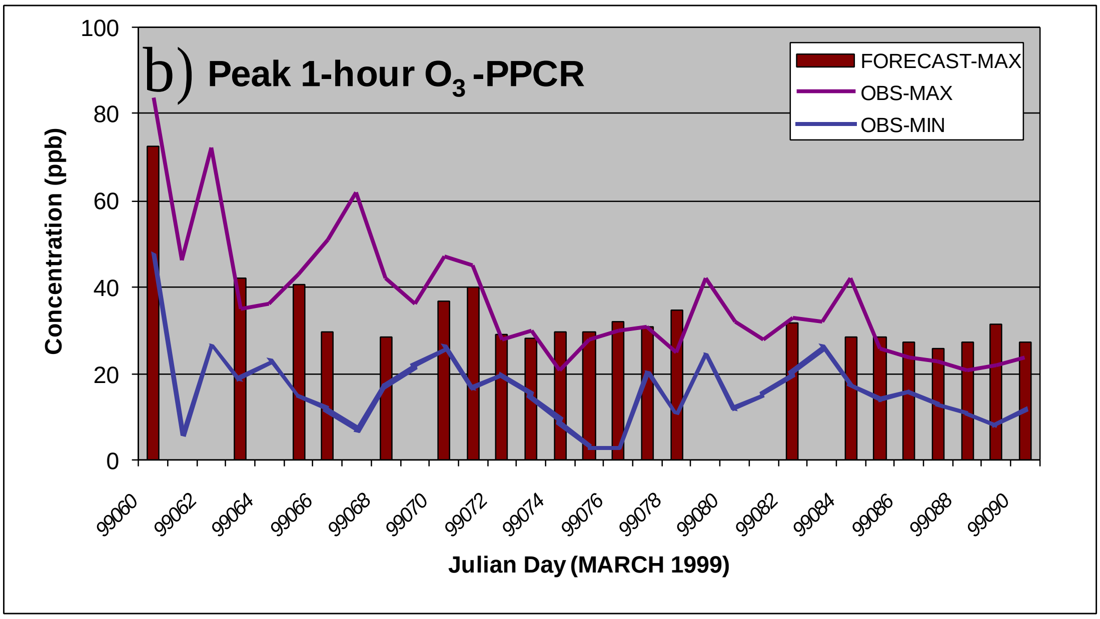


Figure 3. Observed (minimum and maximum of station peaks) and forecast (airshed maximum) 1-hour concentrations of (a) NO_x and (b) O_3 for March 1999.

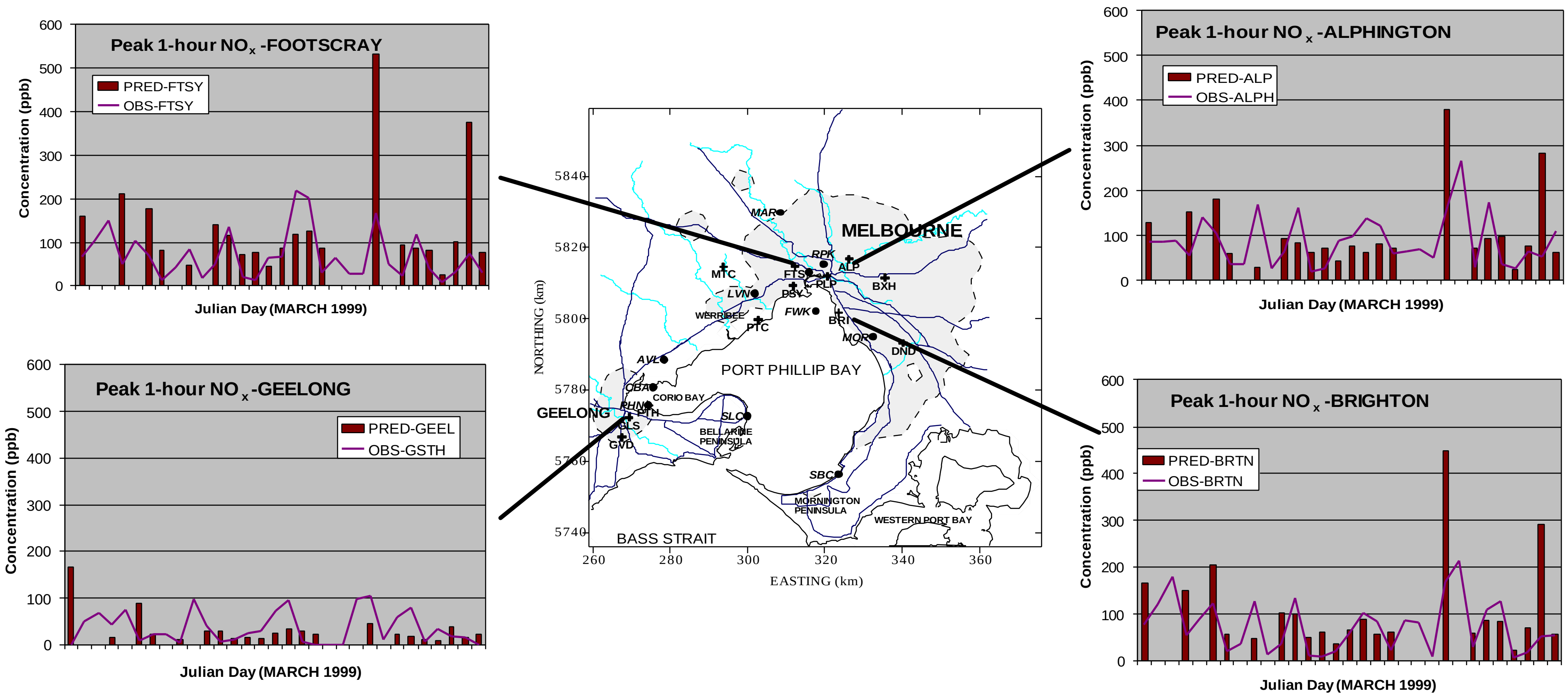


Figure 4. Observed and forecast peak 1-hour concentrations of NO_x for selected sub-regions of PPCR for March 1999.

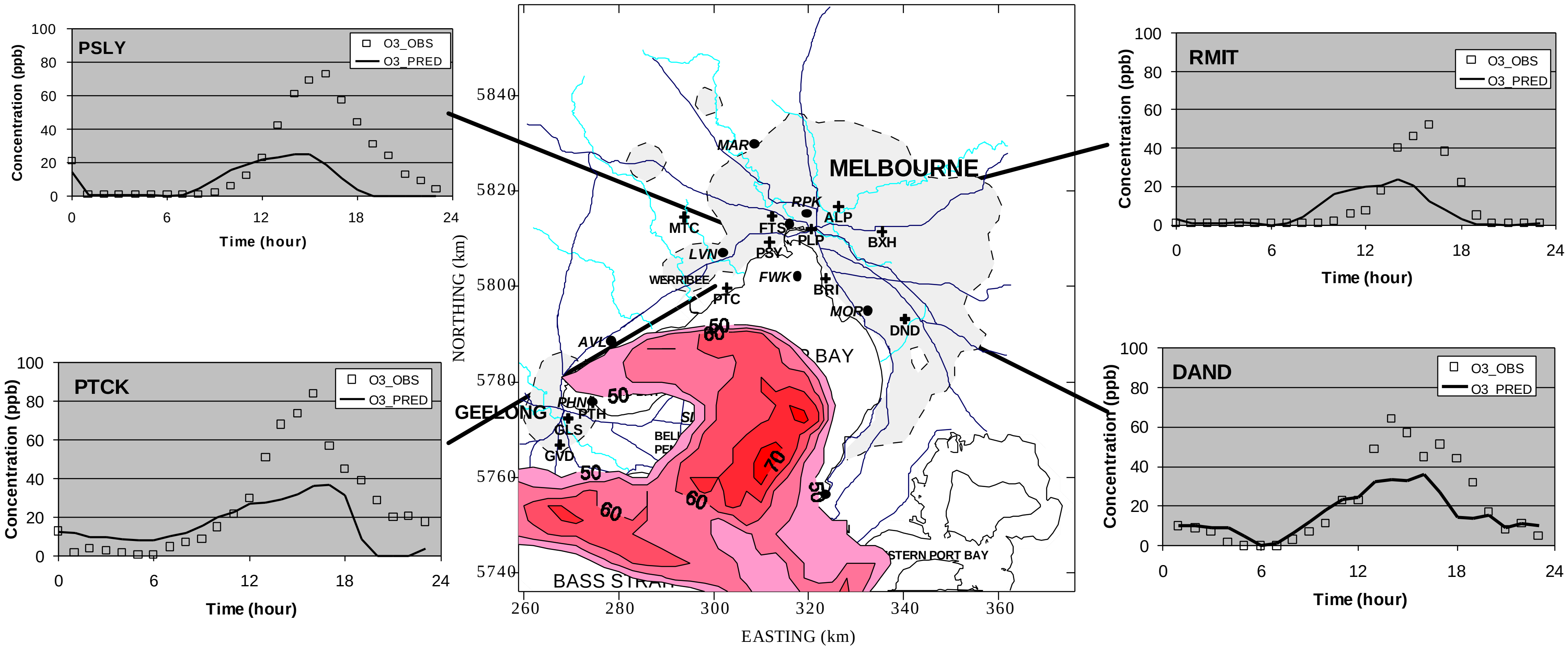


Figure 5. Observed and forecast peak 1-hour concentration time-series of O_3 for 1 March 1999. Also shown is the spatial distribution of forecast maximum 1-hour O_3 concentration.

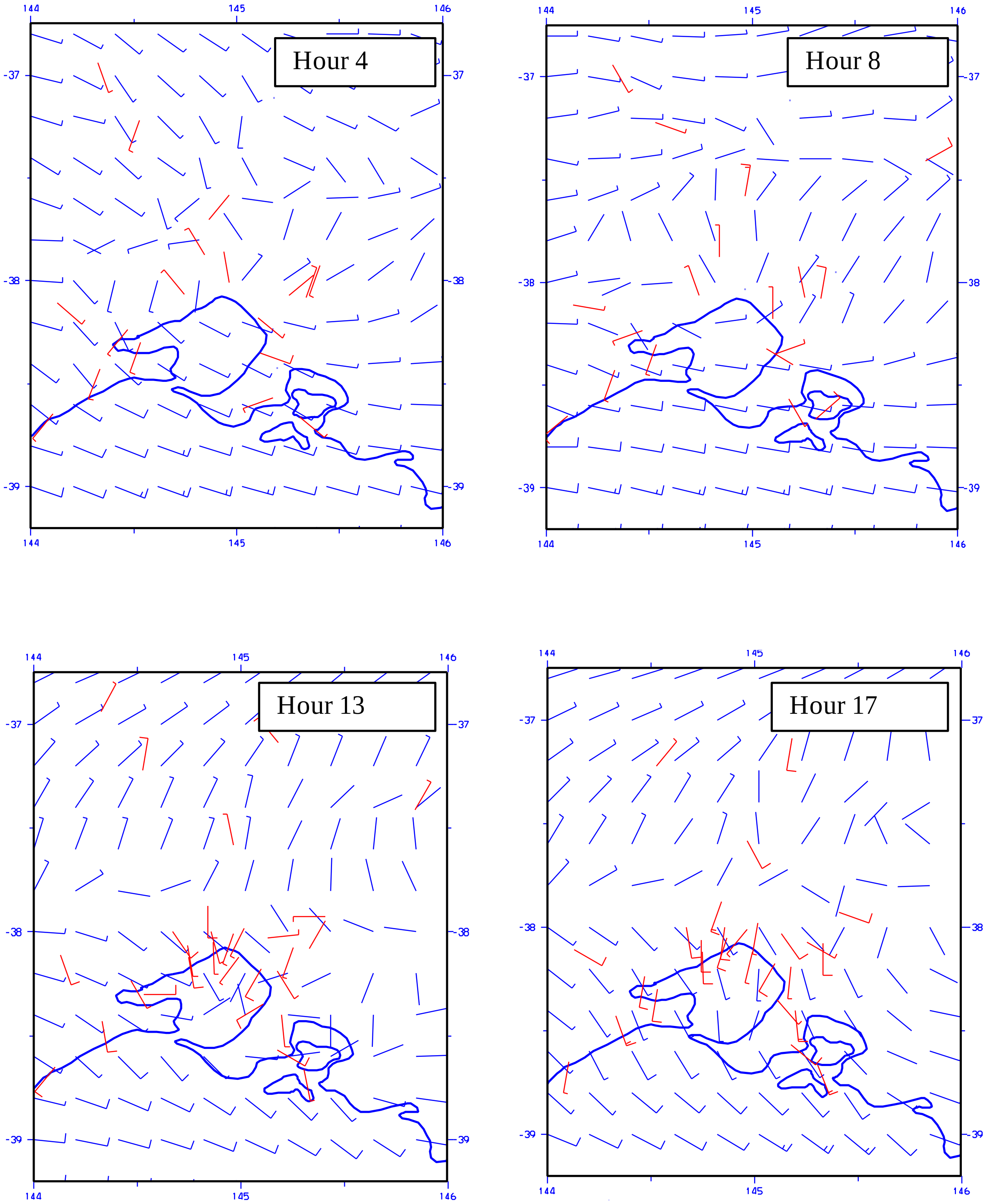


Figure 6. Forecast and observed near-surface winds for selected hours on 1 March 1999. (With no barbs- wind speed less than 5 knots (nominally 2 knots); with half barb- wind speed 5 knots; with full barb- wind speed 10 knots; with 1 and 1/2 barbs- wind speed 15 knots).