THE IMPACT OF DATA ASSIMILATION ON MODELING THE TRANSPORT OF SMOKE FROM TWO PRESCRIBED BURNS OVER THE SYDNEY METROPOLITAN AREA

Milton S. Speer
Bureau of Meteorology, P.O. Box 413, Darlinghurst
New South Wales. Australia 1300.
E-mail: M.Speer@bom.gov.au

Lance M. Leslie
School of Mathematics, University of New South Wales,
Sydney. Australia. 2052.
E-mail: Lleslie@unsw.edu.au

Rees Bunker
New South Wales Rural Fire Services
Locked Bag 17, Granville New South Wales. 2142. Australia
E-mail: rees.bunker@bushfire.nsw.gov.au

ABSTRACT

A mesoscale data assimilation and prediction model has been applied over the Greater Sydney region to an air pollution episode resulting from fire hazard reduction burns during the period 12 to 14 April, 1997. The main objective of the study was, firstly, to model the inter-regional transport that resulted in a sustained pollution episode when smoke was transported over inner Sydney from a prescribed burn early in the study period (11-14 April, 1997) and, secondly, later in the period when pollution reduced visibility to zero over a major highway just to the southwest of Sydney also from a prescribed burn. The model used in the study is a full mesoscale numerical weather prediction (NWP) model as part of a system consisting of both diagnostic and prognostic components. It soon will incorporate a full air chemistry component consisting of an advection-diffusion-reaction model. The advantages of such a complete system is that it models both first and second order fire effects explicitly, based on real-time meteorological data. The main conclusion from the results of this case study is that the capacity to assimilate real-time data into the model allowed an accurate forecast depiction of the wind flow and hence the trajectory of the smoke over inner Sydney and, also, the long lead time wind forecast for later in the period over the region southwest of Sydney would have been excellent guidance for fire managers.

Keywords: smoke transport, mesoscale modeling, data assimilation

INTRODUCTION

On 12 and 13 April 1997 the visibility limit as determined by the New South Wales (NSW) state Environment Protection Authority (concentration PPM-10 threshold 2.1 x 10^{-4} m^{-1}) was breached in the eastern part of the Sydney metropolitan area. During these two days very light winds were experienced in the low levels of the atmosphere over the Sydney metropolitan area, which aided the formation of surface temperature inversions early on both days owing to the lack of vertical turbulent mixing in the boundary layer. Early on both days sub-synoptic circulations dominated in the form of light northwesterly land breezes which gave way to east to northeasterly sea breezes in the afternoon. The observed winds at 600 meters above ground level backed from east northeasterly to northerly over this period at less than 5 knots. Smoke from a prescribed burn just north of Sydney was blown over the metropolitan area to at least a height of 600 meters. Close to the surface, the northwesterly morning land (katabatic) breezes effectively concentrated the smoke in the eastern part of the metropolitan area on both April 12 and 13.

Within the last 12 hours of the study period, that is, between 9 pm 13 April and 9 am 14 April, a synoptic scale wind shift from northeast through northwest to west advected smoke and fog over a major highway to the southwest of Sydney reducing visibility to zero in parts and co-coincided with a vehicle pile-up involving 25 vehicles. In this study we examine the model performance in predicting the air trajectories that resulted in both pollution events.

METHODOLOGY

Model

The methodology initially involved replicating the operational procedure as closely as possible by performing a series of high resolution model experiments using a nesting strategy with a mesoscale numerical weather prediction (NWP) model developed by the second author (Leslie and Purser, 1995). The model called HIRES has the capability to model fire effects (e.g. smoke dispersion) down to the spatial scale of a watershed and the temporal scale of a few hours in a real-time operational mode by providing a vast array of model output as input to, for example, any fire behavior model. This is because HIRES is a high resolution limited area model which uses the full set of primitive dynamical equations which govern atmospheric motions and includes, in its hydrostatic form, parameterisation schemes for boundary layer processes, solar and terrestrial radiation and convection that model these processes implicitly, or in its non-hydrostatic form, includes schemes that model these processes explicitly. An example of regional smoke transport prediction is documented in Leslie and Speer (1998).

Our philosophy is to develop the model using either a deterministic or probabilistic approach with prognostic case studies. In this case study we have chosen the deterministic, or single model forecast, approach.

System

The horizontal and vertical advection dynamics and the parameterisation of physical processes of HIRES is only part of the full atmospheric dispersion model which comprises input fields, output data and additional attached modules. These modules are the diffusion and chemical reaction components. The full atmospheric dispersion system is shown in Fig. 1 which includes both a prognostic component (right hand side) or a diagnostic component (left hand side). In this and most studies we employ the prognostic component.

Data

Low-resolution operational data were used and additional high-resolution observations were assimilated from a range of sources including, sondes, AWSs and aircraft in the vicinity of the burn just north of Sydney. The system also can ingest other data types such as remotely sensed data (radar, satellite). The assimilation scheme employed was a variation on the nudging procedure over a twelve hour period leading up to the initial time.

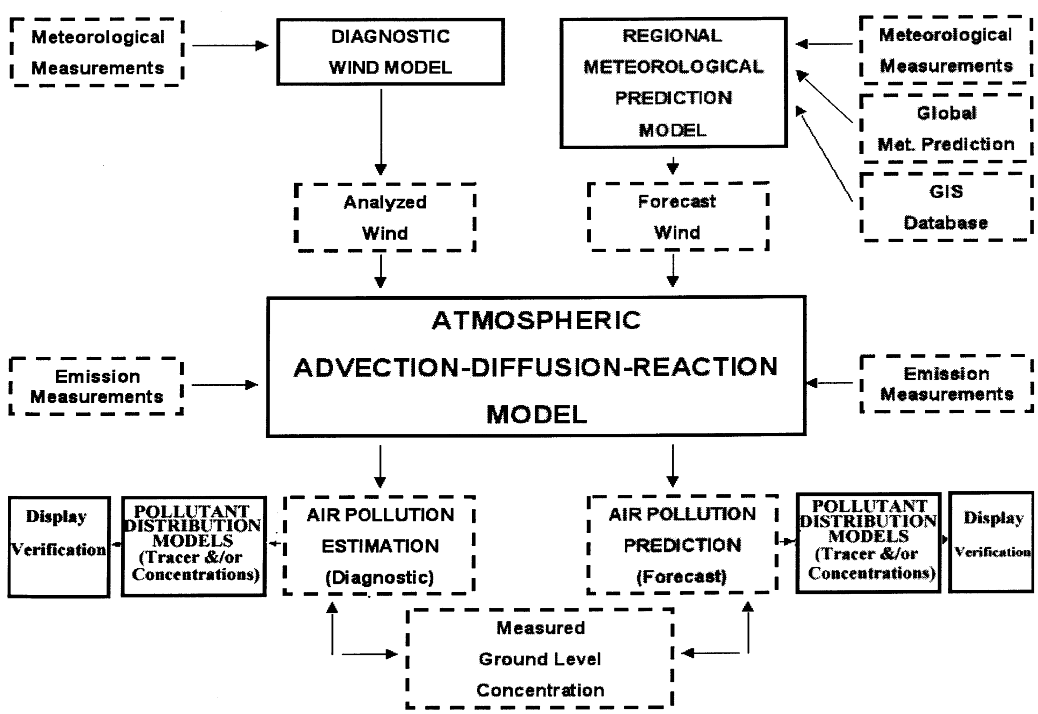

Figure 1.

RESULTS

First event: 12 to 13 April 1997

It was found that without the addition of observations of surface and low level real-time observations of wind speed and direction near the burn that occurred early in the period, the model boundary conditions from the coarse mesh influenced the forecast of wind speed and direction quickly after initialization producing a trajectory which was away from the Sydney metropolitan area instead of towards it. However, when the model was re-initialized with additional surface and low level observations in the vicinity of the fire using a data assimilation methodology, there was a dramatic improvement in the wind forecasts. Performing backward and forward trajectories on this model wind output indicated that low level air emanating from the vicinity of the fire would have moved over the eastern part of the Sydney metropolitan area and stagnated there as shown in Figure 2.

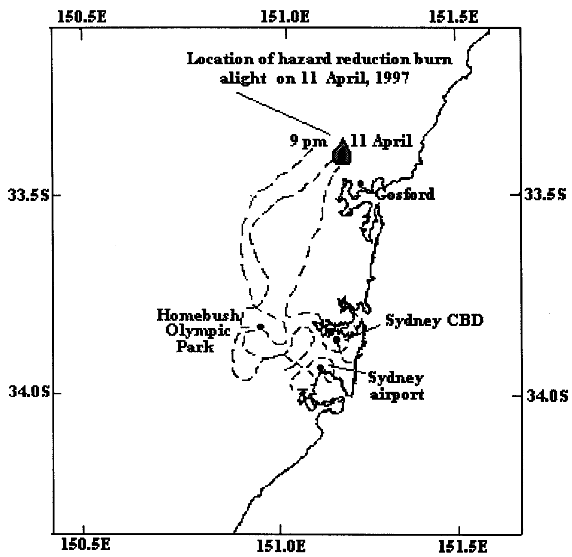

Figure 2. Diagram showing backward air trajectories from the Sydney CBD, Sydney airport and Homebush Olympic Park to 9 pm 11 April then forward trajectories for 24 hours until 9 pm 12 April. Height = 100 metres.

Second event: 13 to 14 April 1997

For the second event which occurred late in the period the model wind forecasts (between +48 and +52 hours) accurately predicted a wind change that transported a combination of smoke and fog over a highway at about the critical time when a multiple vehicle pile-up occurred in extremely poor visibility due smoke and fog. Based on backward trajectories from the highway accident and then forward trajectories, the air that passed over the burn would have then passed over the accident site on the highway as indicated in Fig. 3. In this case there was no need for additional data to be included in the assimilation since the wind change was induced by a large scale conditions were successfully captured in the initialization without extra data. In fact there was very little gain in the forecast timing of the wind change between a model forecast run at 5 km horizontal resolution compared to one at 15 km.

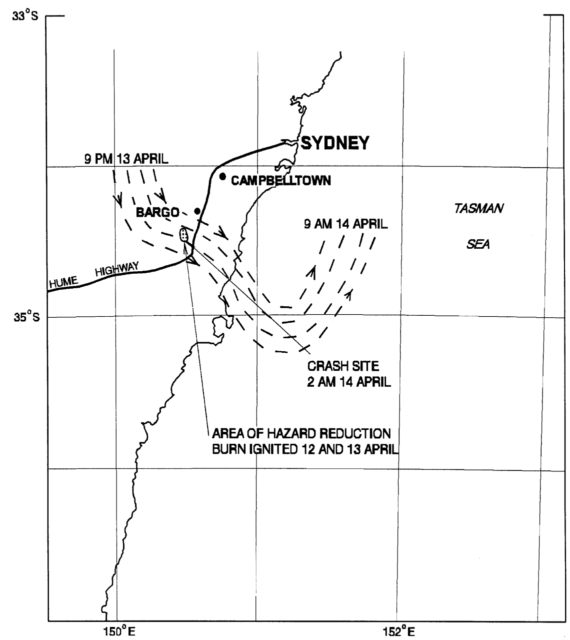

Figure 3. Diagram showing air trajectory, burn area, and crash site.

CONCLUSIONS

The main conclusion from the results of this study is that in a very light wind regime, such as occurred early in the study period, the trajectory of air is strongly influenced by local diurnal circulations and hence high resolution forecasts benefit greatly by including extra data in the assimilation prior to model initialization. When the main influence locally is from the large scale conditions as occurred with the wind change late in the period then there is little or no benefit to be gained from increasing the horizontal resolution passed a certain point (in this case 15 km). In future, the model will become increasingly sophisticated as more components are added. For example, the absorption, chemical rain out, re-suspension etc. that is associated with the major outdoor air pollutants in Sydney (particulates, ozone, nitrogen) will form part of a major chemistry component of the model targeted for progressive implementation of real-time prediction of air pollution transport and dispersion in the metropolitan air sheds of Sydney, Los Angeles and Beijing.

REFERENCES

Leslie, L. M. and R. J. Purser. 1995. Three dimensional mass-conserving sem-Lagrangian scheme employing forward trajectories. *Mon. Wea. Rev.*, **123**, 2551-2556.

Leslie, L. M. and M. S. Speer. 1998. Atmospheric particulate transport modelling in a controlled burn event. *Meteorol. Appl.* **5**, 17-24.