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Application of MM5 and CAMx4 to local scale dispersion of particulate matter for the city of Christchurch, New Zealand

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Abstract

A numerical model, Mesoscale Model version 5 (MM5), is used in conjunction with a three-dimensional Eulerian/Lagrangian dispersion model (CAMx4) to model PM_{10} dispersion for a period of 48 h for the city of Christchurch, New Zealand. In a typical winter, Christchurch usually experiences severe degradation in air quality. The formation of a nocturnal temperature inversion layer during stagnant synoptic conditions, and the emissions of particulate matter (PM_{10}) mainly from solid fuel home heating appliances (the 'Domestic' factor) leads to severe smog episodes on about 30 nights each winter. The modelling results from the highest resolution computational grid are compared with observed meteorology and air pollution dispersion for winter 2000, when the Christchurch Air Pollution Study (CAPS2000) was underway. The numerical modelling system is able to simulate surface-layer meteorology and PM_{10} spatial distribution with a good level of skill, with the Index of Agreement and Pearson's correlation coefficient greater than 0.8 for PM_{10}.

Keywords: MM5; Cold air drainage; Conceptual model; CAPS 2000; Index of agreement; CAMx4; PM_{10}; Air pollution; Christchurch

1. Introduction

Regional and local meteorological and air quality models have become important tools for environmental research, being applied to environmental assessment and assessing the possible impacts of different amounts and sources of air pollution. For any air pollution study, a state-of-the-art limited area meteorological model is often used as a basic tool in a coupled meteorology–air pollution modelling system. It is important to use such advanced air quality models as research tools to understand the processes that control pollution dispersion and the observed spatial and temporal variations in air quality. Properly evaluated advanced models can also be used to forecast atmospheric pollutants in an operational or quasi-operational time frame (Otte et al., 2005). Recently, these two tasks have been explored together for more efficient realization of modelling system potential (Baertch-Ritter et al., 2003; Chenevez et al., 2004; Dayan and Lamb, 2005). At the present time, ensemble meteorological–air quality modelling systems that include the application of both global and mesoscale meteorological models, and several chemical air quality models (for different scale processes and different pollution types) are being actively

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developed (Mayerhofer et al., 2002; Arnold et al., 2004; Erisman et al., 2005).

International need for regional (mesoscale) models appeared many years ago and is associated with an increase in the number of meteorological and environmental problems to be solved at this scale. Model application to the problem of air pollution is very important, not only for the city of Christchurch and the surrounding Canterbury region, but also for all major settlements in New Zealand and overseas. Air pollution has been a seasonal problem in New Zealand for many years, as described in many published papers (McKendry et al., 1986; Spronken-Smith et al., 2001). The increasing needs of New Zealand organizations, such as Environment Canterbury and the Ministry for the Environment, to establish strategies for environment protection demand innovation in the application of modelling techniques (Moody, 1983).

Three-dimensional, prognostic, limited area meteorological models have a lot of advantages, especially from the point of view of representing the important factors that control levels of air pollution, such as complex terrain and the complicated distribution of area and point source emissions in time and space. There are many examples of coupled models used in environmental research, such as MM5–UAM, MM5–CMAQ, MM5–CAMx, RAMS–CAMx, MM5–DAQM MM5-TOPLATS (Byun and Ching, 1999; Kotroni and Lagouvardos, 2002; Michelson et al., 2002; Peters-Lidard et al., 2002).

Numerical mesoscale models, firstly predict the wind fields and then the predicted wind, temperature and humidity fields are used to drive an air pollution or particle dispersion model to estimate the dispersion of air pollutants from different kinds of source (Finardi et al., 1997). The integration of airflow and particle transport models has been regularly applied to environmental situations dominated by both topographic and thermally induced local air circulations (Lamprecht and Berlowitz, 1998). In the research of Bischoff-Gauss et al. (1998), an analysis of the effects of thermally induced wind systems on air pollution transport near Sao Paulo (Brazil) showed the combined effect of topography and the land-sea interface (strong upslope, downslope and onshore flows) on local air pollution dispersion.

Atmospheric pollution is a major problem for big and small cities all over the world. The bigger the city the more complex the problem of air pollution from domestic, industrial and transport sources, or even natural pollutants. A lot of respiratory diseases of varying severity affect inhabitants of these cities, from an increase in the number of colds suffered to heavy attacks of asthma and anaphylactic shocks (Arya, 1999). Acute respiratory disease is not only associated with big cities (i.e. with millions of people). In smaller cities (with less than 1 million population) the situation can sometimes be much worse under the unique local atmospheric conditions resulting from such things as topographic effects and/or land-water distribution (Cogliani, 2001). Historical traditions and/or rapid industrial growth in a city or its suburbs can also be significant. Deterioration of air quality in the near-surface layer can be worsened by particular combinations of human and environmental factors (Owens and Tapper, 1977; Corsmeier et al., 2006). Research into the influence of human activity on air quality is one of the major tasks of mesoscale numerical modelling (Pielke, 1984; Otte and Locser, 2001).

The main aim of this paper is to evaluate the performance of the meteorological-chemical modelling system MM5–CAMx applied to the New Zealand city of Christchurch that experiences high concentrations of particulate air pollution during winter episodes, in an environment dominated by local air circulation processes. Initial research in this area was undertaken by van den Assam (1997), applying the Regional Atmospheric Modeling System (RAMS). Daily and monthly averaged aerosol concentrations for cold periods in Christchurch have been studied using The Air Pollution Model (TAPM, Hurley et al., 2005) and compared with observations obtained during the Christchurch Air Pollution Study 2000 (CAPS2000) for several city sites (Wilson and Zawar-Reza, 2006). An overview of the basic methods used to research winter aerosol pollution in the Christchurch area can be found in Zawar-Reza et al. (2005).

The paper is focused on evaluating the ability of the MM5–CAMx modelling system to accurately represent the local meteorology that contributes to heavy air pollution episodes, as well as on comparing the observed spatial and temporal patterns of aerosol pollution. The use and adjustment of the mesoscale model MM5 and its coupling with the chemical model CAMx provides a unique opportunity to investigate the occurrence of aerosol pollution over Christchurch and the combined influences of near-surface local meteorology and chemical processes. The advantages of using MM5 include free distribution of the model, the wide range of options available with the model,