Modelling street-scale resolution air quality for the West Midlands (UK) using the ADMS-Urban RML system

Jian Zhong, Christina Hood, Kate Johnson, Jenny Stocker, Jonathan Handley, Mark Wolstencroft, Andrea Mazzeo, Xiaoming Cai and William James Bloss

Abstract: Air pollution is a major environmental concern in urban areas, causing substantial adverse effects on human health. This study simulated street-scale resolution air quality for the West Midlands region in the UK using a regional-to-local coupled system, which combined the regional CMAQ model with the local ADMS-Urban model, without double-counting emissions. CMAQ was used to represent dispersion on large temporal and spatial scales, while ADMS-Urban represents the local short-term dispersion from explicit point and road sources. Both models were evaluated against observations with reasonable performance, i.e. CMAQ captured measured air pollutant concentrations at background sites, while coupled ADMS-Urban RML (Regional Model Link) also captured air pollution concentrations at roadside sites, where local effects were important. Street scale air quality maps were produced from the ADMS-Urban RML, which can be linked to health-related exposure studies. The coupled air quality modelling system for WM serves as an effective tool to evaluate potential regional and local air pollution mitigation policies.

Keywords: Street-scale; Air quality; Regional-to-local coupled system; West Midlands; Road sources.

J. Zhong (✉ j.zhong.1@bham.ac.uk) · A. Mazzeo (a.mazzeo@bham.ac.uk)· X. Cai (x.cai@bham.ac.uk) · W. J. Bloss (w.j.bloss@bham.ac.uk); School of Geography, Earth & Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK

C. Hood (chood@cerc.co.uk) · K. Johnson (kjohnson@cerc.co.uk) · J. Stocker (jstocker@cerc.co.uk)· J. Handley (jonathan.handley@cerc.co.uk); Cambridge Environmental Research Consultants, Cambridge, CB2 1SJ, UK

M. Wolstencroft (mark.wolstencroft@birmingham.gov.uk); Birmingham City Council, Birmingham, B5 5BD, UK

1 Introduction

Air pollution is a major environmental concern in urban areas, causing adverse effects on human health. Air quality modelling is an important tool for the simulation of the combined effects of emissions, dispersion, physical and chemical processes in the atmosphere and for the quantification of air pollution concentrations at a variety of spatial and temporal scales [1]. Air quality modelling can serve as an effective tool to evaluate potential air pollution mitigation policies. Owing to recent advances in High Performance Computing, air quality models have been widely used in many applications [1,2]. This study simulated street-scale resolution air quality for the West Midlands (WM) region (~902 km^2) in the UK using a multiscale air quality modelling system, i.e. the ADMS-Urban RML (Regional Model Link) system which couples the regional WRF-CMAQ (Community Multiscale Air Quality) model with the local ADMS-Urban model, without double-counting the local emissions.

2 Methodology

CMAQ model version 5.2.1 has been coupled with the meteorological WRF model version 3.9.1 for atmospheric chemistry simulations focused on the region of the West Midlands, UK. A system of 4 nested domains (Figure 1a) has been set up to allow both models to simulate meteorological fields and air pollutant concentrations at spatial resolutions of 27 km, 9 km, 3 km and 1 km. All domains account for 30 vertical levels above the ground, with 9 vertical levels below 1 km height and a surface layer depth of 20 m. Anthropogenic emissions for CMAQ simulations were processed from the National Atmospheric Emissions Inventory [3] for the UK and from the CAMS-TNO emission inventory version 3.1 for north-west continental Europe [4]. Both inventories' annual totals have been temporally distributed according to monthly, weekly, and hourly variations using time varying profiles [5]. The vertical distribution of anthropogenic emissions follows CAMS-TNO profiles. Biogenic emissions obtained from MEGAN model version 3.1 [6] were also incorporated in CMAQ. The baseline year of simulation is 2016.

ADMS-Urban is a local scale air quality model which uses a quasi-Gaussian plume approach to represent the dispersion pattern of air pollution in the atmosphere. It can explicitly model full range of emission sources at high resolution and capture the effect of urban morphology on air pollution dispersion. The model can calculate street scale resolution air quality maps in urban areas. Modelling of the WM using ADMS-Urban as a stand-alone model with measured meteorological and background data was published in [2], local modelling in the coupled system was based on this configuration, with explicitly modelled emission sources shown in Figure 1b.

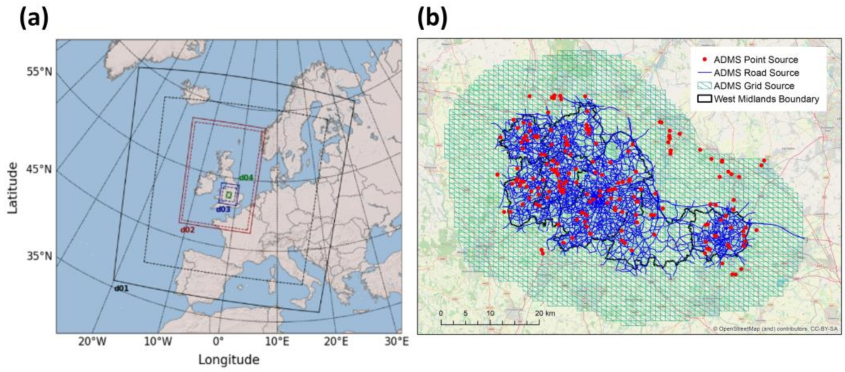

Figure 1. (a) Domain setting in regional WRF (Solid lines) and CMAQ models. (b) Emission sources over West Midlands in the ADMS-Urban model.

The ADMS-Urban RML system [1] nested the local ADMS-Urban model within the regional CMAQ model over WM in this study. This coupled system combines both regional and local scale dispersion and chemical processes without double-counting local emissions, passing regional meteorology and background concentrations into local modelling for each regional model grid cell. This modelling system was installed and run in parallel on HPC clusters at the University of Birmingham.

3 Results and Discussion

Figure 2 plots CMAQ and ADMS-Urban RML model predictions against observations for annual mean NO_2 and $PM_{2.5}$. Both models had good performance in predicting NO_2 for airport and urban background sites. CMAQ had poor performance in capturing NO_2 at roadside sites, while the ADMS-Urban RML had the capability to capture street-scale NO_2 concentrations. For the limited number of $PM_{2.5}$ sites with available observation data in the WM region, both models underestimated measured $PM_{2.5}$ for both urban background and roadside sites. ADMS-Urban RML predicted slightly higher $PM_{2.5}$ concentration for the single roadside site due to traffic emissions.

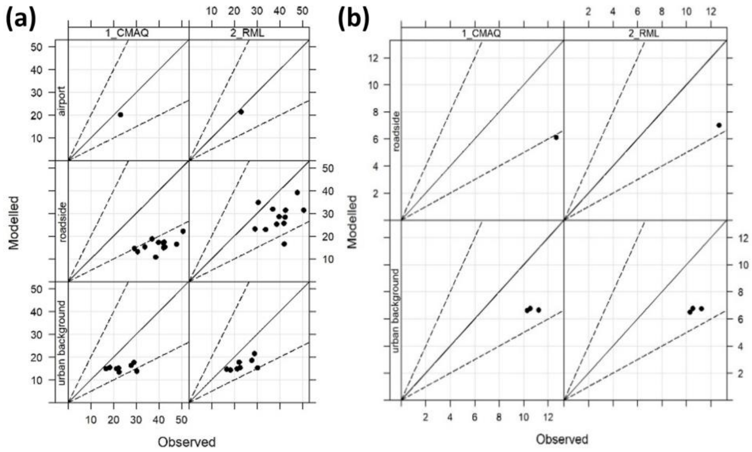

Figure 2. Annual average concentrations from observations, CMAQ and ADMS-Urban RML models: (a) NO_2; (b) $PM_{2.5}$ (both in µg m^{-3}).

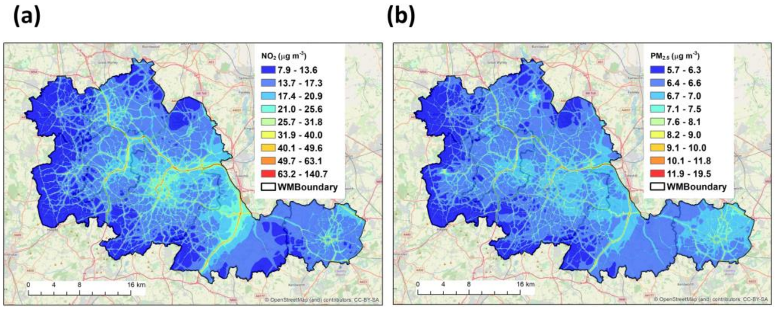

Figure 3. Annual average concentrations of NO_2 and $PM_{2.5}$ at street scale (10 m × 10 m resolution) from the ADMS-Urban RML system.

Figure 3 shows street scale annual average concentrations of NO_2 and $PM_{2.5}$ from the ADMS-Urban RML system. The dispersion of emissions from road sources was captured by the ADMS-Urban model, with higher concentrations predicted for both NO_2 and $PM_{2.5}$ near road sources, especially along motorways and busier major roads. Air quality maps are useful in identifying 'hot spots' where modelled air pollution concentrations are higher than the UK objective values. The street scale air quality maps can also be aggregated to health-related polygon layers such as Lower Layer Super Output Areas or Wards for the assessment of resulting health impacts.

4 Conclusion

This study predicted air pollution concentrations at street-scale resolution for the WM using a regional-to-local coupled modelling system, which combined the regional CMAQ model with the local ADMS-Urban model without double-counting emissions. CMAQ was used to calculate dispersion on large spatial and temporal scales, while ADMS-Urban was used to represent the initial dispersion from explicit point and road sources. Both CMAQ and ADMS-Urban RML predictions were evaluated against observations with reasonable performance, i.e. CMAQ captured air pollution at the airport and urban background sites while the ADMS-Urban RML also captured air pollution at roadside sites. Street scale air quality maps from the ADMS-Urban RML were presented, which could be linked to health-related studies. The coupled air quality modelling system for WM in this study can be used as a baseline tool to assess the effects of specific interventions/policies within the region, such as clean air zones, lower traffic neighbourhoods, climate measures, traffic speed limit changes and adoption of electric vehicles etc., and to provide guidance to reduce air pollution exposure at population level, or for vulnerable sub-groups.

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Questions and Answers

Question: How did the ADMS-Urban RML system avoid double-counting the local emissions?
Answer: The local ADMS-Urban model used concentrations from the regional CMAQ model as urban background conditions. These also included contributions from local emissions, so the concentration field due to initial dispersion from gridded local emissions in the ADMS-Urban model was removed before adding the contribution from the explicit street-scale local emissions.

Question: Can you explain $PM_{2.5}$ evaluation results from the RML system?
Answer: For urban background sites, the RML system predicted concentrations similar to those from the regional CMAQ model, as there was little influence from the explicit road sources. For the roadside site, RML predicted only slightly higher concentrations than the regional CMAQ model as the $PM_{2.5}$ contribution from long-range regional background remained dominant. There were a limited number of available sites for $PM_{2.5}$ within the region.

Question: How did the model capture the effect caused by buildings on air pollution dispersion?
Answer: The ADMS-Urban RML system has a street canyon module which calculates street canyon effects on air pollution dispersion from explicit road sources, and also an urban canopy module which represents the overall flow and turbulence effects caused by buildings within the grids.