MODELLING HIGH RESOLUTION NO_2 CONCENTRATIONS OVER THE UNITED KINGDOM USING RAPIDAIR®

Nicola Masey* and Scott Hamilton
Ricardo Energy and Environment, Harwell, UK

1. INTRODUCTION

Epidemiology studies utilizing air quality models with higher spatial resolution when assigning exposure have identified narrower confidence intervals or differences in the health impact associations identified (Sarnat et al, 2013; Mannshardt et al., 2013). Commonly, a hybrid-modelling approach has been adopted to obtain the high spatial resolution estimates over the large study domains the study participants cover e.g. combination of AERMOD and CMAQ models.

In the UK, regional modelling is carried out at 1 km resolution (Defra, 2019a). This means that any fine-scale variations in pollution concentrations e.g. near road sources, are not captured. This could lead to misallocation of an individual exposure if this model was used in epidemiology studies. This regional model is also used to forecast concentrations in the UK over the coming 5-day period. High pollution alerts could be missed when concentrations are produced at 1 km resolution, meaning individuals may not receive the correct information to plan/reduce their exposures.

The aims of this work were to develop the RapidAIR model to produce regional NO_2 concentrations for the UK at higher resolution than previous models. The RapidAIR model could be used as an alternative high-resolution pollution model for inclusion in an epidemiology study, with the added benefit of providing gridded concentration outputs over the study area (rather than pre-defined receptor concentrations only). In this work, we show regional concentrations for a base year and test a hypothetical regional traffic mitigation scenario.

2. METHODOLOGY

2.1 Traffic Inputs

Traffic flows and speeds on the major road links in the UK were available from the UK National Atmospheric Emissions Inventory (NAEI) database for 2013. This provides a simple breakdown of the flow into car, light goods vehicles, heavy goods vehicles and buses. The study year in this work is 2018, therefore the traffic flows have been projected from 2013 to 2018 using the ratio between the total traffic counts made in the UK in both years.

The fleet used was the average fleet in the UK in 2018 from the default fleet available from NAEI (NAEI, 2017).

2.2 Emissions Calculations

The emissions for each road link in the traffic data were calculated using Ricardo's in-house RapidEMS model. RapidEMS uses COPERT 5 emissions factors to calculate emissions for each link based on its flow, fleet composition and speed.

The traffic data from the NAEI required manipulation to get in the required input format for RapidEMS. This included calculation of the fleet breakdown (%) and assignment of the proportion of petrol and diesel cars. The manipulation of the traffic data was carried out programmatically using Python.

RapidEMS is written in Python 3 (www.python.org) and uses packages including *pandas* and *numpy* to calculate emissions in a computationally efficient manner – in this instance emissions were calculated for all road links in < 5 minutes on a standard 16 Gb laptop. The RapidEMS model directly interfaces with the RapidAIR model to simplify the modelling workflow. As part of this interface, the emissions calculated for each link is automatically joined to the shapefile of major road links in the UK using a unique road link identifier.

2.2 RapidAIR Dispersion Model

The RapidAIR dispersion model is written in Python 3 and uses modern scientific computing methods to produce gridded concentrations for the study area in a computationally efficient manner.

**Corresponding author:* Nicola Masey. Ricardo Energy & Environment, 2nd Floor, 18 Blythswood Square, Glasgow, G2 4BG; e-mail: nicola.masey@ricardo.com

RapidAIR was developed to produce high (< 5 m) resolution concentrations at city-scale. Further information about the RapidAIR model can be found Masey et al., 2018, and an example use case is available in Yang et al, 2019. A schematic of the modelling process is shown in Figure 1.

Meteorological data from surface and upper air stations is required as input to RapidAIR and is used to generate dispersion kernels. Meteorology stations located in a central location for the regional domain were used in this work with sufficient data capture in 2018. This led to the selection of surface data from Waddington and upper air data from Nottingham.

The model domain was selected to cover mainland Britain, an area of 67,000 km^2. The model resolution was set to be 50 m.

The shapefile generated from RapidEMS was automatically passed to RapidAIR and from this, gridded emissions were calculated. A kernel convolution procedure was then carried out to produce gridded road NO_x concentrations over the domain.

When running the model this meant that concentrations in > 26 million cells were calculated. The model was run on an Intel i5 64-bit laptop with 16 Gb RAM and took < 10 minutes to complete.

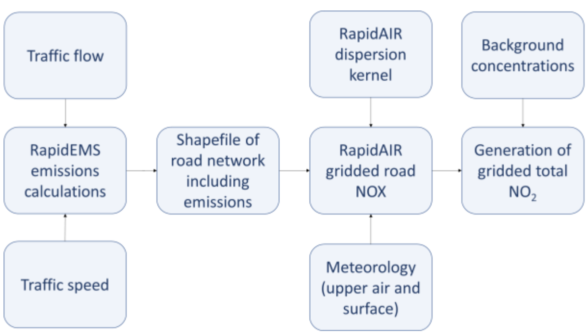

Fig 1. Schematic describing RapidAIR modelling process

2.2.1 Background concentrations

Regional background NO_x concentrations are available in the UK at 1 × 1 km resolution from the Pollution Climate Mapping (PCM) model (Defra, 2019a). Categorizations of the PCM model sources allowed us to remove road transport sources prior to combining the PCM model with the modelled road NO_x concentrations above to prevent double-counting of traffic related pollutants.

2.2.2 NO_x to NO_2 conversion

The modelled NO_x concentrations were converted to NO_2 as this is the legally mandated directive pollutant. We used the Defra NO_x to NO_2 model for the conversion (Defra, 2019b), which is recommended for use in UK air quality assessments. A polynomial regression equation between predicted NO_x and NO_2 concentrations was derived from the DEFRA tool, which was then applied to the modelled concentrations to obtain NO_2 estimates.

2.2.2 Model evaluation

Modelled NO_x was extracted from the gridded outputs of the RapidAIR model at UK Automatic Urban and Rural Network (AURN) monitoring station roadside sites (Defra, 2019c). The modelled NO_2 concentrations were compared to the measured NO_2 concentrations at these sites.

2.3 Regional Modelling Scenarios

In this work we test a baseline model and a road transport mitigation scenario. The base year selected was 2018 as this is the most recent year of measurement data.

The mitigation scenario was designed to test a hypothetical mitigation measure applied regionally. We assumed implementation of legislation in 2018 that forced all vehicles to be Euro 6/VI. The fleet in the emissions calculations was updated to reflect this scenario, while everything else remained unchanged between the baseline and scenario run.

3. RESULTS & DISCUSSION

3.1 2018 Baseline NO_2

Regional concentrations over the UK are shown in Figure 2 at 50 m resolution. Elevated concentrations are observed over the main cities and motorways in the UK. Comparison of the predicted NO_2 and measured NO_2 concentrations at the AURN stations in the UK showed FAC2 = 0.91 (n = 52).

The sites falling outside of a factor of 2 of the measurements were located in complex urban morphology locations e.g. street canyons. Concentrations in street canyons are often elevated due to recirculation effects which are not captured in regional models due to their spatial scale.

Concentrations have also been demonstrated to drop off rapidly moving away from road sources (Gilbert et al., 2003). The sites selected for evaluation were all roadside site, and consequently the modelled concentrations at 50 m resolution will average out these fine-scale variations.

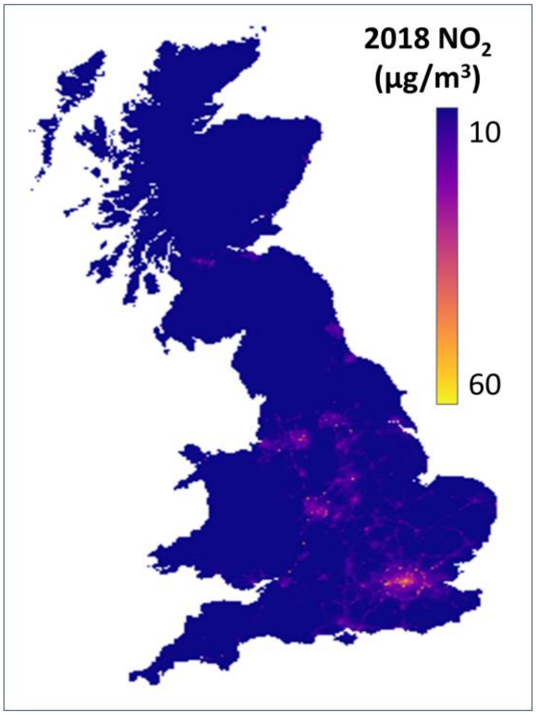

Fig 2. Modelled NO_2 concentrations at 50 m resolution in UK (2018 baseline)

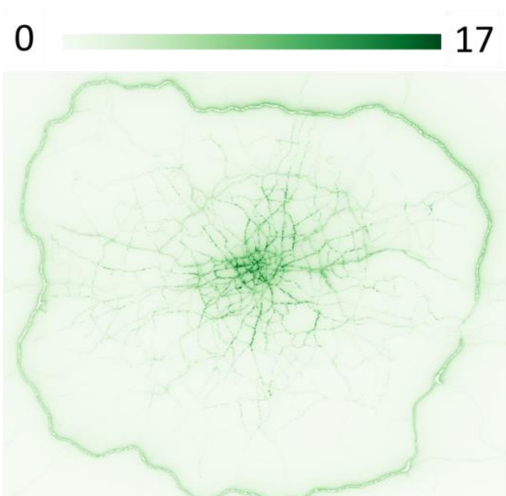

Fig 3. Difference between modelling NO_2 concentrations in 2018 baseline and 2018 Euro 6/VI scenario

3.2 2018 Scenario NO_2

The Euro 6 scenario NO_2 concentrations show an average reduction of 7 % compared to modelled 2018 baseline concentrations at the AURN sites.

Larger reductions are apparent in more urban locations. Figure 3 shows the difference in NO_2 concentrations between the baseline and Euro 6 scenario in London. In London, reductions of up to 17 µg/m³ NO_2 are observed.

3.3 Discussion

The RapidAIR model has been used to successfully produce gridded concentrations over the UK at higher resolution that published data. The advantages of higher spatially resolved data include: better allocation of concentrations for health studies; ability to make more resolved air quality forecasts allowing the public to make better informed choices; and ability to test large-scale mitigation measures and establish any interactions e.g. between cities of any mitigation measures applied.

This work has demonstrated RapidAIR as a suitable candidate for regional modelling. However, there are a number of improvements that could be made to the regional RapidAIR model:

- Use of domain splitting to allow multiple meteorological stations to be used as model inputs. The use of a single meteorological station is unlikely to be representative of all areas in the domain.
- Similarly, domain splitting can be applied to distinguish different land use classes e.g. urban or rural, and consequently apply different surface roughness factors accordingly.
- No canyon or gradient effects have been accounted for. This can have a pronounced effect on local concentrations and should be included in future. The allocation of individual canyons in a regional domain is likely to be very time-consuming. Previous research demonstrated the use of geospatial surrogates to account for canyon effects providing building height data is available (Masey et al., 2018).
- While 50 m resolution is an improvement on current regional models, further improvements in spatial resolution would ensure that any concentration gradients

moving from source were captured more accurately.

The limitations identified above will be addressed in future work.

4. CONCLUSIONS

We have used the RapidAIR model to successfully produce gridded regional concentrations over the UK at higher resolution than has been previously available. The use of Python has simplified the modelling process and allowed the regional estimates to be made quickly and as computationally as possible.

A baseline year of 2018 was modelled along with a hypothetical mitigation scenario targeting road transport emissions. The NO_2 concentrations from the baseline model were within a factor of 2 of AURN measurement site concentrations in 91% of cases. The scenario concentrations were lower than the baseline scenario and demonstrated that regional interventions could be tested using this method.

Further improvements to the model including modelling at higher resolution, inclusion of street canyons and domain splitting should further improve the model verification and will be the focus of future model development.

The RapidAIR model is transferable between countries and could be combined with a larger regional background model instead of UK background map concentrations to produce high resolution concentrations. The added benefit of using RapidAIR over other near-source dispersion models is the production of gridded concentrations as output. This means concentrations at any location in the study area can be identified, allowing for concentrations to be sampled during post-processing. This has applications for e.g. sampling concentrations for new members added to a health study, or combination with GPS data to establish an individuals' concentration throughout the day.

5. REFERENCES

Defra, 2019a: Background Mapping data for local authorities – 2017. Accessed 14/10/19, https://uk-air.defra.gov.uk/data/laqm-background-maps?year=2017

Defra, 2019b: NO_x to NO_2 Calculator. Accessed 14/10/19, https://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html#NOxNO2calc

Defra, 2019c: Automatic Urban and Rural Network (AURN). Accessed 14/10/19, https://uk-air.defra.gov.uk/networks/network-info?view=aurn

Gilbert, N.L., S. Woodhouse, D.M. Steib and J.R. Brook, 2003: Ambient nitrogen dioxide and distance from a major highway. *Sci Total Env*, **312,** 43-46

Mannshardt, E., K. Sucic, M. Fuentes, B, Reich, C. Frey and W. Jiao, 2013: Comparing exposure metrics for the effects of speciated particulate matter on population heath outcomes. *Journal of Exposure Science and Environmental Epidemiology*, **23**, 627-636

Masey, N., S. Hamilton, and I.J. Beverland, 2018: Development and evaluation of the RapidAIR dispersion model, including the use of geospatial surrogates to represent canyon effects. *Environmental Modelling & Software*, **108**, 253-263

NAEI, 2017: Vehicle fleet composition projections. Accessed 14/10/19, https://naei.beis.gov.uk/data/ef-transport

Sarnat, J.A., and Coauthors, 2013: Spatiotemporally-resolved air exchange rate as a modifier of acute air pollution related morbidity in Atlanta. *Journal of Exposure Science and Environmental Epidemiology*, **23**, 606-615

Yang, D., S. Zhang, T. Nui, Y. Wang, H. Wu, K.M. Zhang and Y. Wu, 2019: High-resolution mapping of vehicle emissions of atmospheric pollutants based on large-scale, real-world traffic datasets. *Atmospheric Chemistry and Physics*, **19**, 8831-8843