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Original article

A risk based application of the regional model CMAQ to policy decisions

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A B S T R A C T

A risk based approach to assessing compliance with EU limit values is described, using the advanced chemical transport model CMAQ to determine the regional component of NO_2 and particulate matter under various conditions over the UK. A new air quality data analysis retrieval tool AirDART is used to extract concentrations for selected areas of the country. Roadside concentrations in a street canyon are then calculated using a dispersion model. The two model calculations need to be combined to obtain concentrations in future years assuming appropriate changes in emission. To merge the local and regional contributions exactly requires assumptions regarding parameterisations and is computationally expensive. From a risk based viewpoint not every possible condition need be considered in order to make policy decisions. Instead future trends under typical conditions are estimated, allowing the direct effect of local action plans and of national measures to be assessed. The approach is applied to London, this being a worst case UK example, to demonstrate the procedure.

1. Introduction

Meeting EU air quality limit values is a challenging issue in the UK and Europe. The European Commission published a new policy at the end of 2013 (see http://ec.europa.eu/environment/air/clean_air_policy.htm) with plans to introduce new measures including a Medium Combustion Plant Directive, but no wholesale revision of the national approach to regulating ambient air quality is proposed. In parallel, within the UK, a system of local air quality management has been in operation since 1996 to review, assess and remediate air quality within local government administrative areas. Monitoring only provides current and past levels of air pollution at a limited number of sites, so both the national and local regimes involve emissions and modelling to derive projections of future air quality at locations where people might be exposed. It may be argued that these two systems have not worked well together (Barnes et al., 2014) and indeed the Commission launched legal proceedings against the UK for its failure to cut excessive levels of nitrogen dioxide, announced in a Press Release (see http://europa.eu/rapid/press-release_IP-14-154_en.htm) on 20 February 2014.

The 2014 EMEP analysis (EMEP, 2014) compares the EU particulate matter(PM) limit values for the protection of human health with the EMEP/MSC-W model calculations for 2012. The EMEP/MSC-W model calculations are based on a 50 × 50 km^2 grid and therefore only generate regional background PM concentrations. On average, the model underestimates annual mean measured PM10 by 22% and PM2.5 by 14%. Clearly, the rural and urban PM levels are higher than those calculated at background sites due to the influence of local sources. The comparison of calculated PM_{10} and $PM_{2.5}$ concentrations with EU limit values can flag up the regions where the regional background particulate matter is in excess of critical values. More detailed, complex analysis, including concentrations generated over scales smaller than the grid size used in the model, are required to produce a local correction in every grid square for more accurate analysis. This paper shows how this may be achieved in an efficient, risk based manner.

The second phase of AQMEII (the Air Quality Model Evaluation International Inter-comparison) extends an earlier regional model inter-comparison assessment to on-line air quality models in which the air quality and meteorological models are coupled together. The PM_{10} and $PM_{2.5}$ concentrations simulated by eight on-line coupled,

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regional models, run by seventeen independent groups from Europe and North America, were compared with each other and with observations (Im et al., 2015) using a common spatial grid with a resolution of about 20 km. The models include a coupled version of WRF-CMAQ. A version of CMAQ, which is run separately from its meteorological driver WRF, was used to generate the results in this paper. Model results were compared with observations from the extensive $PM_{2.5}$ and PM_{10} monitoring networks in Europe and North America. The general tendency of all models to underestimate observed PM_{10} concentrations is attributable to sub-grid scale effects. Monitors may be located near sources causing horizontal gradients within a grid square. In Europe the rural and urban PM_{10} concentrations are substantially underestimated, while $PM_{2.5}$ levels do not show such large underestimates suggesting that the large underestimations in the PM_{10} levels can be attributed, in part, to natural emissions. The majority of the models simulating North American PM_{10} and $PM_{2.5}$ concentrations have smaller, negative biases compared to those simulating the European case, in particular regarding $PM_{2.5}$. Im et al. (2015) suggest this may be because man-made emissions in North America are better known.

The chemical transport models used in EMEP and the AQMEII inter-comparisons demonstrate impressive modelling capability. However there is a fundamental practical and a fundamental theoretical difficulty in applying chemical transport models to air quality policy or decision making. The practical difficulty is the vast amount of output data generated from trying to calculate everything from first principles. The use of a simple data retrieval tool, such as AirDART applied in this paper, is one way to tackle this. The theoretical problem is that the model has a finite spatial resolution and therefore can never provide concentrations on the finest length scale, say at ground-level around roads where concentration variations over length scales of a few metres are important. A risk based approach is applied to the second issue by prioritising where the highest risk occurs, namely near roads in major cities. This is more efficient than nesting a detailed, local model within the chemical transport model, but is clearly less complete. The risk-based approach also means that some double counting of emissions is acceptable.

The need for a local correction may be the reason why a recent assessment of the future air quality around London's major airports, Heathrow and Gatwick, does not make use of a latest type of regional, chemical transport model (See https://www.gov.uk/government/organisations/airports-commission, accessed 15 June 1015). Instead the modelling makes use of a very detailed dispersion model for the local air quality component and uses a semi-empirical model, scaled by emission trends, for the background, regional air quality. In contrast this paper proposes an approach in which the regional component is modelled in a more advanced way, with a simple, local correction applied. It is not suggested that either approach is superior, but applying both modelling methods would provide a measure of the model uncertainty, and uncertainty should always be included in important air quality assessments.

This paper applies results from the complex regional model, CMAQ, of past and future air quality levels described in earlier papers (Chemel et al., 2014). However given the uncertainty inherent in estimating emissions and modelling, a risk based approach to assessing future air quality exceedences is adopted in order to be able to interpret results and to identify where measures to improve air quality should be focused.

This is an alternative to fully coupling a regional model to an urban dispersion model (Beevers et al., 2012) whose very detailed, calculated spatial fields do not eliminate uncertainty. Moreover it cannot be demonstrated that the parameterisation used in the two models are consistent. In this paper regional concentrations are extracted from the CMAQ model output database, using a new air quality data analysis retrieval toolkit AirDART. AirDART allows a general, non-specialist user to extract regional concentrations over the British Isles from a set of CMAQ model runs. In future other regional model output could be added to the AirDART data sets, such as those which contributed to a recent Defra model inter-comparison exercise (Derwent et al., 2014). The AirDART approach is illustrated using the Greater London area, since this is region of the country where concentrations are highest. Typical concentrations from urban roads are added to the regional concentration, including some margin of error, to determine whether in urban hotspots in London limit values will be exceeded. This approach is a more practical way to manage air quality and decide about appropriate measures than attempting a detailed calculation of concentrations in every major street in London, based on imperfect data and model results restricted to specialist users.

2. Availability of results from advanced complex chemical transport models

The pollutants of concern to public health are nitrogen dioxide and particulate matter(PM), which are predominantly secondary pollutants and so their assessment requires the use of regional modelling. In an earlier paper (Chemel et al., 2014) results from the advanced chemical transport model, CMAQ, were used to predict likely future levels of PM in 2020 with calculations for 2006 providing a baseline. This latest paper is one in a series which have demonstrated the feasibility of applying the complex CMAQ model to air quality assessments for the UK, despite the requirement for detailed input data sets and the computational burden involved. The output from chemical transport models, such as CMAQ, is vast containing time series of each chemical species within each grid square throughout the region of the calculation.

In order to make the CMAQ model results accessible to general users, the output from the calculations has been made available on a web site AirDART from which sections and summaries of the data can be downloaded. AirDART is a database containing the results from a number of runs of the chemical transport model CMAQ. It enables a user, who is not an expert in modelling to extract results, long and short-term average concentrations and depositions, for a specific, limited area of interest, in order to assess whether air quality limit values are exceeded. An AirDART demonstration web site is available at http://airdart.ricardo-aea.com, courtesy of Ricardo AEA (The data held on the web site is the property of the Environment Agency and access to the data via the web site should be made to authors of this paper. An AirDART User Guide is available from this site or from the authors.) The computer runs listed in AirDART provide a projection of future air quality over the UK, at 6 km resolution. These are based on realistic estimates of future air pollution emissions, assuming current legislation is implemented and new emission standards, such as those for new road vehicles, provide the expected benefit. Details of the computer runs are provided in the AirDART User Guide but the main features are repeated here.

The model setup, which involves parameterisation of various meteorological and chemical processes in the model, are described in Chemel et al. (2014), but are summarised again here to emphasise the range of parameterisations needed in advanced chemical transport models. The 2006 regional meteorology is based on the WRF meso-scale model. The simulation utilised what was considered best practice at the time amongst the options available, namely, the NOAH land surface model, the Yonsei University planetary boundary layer scheme (Hong et al., 2006), the Morrison microphysics scheme, the Grell and Devenyi convective parameterisation scheme, and the RRTMG (Rapid Radiation Transfer Model for GCM) long wave radiation scheme. Each of these schemes