Operational short term health impact assessment of air pollution modelling system over Europe

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Abstract: The last decade, scientific studies have indicated an association between air pollution to which people are exposed and wide range of adverse health outcomes. We have developed a tool which is based on a model (MM5-CMAQ) running over Europe with 50 km spatial resolution, based on EMEP annual emissions, to produce a short-term forecast of the impact on health. In order to estimate the mortality change (forecasted for the next 24 hours) we have chosen a log-linear (Poisson) regression form to estimate the concentration-response function. The parameters involved in the C-R function have been estimated based on epidemiological studies, which have been published. Finally, we have derived the relationship between concentration change and mortality change from the C-R function which is the final health impact function.

Keywords: health; air pollution; MM5; CMAQ; relative risk; epidemiological studies; C-R functions.

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Biographical notes: Roberto San Jose completed his PhD in 1982 related to the unstable surface turbulent boundary layer parameterisation. He has been involved in air pollution modelling mainly using three-dimensional mesoscale models, such as MM5 and CMAQ. He created the Environmental Software and Modelling Group at Computer Science School of the Technical University of Madrid (UPM) in 1992. He spent one year at the Max-Planck Institute for Meteorology and two years at IBM-Bergen Environmental Sciences and Solution Centre. He has more than 150 publications in different national and international scientific journals. He has been a Full Professor since 2001.

Juan Luis Pérez graduated in Computer Sciences at Computer Science School of the Technical University of Madrid in 2000 and in 2005 he defended a PhD thesis related to operational modelling of the MM5-CMAQ system over the internet. He has been an Associate Professor since 2005 and permanent Professor since 2011. He is involved in some international and national research projects about atmospheric simulations and has published many papers in journals and conference proceedings.

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1 Introduction

Much of the population lives in areas where the concentration of air pollution reaches levels that affect health (WHO, 1995). Numerous epidemiological studies have already shown that human exposure to elevated levels of various ambient pollutants may result in a variety of health effects, depending on the types of pollutants, the magnitude, duration and frequency of exposure and the associated toxicity of the pollutants of concern. Air pollution is a complex mixture of various substances. However, most epidemiological studies find a range of health outcomes to be consistently related to particulate matter (WHO, 2003).

Different pollutants may have widely different concentration-response (C-R) characteristics. The health endpoints associated with exposure to individual air pollutants may include the exacerbation of respiratory symptoms and cardiovascular disease, increased hospital admissions, compromised immune systems, premature death, cancer or impairment of neurological development (WHO, 2000a). The short-term adverse health response may lag the exposure by several hours, up to a period of several days (Lipfert, 1994). Individual susceptibility and the prevalence of health conditions that predispose the exposed population to an adverse response further complicate attempts to accurately estimate the actual site-specific health risk with air pollution (WHO, 2000b). Information of the relationship between exposure and response is necessary to estimate the potential health risks.

The conceptual basis for the estimation of human health impacts is: changes in air quality levels are related to changes in incidence levels for a particular health effect. It accomplishes this by running health impact functions, which relate a change in the concentration of a pollutant with change in the incidence of a health point. For example, in the case of a premature mortality, health impact functions may take into account air pollution change, mortality effect estimate. Air quality change is calculated as the difference between tomorrow and today. The mortality effect estimate is an estimate of the percentage change in mortality due to a one unit change in ambient air pollution. This is done taking into account the C-R function-based of epidemiology studies.

The exposure-response function is the key contribution of epidemiology to the health impact assessment. The functions are reported as a relative risk (RR) for a given change in exposure. Exposure-response functions have been derived from published meta-analyses. The following health outcomes were selected, based on the availability of the exposure-reactions functions: total premature mortality, excluding accidents and violent deaths, cardiovascular mortality and respiratory mortality.

The present system forecasts the short term health impact of air quality, PM10 and O3, over Europe on the health outcomes. So the evaluation of health risk requires the assessment of the actual concentration levels in the air over time (today and tomorrow). Air pollution is forecast from the modelling system (MM5-CMAQ) running over Europe with 50 km spatial resolution, based on EMEP annual emissions. The health effects forecast are: mortality for all causes, mortality for respiratory causes and mortality for cardiovascular causes for PM10 daily average and ozone maximum daily eight hours mean. The final product is the forecast of the European mortality change (%) for tomorrow related today's mortality due to air pollution concentration changes.

2 Methods

The relationship between concentration and health effect is modelled with a log-linear regression (Poisson) as a C-R function. Then the relationship between concentration change and mortality change from the C-R functions and this is the final health impact function, equation (1).

$$\Delta y = y_0(e^{\beta \Delta C} - 1) \quad (1)$$

where y_0 is the baseline incidence rate of the health effect, β is the mortality effect estimation, ΔC is the difference between tomorrow and today air pollution concentration. Our system forecast percentage (%) change of the health effect, so it is independent from the population and the incidence rate. The epidemiological studies do not report the β parameter of the C-R function, they report the RR associated with a given change in the pollutant concentration, but β and RR are related by equation (2).

$$\beta = \frac{\ln(RR)}{\Delta c} \quad (2)$$

The system use the RR values published on the *Meta-Analysis of Time-Series Studies and Panel Studies of Particulate Matter (Pm) and Ozone (O3)* by Anderson et al. (2004). It is part of the WHO project 'Systematic review of health aspects of air pollution in Europe', which is funded by the European Commission and is intended to provide input to the clean air for Europe (CAFE) programme. In this case there is no reference values of concentration for each RR, so concentrations are taken from the operation air pollution modelling system on the cities which have RR values. Also Spanish epidemiological studies are used to get more RR values. These published on the *EMECAM PROJECT: Spanish Multicenter Study on the Relationship between Air pollution and the Mortality*. Figure 1 show RRs from Spanish cities and theirs PM10 daily average concentrations. The period of time throughout which this study was conducted, although not exactly the same for all of the cities involved, runs in all cases from 1990 to 1996 (Barcelona 1991–1995, Bilbao 1992–1996, Pamplona 1991–1995, Vigo 1991–1994, Gijon

1993–1996). Figures 2 and 3 show the RR values used for different European cities included in the system.

Figure 1 RR and PM10 daily average for all causes mortality

Figure 2 RR for all causes mortality for the PM10 daily average

Figure 3: RR for all causes mortality for the O₃ maximum octoh. average

The air pollution concentrations are taken from the air quality real-time operational forecasting system which covers all Europe by using the MM5-CMAQ-EMIMO air quality modelling system. It uses the MM5 meteorological mesoscale model developed by Pennsylvania State University (USA) and National Centre for Atmospheric Research (NCAR, USA) (Grell et al., 1994). The CMAQ model is the community multiscale air quality modelling system developed by EPA (USA) (Byun et al., 1998) and EMIMO is the emission model developed by San José et al. (2003) (San José et al., 1997). MM5 is a well-recognised non-hydrostatic mesoscale meteorological models which uses global meteorological data produced by global models such as GFS model (NCEP, USA) to produce high resolution detailed three dimensional fields of wind, temperature and humidity which are used in our case as input for the photochemical dispersion model CMAQ (San José et al., 2008). In addition to the MM5 output data, EMIMO model produces for the specific required spatial resolution, hourly emission data for different inorganic pollutants such as particulate matter, sulphur dioxide, nitrogen oxides, carbon monoxide and total volatile organic compounds VOCs. The VOCs are split according to sparse matrix operator kernel emissions (SMOKE) (Williams et al., 2001; Flassak and Moussiopoulos, 1987).

In this particular case, the EMIMO model is applied by using the annual EMEP official emissions from 2003 for the whole of Europe. The full system is called OPANA V3 since the V2 included adaptations of the MEMO model (REMEST) and online implementation of the sparse matrix vector gear technique (SMVGEAR) implicit technique with the CBM-IV chemical carbon bond mechanism.

Since December, 2005 the system is producing air quality forecasts for the whole of Europe with 50 km spatial resolution. The results are shown on the internet for the next 96 h including the actual day. Figure 4 shows an example of the capabilities of the system.

Figure 4 European operational air quality forecasts by using MM5-CMAQ-EMIMO (OPANA V3) for 13 April 2013 for ozone maxima

The system has been evaluated by comparing the modelling results and the observed results in different air quality monitoring stations (San José et al., 2008). In general agreement is quite good. The emission uncertainties are partly responsible for the lack of accuracy in results obtained by air quality modelling (van Aardenne, 2002). The major uncertainties of the estimation of emission comprise the accurate estimation of the quantity of the primary emissions, the role of the temporal distribution of the emissions, the desegregations of particles and volatile organic compounds and vertical profiles (de Meij et al., 2006).

By each grid cell and health indicator, the system searches the city with the air pollution levels close to the level of the grid cell and it chooses the RR associated to the selected city. It calculates the concentration change between tomorrow and today and finally forecasts the mortality change for tomorrow using the log-linear C-R function.

3 Results and conclusions

Figure 5 shows an example of forecast daily mortality change (%) by ozone for tomorrow, 11 June 2013 related to today. It is mortality for all causes with ozone 8 h average as air quality indicator. We can see increases up to 5% over Mediterranean area and Germany. Figure 6 shows forecast of daily mortality change (%) by particles for tomorrow, 11 June 2013 related to today. It is mortality for all causes with PM 24 h average as air quality indicator. We can see that the mortality will be the same or light decreases by PM.

Figure 5 Example of the European air pollution short-term health impact forecast by UPM. Daily mortality change (%) by ozone for tomorrow 11 June 2013

Figure 6 Example of the European air pollution short-term health impact forecast by UPM. Daily mortality change (%) by particle for tomorrow, 11 June 2013

We have developed an operational health impact system based on the MM5-CMAQ operational air quality forecasts over all Europe with 50 km spatial resolution. The tool can be used to assess the impact of atmospheric pollution on human health for European people. The impact can be estimated as change in all-causes, cardiovascular and respiratory mortality for short-term exposure to ozone and particles, considering short-term effect, usually particles have the greatest health impact.

The system has been fully operational since the beginning of 2013; results can be visualised at <http://ind1.lma.fi.upm.es/eu-health>. The system is fully automated, meaning that the entire procedure of running the models and producing the visualisations is controlled by automated scripts. The results are checked every day and we can conclude that results show a high sensitivity to the dynamical meteorology and chemical components in the atmosphere. The impact of air pollution in the mortality is very important (percentages higher than 20% are very common). The system offers an effective and easy tool, helpful in health services organisation and decision-making.

The approach is that the health impact focuses on individual compounds without considering the simultaneous exposure to several, which is what actually occurs. The interactions between different contaminants require a good knowledge of the mechanisms of toxicity for the different compounds, which is rarely available. In order to take account of co-exposure to different pollutants, it can be assumed that the health effects of individual compounds are additive. Finally the tool is based on assumptions that local situations are similar to the reference conditions used in the epidemiological studies from which the exposure-response coefficients are derived. Uncertainties at emission estimated, calculated ambient concentrations, epidemiological C-R relationships cannot be forgotten but the system can provide valuable and important information.

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