Health Impacts of the Urban Climate and Air Quality under Two Different IPCC Scenarios

Roberto San José¹, Juan L. Pérez¹, Libia Pérez¹, Rosa M. González², Julia Pecci³, Antonio Garzón³, Marino Palacios³ and Leonhard Suchenwirth

¹Environmental Software and Modelling Group, Computer Science School, Technical University of Madrid (UPM), Madrid, Spain. Corresponding author: Roberto San Jose, roberto@fi.upm.es, +34 91 3367465
²Department of Meteorology and Geophysics, Faculty of Physics, Complutense University of Madrid (UCM), Ciudad Universitaria, 28040, Madrid, Spain.
³Indra S.A., C/ Mar Egeo, 4, Pol. Industrial 1, 28830 San Fernando de Henares, Madrid, Spain.
⁴GeoVille Information Systems GmbH, Sparkassenplatz 2, 6020 Innsbruck, Austria.

Received [30 July 2015]; Revised [17 November 2015]; Accepted [20 February 2016]

Abstract: The objective of this research is to quantify the future (2030, 2050 and 2100) short-term health effects of the global climate over five European Cities: Madrid, Antwerp, Milan, Helsinki and London with very high spatial resolution (200 meters) respect to the present (2011) under two IPCC climate projections RCP 4.5 (stabilization emission scenario) and RCP 8.5 (increase emission scenario). To go from global resolution to high urban resolution an integrated modeling system with feasible computational costs was used. We apply a mixed dynamical-diagnostic approach: from the global scale to regional (25 km. over Europe) using the dynamical WRF-Chem model and from the regional to urban scale with the diagnostic meteorological model CALMET and CMAQ is used to downscale the air quality data. The 8.5 scenario is characterized by temperature increases from 2050, reaching the maximum impact in 2100, especially in Madrid and Milan with large increases. The biggest impacts of health effects by the pollutants are Respiratory mortality due to O3 (Antwerp, Milan and London), Hospital admissions due to O3 (Helsinki) and Cardiovascular mortality by PM10 (Madrid).

Keywords: Health impact, climate, air pollution, downscaling
I. INTRODUCTION

Climate change can affect air quality by meteorological variables such as temperature, precipitation and/or solar radiation. A current research challenge is to implement tools that allow us to calculate the impact of climate change on air quality and health of citizens at the urban level [1]. At present more than half the world's population lives in urban areas [2] and by 2020 nearly 80% of Europeans live in cities. The urban population growth rate is more rapid in developing countries, so urban climate is an important issue for the people living in the cities. The future of air quality, however, is not just a matter of emissions. We also need to consider global climate change with the aim to integrally assess impacts on air quality (ozone and particles) and local climate (heat waves, apparent temperature), as well as the effects on population health. In addition, due to the interdisciplinary nature of the subject, this task requires the collaboration of professionals from various areas such as climate science, air quality and public health.

In the cities, climate change affects the levels of air pollution because production, dispersion and deposition of pollutants, such as ozone and particulate matter depends in part on the local values of temperature, wind, solar radiation and precipitation [3]. Then, knowing the present and future impacts of climate change on air quality as well as on mortality and morbidity of citizens should be a priority for researchers. Keep in mind that to be studying urban areas need information from very high resolution to capture the high spatial variability of air pollution within a city [4]. Downscaling processes and procedures provides climate change information at a suitable spatial and temporal scale. To simulate regional/local weather and air quality dynamics, results from global models are downscaled using dynamical downscaling. The starting point of dynamical downscaling is typically a set of coarse-resolution large-scale meteorological fields (either from a general circulation model, GCM, or from global reanalysis data) which are used to provide the initial, and lateral and surface boundary conditions to a regional climate model (RCM). Typically, the RCM simulation does not feed back into the GCM, but adds regional detail in response to finer-scale forcing (e.g., topography, land use/land cover) as it interacts with the larger-scale atmospheric circulation [5]. In this study, we have implemented a downscaling technique using an RCM and a local diagnostic model to analyze the implications of climate change on local weather and air quality in urban areas.

Our goal is to quantitatively estimate the local impact on health due to global climate on the cities to enable the authorities to implement the most appropriate policies and strategies to minimize the effects of climate on citizens. Rapid advances in computing and atmospheric physics, especially in using downscaling techniques offer new opportunities to investigate health problems related to urban climate [6].
One of the first health impact assessments of future climate conditions study with tenths of kilometres of resolution was over greater New York region [7]. This work is focused in very high resolution (200 meters). The system takes outputs from a global climate model to produce detailed information on meteorology and chemistry using a dynamical downscaling procedure with 25 km spatial resolution covering all Europe. In addition we use a diagnostic downscaling procedure to produce urban meteorological and air pollution maps with 200 m spatial resolution. At the city level, a simplified chemical-transport model is used to understand the spatial distribution of the pollutants using high resolution meteorological inputs which have been produced by the diagnostic model.

This work is part of FP-7 EU DECUMANUS project. The aim of this project is the development and consolidation of a set of sustainable decision support services that allow city managers to deploy geo-spatial products in the development and implementation of their energy efficiency and climate change strategies, in meeting the diverse challenges of sustainable urban planning and development. The DECUMANUS services will offer information to the end users (city managers). The information will be produced by the scientific team operating the proposed tools as the dynamical technique described in this research work for urban and health information.

II. METHODOLOGY

The modelling system was used to simulate the climate and air quality for present year (2011) and future years (2030, 2050 and 2100) using 2011 emissions as control run, because we want to investigate the effects on the global climate on the actual (2011) cities. Under following two IPCC (Intergovernmental Panel on Climate Change) scenarios based on the Fifth Assessment Report (AR5) and on the Representative Concentration Pathways (RCP): 4.5 and 8.5. The RCP 8.5 [8, 9], is characterized by increasing greenhouse gas emissions over time and represents scenarios in the literature leading to high greenhouse gas concentration levels. This can be considered as a non-mitigation business as usual scenario with high emissions. RCP 4.5 is similar to the lowest-emission scenarios (B1) assessed in the IPCC AR4. The RCP 4.5 [10, 11] is a stabilization scenario where total radiative forcing is stabilized around 2050 by employment of a range of technologies and strategies for reducing greenhouse gas emissions. This can be considered as a weak climate change mitigation scenario.

Outputs from the Community Earth System Model (CESM) version 1.0 were used for global climate data. The six hourly global climate outputs (RCP 4.5 and RCP 8.5) have been published in the Earth System Grid (ESG, https://www.earthsystemgrid.org/home.htm), and are available for use by the research community. Also, one simulation (NNRP) with a real-present scenario (reanalysis data) has been run for the year 2011. This simulation will be used as validation simulation of the modelling system.
The global climate model outputs using the RCP 4.5 and RCP 8.5 climate scenarios are being regionally downscaled by using the WRF-Chem model [12]. The regional and urban air quality model (CMAQ) [13] is driven by the meteorology produced by the diagnostic model CALMET [14] with the emissions produced by EMIMO (UPM) (EMIssion Model) [15] model for 2011. We have used an adapted version of CMAQ for this task using “linear chemistry” (CMAQL) which reduces on about 50% the total computational time. The emissions are the same for the four year simulations (2011, 2030, 2050 and 2100) and for the two RCP climate scenarios (4.5 and 8.5) because in these simulations we only change the initial and boundary conditions. Urban models for simulation of meteorology and air quality uses the boundary conditions and initial values supplied by the air quality model at European level (WRF-Chem 25 km.). Surface concentrations calculated at 1 km spatial resolution in the urban air quality simulations scale are finally refined to a grid with a spatial resolution of 200 meters by using a tool called interpolation Cressman objective analysis. [16]. This scheme is used to develop meteorological fields and air quality concentrations for present times (2011) and future times (2030, 2050 and 2100). All simulations have been run for full year time period. The simulation methodology is summarized in the Figure 1.

Figure 1 Conceptual overview of the model chain system used in the present study.
The methodology to estimate percentages of climate/pollution-related deaths and hospital admissions due to global climate are based on epidemiologic analysis of weather/air pollution and health data to characterize and quantify mortality/morbidity associations. The exposure-response relationships estimated from the epidemiological studies were applied to projections of climate. The short-term relationship between the daily number of deaths/hospital admissions and day-to-day fluctuations in exposure variables (temperature, heat waves, ozone and particles) for many cities are published in different scientific papers.

The estimated percentage of mortality/morbidity attributable to exposure variables: temperature, heat waves, ozone concentrations or particles concentrations are calculated by day to day and them average to month and year periods. Several health effects or outcomes are calculated for mortality and morbidity: All causes mortality, cardiovascular mortality, respiratory mortality, respiratory hospital admissions and cardiovascular hospital admissions. These outcomes are for all ages, except in case of the heat waves where mortality + 65 years old are calculated. The short-term health effects of the heat are analyzed based on two exposure variables: Apparent Temperature (AT) and Heat waves (HW). Only summer months (June-August) are considered to study the health effects of the heat waves days. Exposure to heat waves takes into account the extreme day values using the maximum apparent temperature (ATMAX) and high night temperatures by the minimum temperature of the day (TMIN). Heat waves days were defined as days with ATMAX exceeding a threshold value or days in which TMIN exceeds other threshold value. For air quality indicators we have used PM10 and O3 pollutants. For PM10 the exposure indicator is the daily mean and for ozone we used the daily maximum 8-hour average. The health outcomes have been chosen based on data availability in agreement with the data uses in the epidemiological studies providing RRs. The relationship between the exposure variable and its effect on health is defined with a log-linear regression (Poisson) and is called exposure-response function (ER). If we derive this function we obtain the Equation 1 [18], which calculates the change in mortality or morbidity by a change in the exposure variable.

\[
\Delta y = y_0 (e^{\beta \Delta C} - 1) \tag{1}
\]

Where \( y_0 \) is the baseline incidence rate of the studied health effect, \( \beta \) is a parameter which define the mortality effect estimation from epidemiological studies, \( \Delta C \) is the change of the exposure variable (future minus present). Our system calculate percentage (%) of change of the health effect, so it is independent from the population and the incidence rate. The epidemiological studies do not report the \( \beta \) parameter of the C-R function, they publish the relative risk (RR) associated with a given change in the exposure variable, but \( \beta \) and RR are related following the Equation 2 [19].

\[
\beta = \frac{Ln(RR)}{\Delta C} \tag{2}
\]
III. RESULTS

Results of the modelling system have been evaluated using data from the local meteorological and air quality network of the cities with a variety of metrics are used to evaluate model performance. For validation we have compared the hourly model outputs for present conditions (2011) following reanalysis scenario (NNRP) to hourly observations. A statistical evaluation of the pairing of the gas species outputs (SO2, NO2, CO, O3 and PM10) and meteorological parameters (temperature, wind and precipitation) in time (hourly) between WRF/Chem-CALMET-CMAQL outputs and monitoring stations datasets is shown in the next table. There are three metrics, Normalized Mean Bias NMB, Root Mean Standard Error (RMSE) and the correlation coefficient (R2). The results of the comparison between the modeled data and the observed data show that the simulated concentrations are within the ranges of measured data. The simulated concentrations regarding the observed O3 concentrations are somewhat lower in Antwerp and Milan indicating that simulations of climate and air quality for the current conditions, underestimate the concentrations of O3. Generally we have found a slight overestimation of the modeled values compared to those observed. The underestimation of ozone can be attributed to overestimated surface wind speeds and/or underestimations of emissions. Wind speed is over-predicted for all cities. The high bias of the wind speed is mainly due to a poor representation of surface drag caused by the unresolved topography in the 25 km. resolution of the cells of the European domain of WRF-chem. The average simulated levels are within the inter-annual variability of the measured since most of the R2 values exceed the value of 0.5. The statistical evaluation shows strong evidence that high resolution downscaling procedure could achieve reasonably good performance, particularly for BIAS and R2 statistics [17].

In this part of the document, we show examples of the spatial distribution of the forecasted health impact for the 2100 year under the two IPCC climate scenarios (4.5 and 8.5) over the five European cities: Madrid (Figure. 2a and 2b), Helsinki (Figure. 3a and 3b), Milan (Figure. 4a and 4b), Antwerp (Figure. 5a and 5b) and London (Figure. 6a and 6b) for different health outcomes.
Figure 2. Year 2100, differences (%) of annual mean changes short-term cardiovascular mortality due to PM10 daily average concentrations over Madrid (200 m.) under RCP 4.5 (a) top) and RCP 8.5 (b)bottom) climate scenarios respect to 2011.
Figure 2a shows increases of cardiovascular mortality up to 0.37% by PM10 under 4.5 scenario and spatially the highest values of the health impact appear to be concentrated into the city center (area with high population density) but opposite effect is expected under 8.5 scenario, Figure 2b, with liglity reductions in the city center.

Figure 3. Year 2100, differences (%) of annual mean changes short-term respiratory hospital admissions due to O3 8 hours average maximum concentrations over Helsinki (200 m.) under RCP 4.5 (a) top) and RCP 8.5 (b) bottom) climate scenarios respect to 2011.

Figure 3a shows an estimated increase in annual average of the hospital admissions due to O3 concentration between 0.05% and 0.08% for 2100 year respect to 2011 under the RCP 4.5 but an decrease is expected under the RCP 8.5, Fig 3b. The major impacts are located in the North of the Helsinki area.
Figure 4 Year 2100, differences (%) of annual mean changes short-term respiratory mortality due to heat waves days over Milan (200 m.) under RCP 4.5 (a) top) and RCP 8.5 (b) bottom) climate scenarios respect to 2011.

Figure 4b shows than the year 2100 can be increases up to 64% in the mortality with respiratory causes due to heat waves for people with more than 65 years old under RCP 8.5 and opposite effect are showed in the RCP 4.5, Fig 4a. So the efforts to reduce emissions following the RCP 4.5 scenario will produce improve the people health.
because the temperature of the Milan will be reduced.

Figure 5. Year 2100, differences (%) of annual mean changes short-term respiratory mortality due to O3 8 hours average maximum concentrations over Antwerp (200 m.) under RCP 4.5 (a) top) and RCP 8.5 (b) bottom) climate scenarios respect to 2011.
Figure 5a and Figure 5b show that in case of Antwerp the mortality with respiratory problems due to O3 concentrations will be reduced for 2100 year under the two studied climate scenarios, so global climate in this case it is not a big problem for the health of the cities. The major reductions is expected in the South of the city under the RCP 4.5 scenario.

Figure 6. Year 2100, differences (%) of annual mean changes short-term respiratory mortality due to maximum daily apparent temperature (AT) over Kesington and Chelsea (London) (200 m.) under RCP 4.5 (a) top) and RCP 8.5 (b) bottom) climate scenarios respect to 2011.
Figure 6a and Figure 6b show that in case of the Kesington and Chelsea area (London) the mortality with respiratory problems due to increments of the apparent temperature (AT) will be increased for 2100 year under the two studied climate scenarios, so global climate in this case it is a big problem for the health of the citizens, specially under the RCP 8.5 scenario with increases up to 5.3%.

IV. CONCLUSION

This research has shown an example of the assessment of the impact of global climate change on urban climate, air quality and health; the information provided by the presented tool can be used for integrated assessment of air pollution and climate change adaptation and therefore develop more appropriate mitigation strategies. We have studied the impact of climate change over five European cities, Madrid, Antwerp, Milan, Helsinki and London (Kensington and Chelsea area) with 200 m spatial resolution, using two different future projections of global climate: RCP 4.5 and RCP 8.5 scenarios. The modelling system was used to simulate climate and air quality for present (2011) times and future (2030, 2050 and 2100) times, using 2011 emissions inventory, because we were interested on knowing the impact of future climate projections in urban domains with very high spatial resolution. So that, only one input data, -boundary conditions from climate model projections-, is changed in each simulation. We compare the future years 2030, 2050 and 2100 with control year 2011 from a health impact point of view. Comparison of simulations for present situation (2011, with reanalysis data as boundary and initial conditions) shows acceptable agreement with measurements in the urban background for climate realizations.

The biggest impacts of health effects by the pollutants are Respiratory mortality due to O3 (Antwerp, Milan and London), Hospital admissions due to O3 (Helsinki) and Cardiovascular mortality by PM10 (Madrid). In the 4.5 scenario reductions occur in all variables related to temperature values, except in 2050 Madrid which increases are founded. The 8.5 scenario is characterized by temperature increases from 2050, reaching the maximum impact in 2100, specially in Madrid and Milan with large increases. Due to 4.5 scenario is characterized by decreases in temperature, this situation produces improvements in mortality by climate, specially during 2100 over Milan. 8.5 scenario is the opposite and results show increases in the human health problems by temperature. The worst impacts are expected over Milan and Madrid, 2100. The impact on Milan is double than of Madrid and Madrid impacts are 3 times more than over Helsinki, Antwerp and London.
ACKNOWLEDGMENT

The UPM authors acknowledge the computer resources and technical assistance provided by the Centro de Supercomputación y Visualización de Madrid (CeSViMa). The UPM authors thankfully acknowledge the computer resources, technical expertise and assistance provided by the Red Española de Supercomputación.). We acknowledge the DECUMANUS EU project from EU Space Call FP7-SPACE-2013-1 at SPA.20131.1-06

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