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EFFECTS OF CLIMATE CHANGE ON THE HEALTH OF CITIZENS MODELLING URBAN WEATHER AND AIR POLLUTION

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Abstract

A dynamical downscaling tool has been implemented to understand the impacts of global climate on citizens health. We have used the WRF-Chem mesoscale model (NOAA, USA) to produce information covering Europe with 25 km of spatial resolution and two nested domains with 5 km and 1 km of spatial resolution over London. Finally, detailed simulations are carried out using the MICROSYS-CFD model to take into account the effects of urban buildings on the urban atmosphere in the Kensington and Chelsea area. The tool produces very high spatial air quality and meteorological data (50 meters) and also temporal resolution (1 hour) to estimate health impacts in the short term, using exposure-response functions extracted from epidemiological studies. The comparison shows an acceptable agreement of the modelled data with the measurements. The effects on the health of citizens by temperature change in the future are more important than by changes in atmospheric pollutant concentrations. The maps show how the effects depend on the city's geometry and how the tool can highlight the most vulnerable areas to help to design plans and implement strategic measures to mitigate the effects of global climate change on people's health.

Keywords: health, climate, downscaling, impact, urban

INTRODUCTION

There are several ways for addressing climate change effects, for example by taking actions to reduce Green House Gases (GHG) emissions from the transportation sector [1], but we need complex modelling tools that could help to support air pollution mitigation strategies [2] and develop efficient energy strategies [3]. City areas are those areas where the local response to global climate change is mostly marked. [4]. Previous studies have shown that global climate change will have a significant impact on both local climate and urban air quality [5]. Air pollution and extreme temperatures can affect human health by modifying mortality and morbidity rates [6]. The development of resilience strategies that avoid the effects of climate change on health is a major challenge to which the scientific community must contribute [7]. Urban climate patterns and air pollution are strongly influenced by topography, land use, buildings, etc., so studies of urban areas need very high spatial resolution information to capture the spatial and temporal variability of weather conditions and air pollution in a city [8].

There are two methods for downscaling future climate projections to finer spatial scales: a) dynamical downscaling and b) statistical downscaling. Dynamical downscaling is a method based on the application of Regional/urban Climate Models (RCMs) on a specific area where the model receives boundary and initial conditions from the global climate model. Typically, RCM simulation does not feed back into the Global Climate Model (GCM), but adds regional/local information to the situations predicted by the global model which did not know these local details because of the coarser spatial and temporal resolution. The difficulty of this procedure is the very high computational demand. The statistical downscaling produces variables at the local level based on the relationships between observations and global model data, which are then applied in future climate projections. The main advantage is that the procedure is not very computationally demanding. However, the method is of limited value because observations are needed and furthermore, the relationships derived from the present may not be true in the future. In addition the statistical methods do not take into account all internal physical, chemical and geographical characteristics so the limitations to analyse why the results are produced are obvious compared with the dynamical method.

In our case, we propose a dynamically downscaling methodology of climate and air pollution that combines the state of the art of meteorological and air quality models with the objective of transforming the global model outputs into high spatial resolution products. To dynamically downscale a global model, we need a Regional Climate Model (RCM) forced by global fields in initial and boundary conditions [9]. Atmospheric flux and urban climate are influenced by city features which enhance atmospheric turbulence and change the turbulent transport, dispersion and deposition of air pollutants [10]. In the case of urban areas with their buildings, streets, etc., local/regional resolution (Kms) is not enough and we need to carry out Computational Fluid Dynamics (CFD) simulations with very high spatial resolution. Although these tools are very demanding from a computational point of view, they are based on physical laws and produce a complete set of variables for the output of climate and atmospheric pollution, simulating in the most realistic possible way the urban atmospheric dynamics. Recent scientific advances in computer science and atmosphere, as well as the availability of computational resources, have opened up new opportunities for research into the health consequences related to air pollution and climate at the city level [11]. This work is part of the EU DECUMANUS project of FP7. DECUMANUS is dedicated to providing urban intelligence and accessible services to urban managers facing societal challenges, including climate change, based on the philosophy that it is possible to adapt - and mitigate -, challenges if they can be understood and measured.

In previous studies on climate change and human health, projections of global climate models or regional climate modelling outputs [12] , [13] and [14], have been used directly, but few studies have taken into account the results of a dynamical downscaling, using very high spatial resolution data to analyze local impacts of climate change on the citizens health. Jacob and Winner [15] present a review of studies that have provided estimates of the climate effect on air quality through air quality correlations with meteorological variables, analysis of perturbations in Chemical Transport Models (CTMs) and CTM simulations driven by simulations of 21st century climate change General Circulation Model (GCM). Dynamical downscaling has been studied since the early 1990s ([16] and

[17]) using regional models with coarse resolutions (about 50 km). More recently, a finer spatial resolution has been applied: Bell et al. [18] 40 km and Salathé et al. [19] 15 km. Gao et al. [20] implemented a dynamically downscaling system with the WRF (Weather Research Forecasting) model up to 4 km spatial resolution over the eastern United States. The WRF was also fed by the results of the CESM (Community Earth System Model) model. The RCP (Representative Concentration Pathway) 8.5 was used to study future heat waves and extreme precipitation in 2057-2059. The results show that there is a large increase in both the intensity of heat waves and annual extreme rainfall. Most dynamical downscaling studies use the WRF model, but focus on climate products without taking into account changes in air quality. Our study integrates climate, air pollution and health and includes a CFD model to obtain maps with a very high spatial resolution (50 m). The study of Gao et al. (2013) uses the WRF model to drive the Community Multi-Scale Air Quality (CMAQ) model to understand projected climate changes in ozone (O₃) concentrations. In addition, Kim et al. [21] has used the outcome of the downscaling methodology to a 12 km resolution under RCP 4.5 and RCP8.5 climate scenarios to assess the premature ozone-related mortality attributed to climate change in the United States for the future years (2057-2059) and base years (2001-2004). He also studied the uncertainty in the estimation of mortality. An important result is that uncertainties vary substantially in space, and spatially resolved data are crucial for developing an effective mitigation and adaptation policy at the community level. However, the WRF/CMAQ model used in both studies is an off-line coupled model, which does not take into account the feedback between meteorology/climate and chemistry. In our study, an online coupled meteorology-chemical model is used to account for these interactions.

Khairunnisa et al. [22] apply the WRF/Chem model to a resolution of 36 km × 36 km for the base period of time (2001-2010) and future decade (2046-2055) under the RCP 4.5 and RCP 8.5 scenarios, to examine changes in future climate, air quality and their interactions. The WRF/Chem assessment shows good overall performance for most meteorological and chemical variables. The results showed different spatial distributions of projected changes in the meteorological variables. Future O₃ mixing ratios will decrease for most parts of the United States under the RCP4.5 scenario, but will increase for all areas under the RCP8.5 scenario. These results are consistent with the findings of this study. These types of studies have also been applied in Europe, for example Markakis et al. [23] have simulated O₃ and PM_{2.5} concentrations in Paris with 4 km spatial resolution using the CHIMERE model. An interesting result was found: ozone formation over Paris in the current urban-scale study is driven by volatile organic compounds (VOCs) -limited chemical, while at regional scale ozone formation occurs under NO_x-sensitive conditions. The BENMAP methodology is used in Sun et al. [24] to assess PM (Particulate Matter) and O₃-related mortality in 2050s versus 2000s over the US by applying a dynamical downscaling scale of up to 12 km spatial resolution under the RCP 8.5 climate scenario. Tagaris et al. [25] study the potential health impact of environmental ozone and PM_{2.5} concentrations, modified by climate change in the United States, and they have maintained constant boundary conditions for air pollutants, emission sources, population, activity levels and pollution controls as in our study.

Energy scenarios are important inputs to develop climate change scenarios such as those produced by the Intergovernmental Panel on Climate Change (IPCC). For example GHG

emissions changes are due to modify the energy demand for transport and buildings. So energy effects have impacts of on human health. A clear example is the Paris Agreement on Climate Change which has the potential to improve air quality and human health by encouraging the electrification of transportation and a transition from coal to sustainable energy. Many economic sectors are affected by climate change, e.g. health, agriculture, forestry, water management, energy supply and demand, tourism, buildings and infrastructure. In recent years, many advances in assessing climate impacts have been made for each of these sectors. To keep the effects of the many impacts traceable, we have simulated the economic impacts separately for health and energy demand. In this research we have focused in health impacts. Health impact assessment often is part of a wider prospective environmental impact assessment.

MATERIAL AND METHODS

We use a chain of models that allows outputs from the Community Earth Systems Model (CESM) [26] to be introduced into the Weather Research and Forecasting Chemical (WRF/Chem) model [27], which uses a sophisticated Urban Canopy Model (UCM) [28] to represent near-surface processes. WRF/Chem is an online chemical and meteorological model, so chemistry and meteorology are integrated into one code. The WRF/Chem outputs are coupled with the Computational Fluid Dynamics (CFD) model called MICROSYS [29], which operates at very high spatial resolution (50 meters). This downscaling procedure was performed using boundary and initial data from the modelling system with 1 km spatial resolution. The WRF/Chem model dynamically downscaled the CESM global model data from 50 km spatial resolution to 1 km. WRF/Chem is run through different horizontal spatial scales (50 km, 5 km, 1 km) using a domain nesting procedure. The outputs of the WRF/Chem model with UCM (Urban Canopy Model) with a resolution of 1 km were introduced (off-line) in MICROSYS model to initialize the simulations and provide the boundary conditions. Figure 1 gives an overview of the models cascade approach for dynamical downscaling methodology for meteorology and air quality variables.

Figure 1: Diagram of the used models for the dynamical downscaling process

The UCM (Urban Canopy Model) model is based on the city's energy budget approach [30]. The UCM model adopts the turbulent flow resistance net approach in the canyon. It takes into account recirculation and ventilation of air for calculation of turbulent heat flow within the canyon. Shading is represented in terms of sky view factors that represent the area of each urban surface and the sky that is visible by other urban surfaces (e. g. walls and roads). The UCM model is coupled into the WRF/Chem model at each time step where the physical equations are solved stationary. The exchange radiation, sensible heat, latent heat and moment fluxes are calculated by the UCM model and are coupled to the parameterisation of the closure turbulence boundary layer in WRF boundary layer model. For regional and urban scales, we use the WRF-Chem meteorological-chemical transport model. This modelling system includes the RADM2 gas phase mechanism, the MADE inorganic aerosol scheme and the SORGAM aerosol module for secondary organic aerosols (SOA). The WRF/Chem model has been configured with the following physical settings: Noah Land Surface Model [31]; Morrison's dual-moment microphysical scheme of

Morrison [32]; RRTMG (rapid radiological transfer model for global radiation); parameterization of the cluster of 3D Grell wave arrays [27]; Yonsei University's planetary boundary layer (YSU [33]) and Monin-Obukov surface layer. Anthropogenic and biogenic emissions are produced by the EMIMO model (developed by UPM) (EMission MOdel) [34] by 2011 with an hourly resolution of one hour. The MICROSYS CFD model is based on the MIMO CFD model (developed at the University of Karlsruhe), which takes into account building obstacles. The model includes a three-dimensional stable-state system of Reynolds equations, a $k-\epsilon$ and the "advection-diffusion" equation to simulate online pollution transport. This CFD model has been coupled with a simple chemical mechanism for O₃-NO_x ratios. Surface energy flows have been implemented in the MICROSYS code based on the procedures applied in the UCM model and the NOAA Land-surface model included in the WRF modeling system. A micro shadow model (developed by UPM) SHAMO has been executed to calculate shaded areas (including reflections on vertical walls of buildings) and short-wave radiation in high spatial resolution domains (some few meters). Simulations of current emissions will be carried out in the future to isolate the effects of climate change.

The EMIMO model is an emissions inventory model developed in our laboratory (UPM) to feed emissions into air quality modelling systems such as WRF-Chem and MIROSYS as a CFD system. The EMIMO model is based on TNO 7 km spatial resolution European emissions as described in Denier and others [35]. EMIMO model adapts to produce hourly emissions for primary pollutants with the required spatial resolution for air quality modelling systems in a top-down and bottom-up approach using land use, population and traffic data as surrogate inputs. In our experiment, EMIMO model produced the estimated emission data set for simulations with spatial resolutions: 25 km, 5 km and 1 km. Subsequently, EMIMO model produced - using a bottom-up approach - the emissions for the MICROSYS CFD model.

The impacts of climate change on citizens' health have been analysed for two Representative Paths of Concentrations (RCPs) [36] also called climate scenarios, RCP 4.5 and RCP 8.5. These climate scenarios are currently being used in global climate model simulations from the IPCC (Intergovernmental Panel on Climate Change) based on the Fifth Assessment Report (AR5) [37]. The IPCC report identifies up to four climate scenarios, ranging from very strong (non-realistic) mitigation scenarios (RCP 2.6) to a stable scenario (RCP 8.5). The choice of the worst-case scenario (RCP 8.5) and the best realistic scenario (RCP 4.5) was motivated by the objective of showing extreme changes that can be predicted on an urban scale and helping to implement mitigation and adaptation strategies. The RCP 8.5 scenario [38] is based on a small effort to reduce emissions and represents a failure to curb warming in 2100. It is characterised by increased greenhouse gas emissions over time. RCP 4.5 is a stabilization scenario in which total radiative forcing is stabilized in 2050 using a range of technologies and strategies to reduce greenhouse gas emissions. This scenario can be seen as a climate change mitigation scenario [39]. Scenario RCP 4.5 includes strategies to reduce GHG that will result in stabilization of radiative forcing to 4.5 W/m² by 2100, while RCP 8.5 assumes that radiative forcing can reach 8.5 W/m² by 2100. A simulation (NNRP) with a real-present scenario (analysis data) for 2011 has also been executed. This simulation will be used as a reference simulation of the modelling system for evaluation.

The objective of the paper is not to assess the degree of realism of the climate scenarios RCP defined by the IPCC. Our goal was to study how a current or actual city would respond to different climatic conditions, such as those defined by the already mentioned climate scenarios RCP. Specifically, we focus on the impact on mortality and morbidity associated with changing concentrations of various pollutants and increasing temperature. The results of the different impacts are provided using the cost in terms of 2000 year US dollars. The selection of two scenarios does not mean that these scenarios will occur in the future but the urban planner will have information on the city reaction to these scenarios. The RCP 4.5 and RCP 8.5 might be suitable for studying the impact of climate change over the cities and inferring the possible response of the citizen health, because they have the ability to consider the moderate (RCP 4.5) and extreme (RCP 8.5) scenario required for planning a better mitigation strategy. The two selected scenarios have been used in several works to assess the climate change over different areas and different applications [40][41][42][43].

The methodology for estimating the rates of climate/contamination-related deaths and hospital admissions due to global climate change is based on epidemiological analysis of atmospheric and meteorological pollution that characterizes and quantifies mortality/morbidity associations with exposure to weather and pollution variables. The exposure-response ratios estimated from epidemiological studies are applied to climate projections. The short-term relationship between the daily number of hospital admissions/deaths and the daily fluctuations in exposure variables (temperature, heat waves, ozone and particulate matter) for many cities are published in different scientific articles. The estimated mortality/morbidity rate attributed to the exposure variables (temperature, heat waves, ozone concentrations or particulate concentrations) is calculated with a daily temporal resolution and then averaged monthly and annually. Several health effects or outcomes are calculated for the impacts of mortality and morbidity, such as: all-cause mortality, cardiovascular mortality, respiratory mortality, admission to hospitals for respiratory and cardiovascular diseases. These results are for all ages, except for heat waves where mortality + 65 years is calculated. The short-term effects of heat on health are analysed from two exposure variables: Apparent Temperature (AT) and Heat Waves (HW). The AT is defined as an individual's perceived air temperature given the humidity. It is calculated with the equation 1:

$$AT(^{\circ}C) = -2.653 + (0.004 \times T) + 0.0153 \times (DPT)^2 \quad (1)$$

Where T ($^{\circ}C$) is the air temperature and DPT ($^{\circ}C$) is the dew point temperature. Only the summer months (June-August) are considered to study the health effects of heat wave days. Exposure to heat waves takes extreme daytime values into account by using the daily maximum apparent temperature (ATMAX) and high night-time temperatures by the minimum daytime temperature (TMIN). Heat wave days were defined as days when ATMAX exceeded a threshold value or days when TMIN exceeded another threshold value. For air quality indicators we have used PM10 and O3 pollutants. For PM10 the exposure indicator is the daily average and for ozone we use the maximum daily average of

8 hours. Health outcomes have been chosen based on data availability according to the uses of data in epidemiological studies that provide relative risks (RRs).

The relationship between exposure variables and their effects on health can be modelled using log-linear (Poisson) regression and this function is called the exposure-response (ER) function. If we derive this function we get the equation (2) that allows us to estimate the change in mortality or morbidity as a result of a change in the respective exposure variable.

$$\Delta y = y_0(e^{\beta\Delta C} - 1) \quad (2)$$

where y_0 is the baseline incidence rate of the studied health effect, β is a parameter that gives us an estimate of the effect of mortality and that has been obtained from epidemiological studies, ΔC is the change of the exposure variable (future minus present) [44]. The Δy change in the health outcome because changes in an environmental factor (temperature, number of heat waves or air concentrations) is multiplied by the exposed population in the present (2011). We use gridded population distribution with 200 meters of spatial resolution which was generated under the DECUMANUS EU project. Also y_0 and β are fixed to the 2011 values to isolate only the climate impacts, so in our study uses a constant population and mortality rate over time like other studies [45].

Estimates of the economic costs of global climate impacts on citizens' health can be used in cost-benefit analyses to compare different possible adaptation strategies [46]. The morbidity and mortality costs arising from the global climate scenarios are then evaluated for each health outcome separately by multiplication of the number of cases with the respective cost estimates. Monetary estimates of changes in premature mortality risk are often expressed in terms of Value of Statistical Life (VSL). We have data available from meta-analysis of VSL studies and VSL values by OECD country-specific VSL (2010) in US\$. In the case of estimating the cost of morbidity, the total value to society of a person's avoidance of hospital admission has one main component: the Cost Of Illness (COI). The metric of the cost of illness summarizes the expenses a person must bear for hospital admission. Unit values available for hospital admissions are: Cardiovascular: \$26,123 and Respiratory: \$19,612. Unit values are based on the estimated specific hospitalization cost related to the ICD code and the opportunity -cost of time-, spent in the hospital (based on the average length of an inpatient stay due to illness). The opportunity cost of a day spent in the hospital is estimated to be the value of the lost daily wage, regardless of whether or not the individual is on leave. These values are used in the BENMAP methodology and are based on the discharge statistics provided by the Health and Quality Research Agency of the National Inpatient Sample Project's (NIS) National Inpatient Sample Project (2007).

We have applied the tool described above to assess possible future changes in mortality and morbidity and their respective economic costs in the Kensington and Chelsea area (K&C), London. We use the result with 50 meters spatial resolution and one hour temporal resolution for the years 2011, 2030, 2050 and 2100 from the dynamical downscaling process as explained before. In this specific exercise, we will study the impacts of the next three years 2100, 2050 and 2030 compared to the base or reference year 2011.

The objective of the actual study is to understand the response of a city as it is today to future climate scenarios as described and produced by the IPCC RCP 4.5 and 8.5 alternatives. In other words, the changes shown and the health impacts are due only to climate changes, and no other changes have been added such as interventions in local emissions by local urban planners. By using boundary conditions from the RCP4.5 and RCP8.5 scenarios for 2030, 2050 and 2100 and applying these boundary conditions for the 2011 simulation over the cities, we can estimate what would be the impact of global climate in the actual city conditions. So that, we can also estimate the impact on citizen health under those climate scenarios and at local level. The Boundary conditions downloaded from RCP's scenarios include global emission estimations on what would be the projection of the city emissions for future years until 2100, but in our case we are only interested on having the "impact" produced by the boundary conditions on our reference or base year, 2011. The objective of this work is not reproducing the future reality but estimate the impact of future climate "scenarios" in our actual cities. The main objective is to help to understand the relation between global climate and local response for different cities by focusing on the health impact and its economic costs. Local conditions (landuse, city geometry, emissions) are not changed to isolate the impact of the global climate by considering the actual state of the city. In the global climate scenarios, the city geometry changes according to the specific conditions provided by the RCP 4.5 and 8.5 global climate scenarios, but in our contribution we use "actual city" parameters (actual city geometry, actual emissions, etc.) with the "produced boundary conditions by the climate scenarios in 2100, 2050 and 2030" where city geometry and other parameters change.

To describe the effect of exposure variables on mortality and morbidity on health, Table 1 presents the Relative Risk (RR) and mortality/morbidity rates used in health impact assessment, with the reference of the epidemiological study where the RR is published. The RRs are presented for an increment of 10 $\mu\text{g}/\text{m}^3$ in O₃ and PM₁₀ concentrations, so they are no depending of the currently observed concentrations. These increments are commonly used to express relative risks of these air pollutants. We know that the use of these RRs for a specific location has a number of uncertainties. We have used relative risks proposed by published prestigious systematic journals, which can be assumed to provide the most appropriate, although imperfect, value. The RRs used in this work are the best RRs that can be found in the scientific library based on real epidemiological studies and for short range applications.

For cost calculations, the VSL estimated value (2010) in \$US is 3.55 million in the United Kingdom.

Table 1. London, relative risks values for each exposure variables and reference

Exposure Variable	Health Outcome	RR	Epidemiological Study	Mortality/Morbidity rates
PM10 daily average	All causes mortality	1,00694	Katsouyanni et al., 2001 [47]	423.6
PM10 daily average	Cardiovascular mortality	1,00551	Bremner et al. 1999 [48]	125.77
PM10 daily average	Respiratory mortality	1,00286	Bremner et al. 1999 [48]	51.77

PM10 daily average	Respiratory hospital admissions	1,00860	Atkinson et al. 2005 [49]	946.13
PM10 daily average	Cardiovascular hospital admissions	1,00600	Atkinson et al. 2005 [49]	1103.97
O3 max mean 8h	All causes mortality	1,00310	Gryparis et al. 2004 [50]	423.6
O3 max mean 8h	Cardiovascular mortality	1,00672	Bremner et al. 1999 [48]	125.77
O3 max mean 8h	Respiratory mortality	1,01250	Atkinson et al. 2005 [49]	51.77
O3 max mean 8h	Respiratory hospital admissions	1,00300	Anderson et al. 2004 [51]	946.13
Apparent temperature max > 23.9 °C	All causes mortality	1,01540	Baccini et al. 2008 [52]	423.6
Apparent temperature max > 23.9 °C	Cardiovascular mortality	1,02440	Baccini et al. 2008 [52]	125.77
Apparent temperature max > 23.9 °C	Respiratory mortality	1,06100	Baccini et al. 2008 [52]	51.77
Apparent temperature P90 > 24.6 °C	Respiratory hospital admissions	1,01700	Michelozzi et al. 2009 [53]	946.13
Days of heat waves*	All causes mortality +65	1,10400	D'ippoliti et al. 2010 [54]	2774.73
Days of heat waves *	Cardiovascular mortality +65	1,09300	D'ippoliti et al. 2010 [54]	922.49
Days of heat waves *	Respiratory mortality +65	1,18000	D'ippoliti et al. 2010 [54]	403.04

*(Tmin > 16,8 or Tmax > 27,1

RESULTS

Kensington and Chelsea air quality stations were used to evaluate the accuracy of the modelling system outputs (Table 2). For evaluation purposes, we have compared the hourly model outputs for present conditions (2011) following reanalysis scenario (NNRP) to hourly observations. The monitoring stations have been identified with their typical identifier names. "AVG Station" means the average of the values for all monitoring stations located in the study area. In order to assess the uncertainty of the modeling system with respect to observations, the following statistical parameters have been evaluated: normalized mean bias (NMB), Root Mean Square Error (RMSE) and Pearson's correlation coefficient (R^2). The NMB, RMSE and R^2 are defined by equations (3) – (5) listed below:

$$NMB(\%) = \frac{1}{N} \sum_{i=1}^N \frac{C_{o,i} - C_{m,i}}{C_{o,i}} * 100 \quad (3)$$

$$RMSE(ug / m^3) = \sqrt{\frac{1}{N} \sum_{i=1}^N (C_{o,i} - C_{m,i})^2} \quad (4)$$

$$R^2 = \frac{\sum_{i=1}^N (C_{m,i} - \bar{C}_m)(C_{o,i} - \bar{C}_o)}{\sqrt{\sum_{i=1}^N (C_{m,i} - \bar{C}_m)^2 \sum_{i=1}^N (C_{o,i} - \bar{C}_o)^2}} \quad (5)$$

Where C_m is the hour i model concentration at grid cell where station is located, C_o is the observed concentration at hour i and N equals the number of prediction-observation pairs.

Table 2. London results of the evaluation of the results of the modelling system

STATION_ID	POLLUTANT	NMB (%)	RMSE ($\mu g/m^3$)	R ²
0	SO ₂	0,51	2,56	0,19
1	SO ₂	-62,07	3,08	0,26
2	SO ₂	-11,74	2,9	0,12
0	NO ₂	33,58	48,26	0,35
1	NO ₂	-31,67	35,57	0,38
2	NO ₂	22,02	48,87	0,24
3	NO ₂	50,52	57,67	0,31
4	NO ₂	44,21	62,17	0,25
5	NO ₂	50,42	68,78	0,34
0	CO	17,73	136,87	0,37
1	CO	-8,47	119,33	0,36
2	CO	19,47	176,36	0,27
1	O ₃	-58,2	33,26	0,61
0	PM ₁₀	34,87	18,39	0,46
1	PM ₁₀	16,09	17,39	0,41
2	PM ₁₀	36,36	18,05	0,42
5	PM ₁₀	46,38	22,71	0,44

The results of the comparison between the modelled data and the observed data show that the simulated concentrations are within the ranges of measured data. The average simulated levels are within the inter-annual variability of the measured data sets since most of the R values exceed the value of 0.5 -except SO₂, but SO₂ concentrations are very low in the cities-. The statistical evaluation shows significant evidence that high resolution

downscaling procedure could achieve reasonably good performance, particularly for BIAS and R^2 statistics.

The modelling system seems to generally underestimate NO₂ and PM₁₀ concentrations (positive bias) and overestimate O₃ (negative bias) concentrations. The main variables in the uncertainty are wind velocity and direction bias (not showed). Another important uncertainty factor is the emission database which is mainly due to the lack of city specific data. In addition, the exact location of the sensors above surface is another source of uncertainty since it is not completely declared in the monitoring station location data. . In this particular case the underestimation might be attributed to underestimation of traffic emissions, because the dispersion of pollutants is generally underestimated, especially in the vicinity of emission hotspots. The evaluation process suggests that additional efforts should be made to better calculate the traffic emissions. The model produces concentrations for 50 m x 50 m grid cells and the observations are given data for a specific located point. The evaluation process includes, not just model uncertainties, but also monitoring, representativeness and stochastic uncertainties. However, the values for all quantitative measures except the SO₂ are within acceptable error bounds. Thus, based on comparing the results with observations, the simulations presented here reproduce the observed ground concentration within acceptable error bounds. The evaluation of the 1 km spatial resolution results, give us somehow worst results, because higher grid spatial resolution has the advantage of capturing smaller turbulence eddies and concentration fluctuations. It is important to remark that we have only one monitoring station with observed O₃ concentrations in the simulation area. The correlations between observations and model concentrations demonstrate that meteorological variability is a key main factor which drives the concentration variability . This variability is well captured ($R > 0.5$) by the dynamical modelling approach. The monitoring stations are located on traffic sites, so the concentrations variability is dominated by traffic intensity and values of R greater than 0.5 are acceptable. Finally, it is important to remember that our objective is not to forecast the city's concentrations in the future, but rather to predict how the climate conditions may affect a city and the subsequent health impact. Climate impacts on health are obtained by comparing two simulations that have the same emissions, which we have identified as one of the main sources of uncertainty in the results. By comparing two simulations with the same uncertainty in the input data, the uncertainty of the impacts (differences between both simulations) is smoothed out.

Spatial distribution of yearly average temperature differences (%) considering the RCP 4.5 and RCP 8.5 global climate scenarios over the current Kensington and Chelsea area between 2100 and 2011 with 50 meters of spatial resolution are showed in the Figure 2.

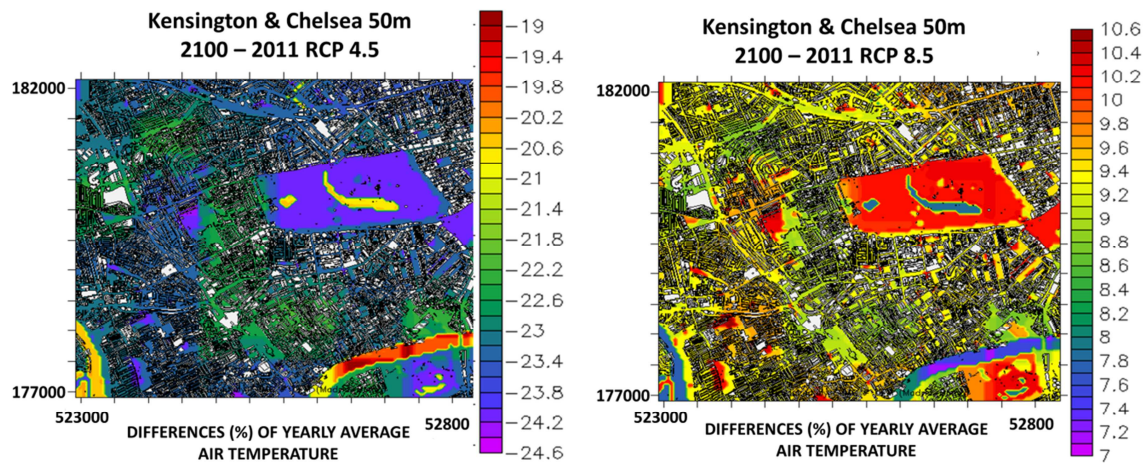


Figure 2: Spatial distribution of the percent (%) change of air temperature over Kensington and Chelsea area by considering the RCP 8.5 and RCP 4.5 climate scenarios for year 2100 relative to present (2011)

Figure 2 shows the impacts of the 2100 global climate over the current city conditions. The spatial distributions of changes in temperature are consistent under the two climate global scenarios. However, the warming is substantially strong in the RCP 8.5 and cooling is predominant in the RCP 4.5. The global climate scenario RCP 8.5 produces a warmer temperature pattern over the area, ranging between 7% (0.76 °C) and 10.6% (1.32 °C). In case of the climate scenario RCP 4.5 the annual mean temperature decreases between -24.6% (-3.2°C) and -19% (-2.1°). Under both climate scenarios, the Figure 2 shows heterogeneous pattern of change across the city. Spatial distribution of the impacts indicates largest temperature changes over the park and open areas and some specific streets and shortest changes over the water areas. The very high density urban areas are already facing issues with urban heat island effect and in the future these effects are maintained. The figure helps to identify heat spots and the most vulnerable areas to the global climate change in the future.

In table 3, we present the economic cost associated to the climate impact for a 50 meters mean grid cell for years 2030, 2050 and 2100 for a mean grid cell of 50 meters by 50 meters located on Kensington and Chelsea.

Table 3. Monetary estimates of the 2100 annual health costs due to climate change's effects on K&C for 50 meters

Mean 50m. grid cell			Kensington and Chelsea					
			2030		2050		2100	
Outcome	Cause	Factor	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Hopspital Cost (2000 \$)	Resp.	ATP90	2620,1	-4525,1	971,5	1458,8	1362,5	11669,8
	Resp.	PM10	-1448,5	-196,3	-409,3	-1705,9	5153,9	-777,8
	Resp.	O3	-856,1	-723,9	-899,9	423,6	-4417,7	-594,9
	Cardio	PM10	-1627	-263,2	-502,4	-1898	5530,1	-887,5

Mortality Cost (2000 K\$)	All +65	H. Waves	298,5	-957,7	125,8	-418	-245	411,4
	Cardio	H. Waves	88,6	-284,4	37,6	-124,1	-72,9	122,8
	Resp.	H. Waves	75,7	-242,5	30,6	-106,4	-61,4	100,7
	All	ATMAX	211,7	-468,9	111,1	139,7	79,8	963,9
	Cardio	ATMX	102	-223,4	53,5	68,7	39,7	473
	Resp.	ATMAX	115,9	-242,2	60,6	84,8	51,1	581
	All	PM10	-96,9	-14,8	-29	-113,4	334,8	-52,6
	Cardio	PM10	-23,3	-3,9	-7,3	-27,1	78,5	-12,7
	Resp.	PM10	-5,2	-1	-1,7	-5,9	16,6	-2,9
	All	O3	-71,6	-60,6	-75,3	35,5	-369,9	-49,8
	Cardio	O3	-44,7	-37,7	-47,2	24,1	-235,9	-30,6
	Resp.	O3	-32,6	-27,4	-34,6	19,9	-178,1	-21,7

The major impacts will occur at 2100. For this year, the emission reduction strategies (scenario RCP 4.5) will reduce the health impact cost, but if the future is close to the RCP 8.5 scenario, the citizens will suffer important health problems. The increment of the annual cost for hospital admission for 2100 year respect to the 2011 year could be up to \$11669 in the RCP 8.5 climate scenario and \$1362 in the RCP 4.5 for an average grid cell in the domain. For the mortality costs, we observe increments of K\$963.9 in RCP 8.5 and reductions of K\$73.8 for RCP 4.5. Heat is the environmental factor which causes these increments in the RCP 8.5 whilst in the RCP 4.5 the health effects for O₃ exposure and the reduction in the number of heat waves. The total annual cost of the climate change could be up to 1 K\$/m² with the climate scenario RCP 8.5 and we can save up to 0.22 K\$/m² if the global climate scenario RCP 4.5 is present in the year 2100.

“In table 3 we see how the global climatic conditions, for the scenario RCP 8.5 and for the year 2030, would impact on the citizen's health, in the current zone of Kensington and Chelsea in London (UK), reducing mortality and morbidity with respect to the climatic conditions in 2011. In the study area the climatic conditions of the global scenario RCP 8.5 by 2030 would cause a domain-average decrease in temperature of around 4.3% and an increase in ventilation due to an increase in wind speed. The more ventilation the less in primary pollutant concentrations, such as particulate matter and, in the case of ozone, as well. The higher the decrease in temperature the higher the decrease in ozone concentrations. This decrease in temperature and pollution is responsible for the reduction of mortality and morbidity costs in 2030 for the scenario RCP 8.5. Although the RCP 8.5 scenario at a global level is characterized by temperature increases, when trying to study the response of an area of a city to this global climate change, we observe that the response does not follow global patterns in many cases because the local climate is strongly affected by local conditions and this effect is particularly intense in urban environments. This is the main reason to have studies with very high spatial resolution so we can see the different responses to different areas or zones in a large city. Downscaled climate results show significant improvement over global outputs, primarily due to the incorporation of local detailed topography and land use information. It is important to remember that the objective of the study is to know how a current city, with its emissions, land uses, current buildings, etc...may respond to a change in climatic conditions, in particular how it would

react if climatic conditions were to occur now under the global climate scenarios RCP 4.5 and RCP 8.5. In other words, the changes shown are due to climate change produced by global climate models only, and no other changes have been added such as interventions in local emissions.

The Figure 3 shows the spatial distribution of annual total costs due to premature mortality by changes in the daily maximum apparent temperature for year 2100 under two possible climate scenarios RCP 4.5 and RCP 8.5 over area of Kensington and Chelsea.

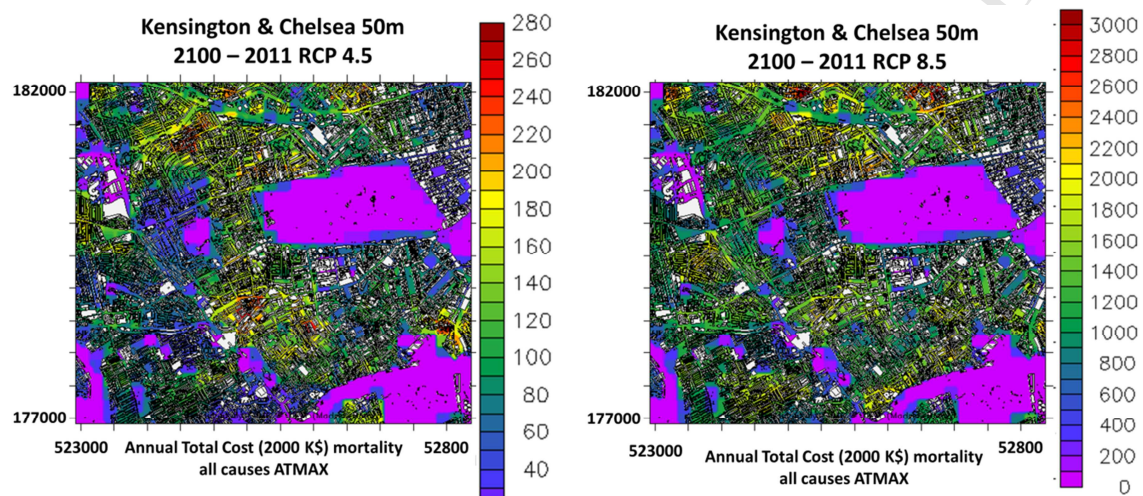


Figure 3 : Kensington and Chelsea, 50 meters differences of annual total cost (2000 K\$) of mortality by exposure to high temperature (ATMAX), 2100-2011 with RCP 4.5 (left) and RCP 8.5 (right).

The economic cost is nearly ten times larger in RCP 8.5 than in RCP 4.5. Purple areas (parks and water bodies) are areas where people do not live, so no one is exposed to environmental agents. Zones with a high density of buildings and population are the most vulnerable to climate change. The figure also identifies a number of hot spots where the climate change cost could be up to 1.0 K\$/m² and areas, very near the hot spots, where the cost is lower, 0.5 K\$/m², 30% less. This phenomenon is found on the same street in several cases. These findings showed that it is very important to have very high spatial resolution health impacts on urban areas.

Figure 4 shows that the annual total cost of respiratory admissions due to O₃ concentration changes between the future (2100) and the present (2011) years. Also, the analysis is performed for the RCP 4.5 and RCP 8.5 climate scenarios over Kensington and Chelsea (London) with 50 meters spatial resolution.

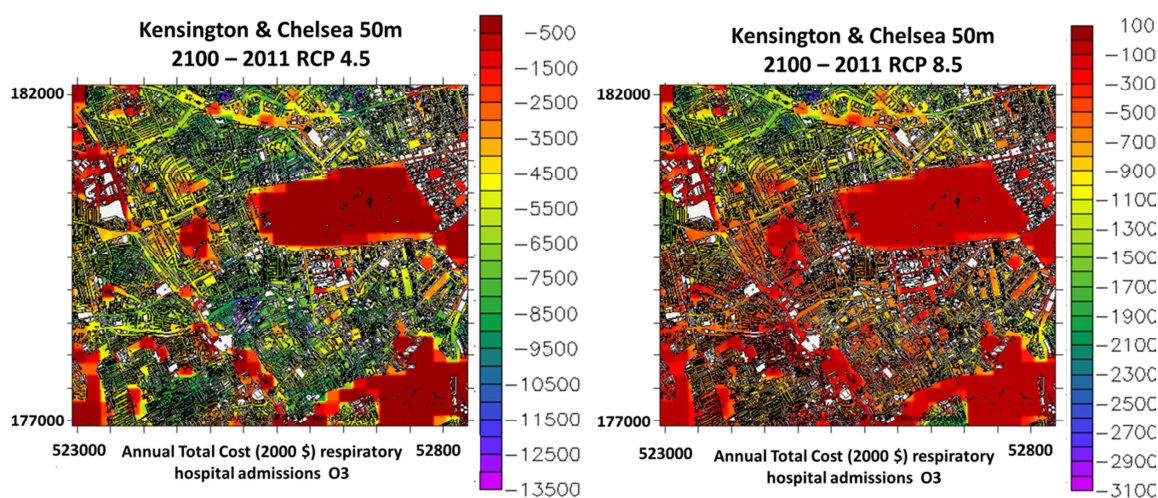


Figure 4: Kensington and Chelsea, 50 meters differences of annual total cost (2000 \$) by the number of respiratory hospital admissions by exposure to O₃, 2100-2011 with RCP 4.5 (left) and RCP 8.5 (right).

The analysis is performed to analyze the change on the number of hospitalizations for respiratory causes due to exposure to O₃ concentrations. The figure 4 shows that in the RCP 8.5 and RCP 4.5 climate scenarios, there are reductions in the number of hospitalizations due to short-term exposure to O₃ concentrations. In the RCP 4.5 climate scenario, there are significant decreases in hospital admissions induced by exposure to O₃ concentrations because air temperature is expected to decrease in the 2100 year versus 2011 year. In RCP 4.5 climate scenario, we do expect decreases in the number of hospitalizations due to O₃ concentrations changes, and these changes can be estimated up to 13500 (2000 \$US) in a 50 meters by 50 meters grid cell. There are very important differences between -1500 \$US and \$US 13500-, in a very small area (25 Km²) of the city. This local effect (important differences between neighbouring zones) can be observed due to the high spatial resolution used in this approach.

CONCLUSIONS

This document presents a tool for estimating the cost of the impact of global climate change on human mortality and morbidity due to changes in higher or lower temperatures and pollution concentrations. The tool is an integrated modeling system for assessing the potential impacts of climate change on urban-scale public health. The integrated framework facilitates climate and health impacts projections associated with appropriate spatial and temporal scales for urban planning. The methodology was applied to Kensington and Chelsea, London (UK) area using very high spatial resolution information, 50 meters. We have considered two climate projections, which are based on two IPCC climate scenarios: RCP 8.5 and RCP 4.5, which have dynamically downscaled from global model data sets. The downscaling methodology is based on a three-dimensional numerical nesting procedure. The model chain used includes the outputs of a global climate model (GCMs), as well as a mesoscale meteorological and chemical urban model (WRF/Chem model activating the UCM – urban canopy model – submodel, with 1 km spatial resolution and a

microscale CFD model (MICROSYS) to produce further downscaling from 1 km to 50 m spatial resolution. The modelling system was used to simulate climate and air quality concentrations for current (2011) and future times (2030, 2050 and 2100) using the 2011 emissions inventory.

The results of air pollution at microscopic scale were evaluated using observations from existing air quality stations. The evaluation of the WRF-Chem model and the MICROSYS CFD model show a good agreement between observed and modelled datasets and, as a consequence, the usefulness of our integrated modeling approach. It is important to acknowledge that there are many uncertainties in any attempt to estimate the economic and people's health impacts due to climate change on urban areas. There are model uncertainties in economic and environmental modelling that are not easily quantifiable. To improve the simulation tool, additional validation studies with longer time periods are required by comparing simulation results with field measurements. The nested numerical modeling approach can be applied in other cities around the world by using a similar approach and introducing new corresponding input parameters for the local environment.

The greatest increase in mortality and morbidity costs were observed in the RCP 8.5 climate scenario when increasing greenhouse gases are present. This is the opposite when dealing with the RCP 4.5 stabilization climate scenario. This is due the RCP 8.5 scenario is characterized by temperature increases in the year 2100. With these simulations of high spatial resolution, we have been able to observe that the influence of buildings is very important. We have detected important hot spots or very sensitive areas which are affected by global and local climate change. The results of this study could be used by local authorities and other stakeholders to help to develop environmental policies that protect citizens' health against climate change. This study contributes to improve the current understanding of climate change issues related to citizens' health in urban environments.

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DYNAMICAL DOWNSCALING

