ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 6, December 2015

Evaluation and application a new approach for downscaling climate change projections over urban areas and its implications on health

Roberto San José [1], Juan L. Pérez [1], Libia Pérez [1], Rosa M. González [2] and Antonio Garzón [3]
[1]Environmental Software and Modelling Group, Computer Science School, Technical University of Madrid (UPM), Madrid, Spain. [2]Department of Meteorology and Geophysics, Faculty of Physics, Complutense University of Madrid (UCM), Ciudad Universitaria, 28040, Madrid, Spain. [3]Indra S.A., C/ Mar Egeo, 4, Pol. Industrial 1, 28830 San Fernando de Henares, Madrid, Spain

Abstract*— A new downscaling approach with feasible computational costs to go from global resolution to high urban resolutions is presented, evaluated and applied. It is a mixed dynamical and diagnostic approach: it includes the mesoscale/regional meteorological/air pollution model WRF-Chem (NOAA, USA) to produce information about concentrations and meteorological data covering Europe with 25 km of spatial resolution (dynamical downscaling) and at urban scale we use the diagnostic meteorological model CALMET and the air pollution CMAQ with simple chemical reactions (CMAQL). Comparison of simulations to the current situation (using NNRP 2011 reanalysis datasets) shows acceptable agreement with measurements that give us great confidence in the results. Also the hybrid downscaling tool has been compared with a full dynamical downscaling technique. The comparison between both downscaling techniques shows that in spite of CALMET-CMAQL model is much faster and computationally cheap, The described tool is used to quantify the future (2030, 2050 and 2100) impacts of the global climate over European Cities 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).

***Index Terms*—Climate, Health, Downscaling, Simulation**

I. INTRODUCTION

Recent studies have suggested that global climate change will have a significant impact on both local weather and urban air quality [1]. We need to consider global climate change with the aim to integrally assess impacts on local climate, air quality and health impacts. Warmer temperatures could increase the concentrations of unhealthy air pollutants. The combined effect of global climate change and urban growth makes people in cities more vulnerable to environmental problems like extreme weather and poor air quality. There is increasing concern regarding the impact of global climate change on urban areas. Climate change is expected to influence urban living conditions and over 50% of the world's population lives in cities [2]. Studies of the complex interactions between climate, air quality and urban areas represent a relatively new and important field of research. A current research challenge is to implement computational tools that allow us to calculate the impact of climate change on air quality and health of citizens at the urban level [3].

Global Circulation Models (GCM) produce outputs very coarse for regional and local applications, so they cannot be applied for urban climate impact studies because the effects of climate change should be presented on local or regional scales that are still not resolved by GCMs, this limitation is amplified in areas of complex geomorphology. Downscaling techniques have attracted during the last decade a substantial amount of research in order to produce high spatial resolution regional climate maps with reasonable computer power. There are a large set of mathematical downscaling techniques to produce local climate data with maximum accuracy. These should include studies to bridge the spatial and temporal scales connecting local emissions, air quality and weather with climate and global atmospheric chemistry. The interactions involving nonlinear processes so we need require coherent and robust modelling approaches as a multi-scale modelling framework for global to local scale. 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]. One of the first health impact assessments of future climate conditions study with tenths of kilometres of resolution was over greater New York region [5].

Global climate scenarios are defined by the IPCC (Intergovernmental Panel on Climate Change). They are based on the Fifth Assessment Report (AR5) and on the Representative Concentration Pathways (RCP). They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterized by the radiative forcing produced by CO2 emissions by the end of the 21st century.

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

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 6, December 2015

sustainable urban planning and development. The DECUMANUS services will offer information to the end users (city managers).

II. MATERIAL AND METHODS

The 8.5 pathway arises from little effort to reduce emissions and represents a failure to curb warming by 2100. The RCP 8.5 [6], [7] is developed by the MESSAGE modelling team and the IIASA Integrated Assessment Framework at the International Institute for Applies Systems Analysis (IIASA), Austria. The RCP 8.5 is characterized by increasing greenhouse gas emissions over time and represents scenarios in the literature leading to high greenhouse gas concentration levels. The underlying scenario drivers and resulting development path are based on the A2r scenario detailed in Riahi et al. (2007) [8]. This can be considered as a non-mitigation business as usual scenario with high emissions, similar to SRES A1FI. RCP 4.5 is similar to the lowest-emission scenarios (B1) assessed in the IPCC AR4. The RCP 4.5 [9], [10] is developed by the Mini CAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI). It 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. The scenario drivers and technology options are detailed in Clarke et al. (2007) [11]. Additional detail on the simulation of land use and terrestrial carbon emissions is given by Wise et al (2009) [12]. 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. CESM 1.0. The six hourly global **climate** outputs (RCP 4.5 and RCP 8.5) have been published in the Earth System Grid. Also, one simulation (NNRP) with a real-present scenario (reanalysis data) has been run for the year 2011. This simulation will be used as evaluation simulation of the modelling system.

To simulate present and future climate projections over Europe, we use a regional meteorological-chemistry transport model WRF-Chem [13]. WRF-Chem model represent our dynamical downscaling technique. The European air quality simulations covered all Europe with 25 km spatial resolution and 33 vertical levels up to 50 hPa. For the final step in the downscaling process, we have selected a very well-known meteorological diagnostic model, CALMET [14] from California Air Resources Board (CARB), V5.8.4 July, 31, 2013. CALMET model is applied to process the downscaling from 25 km spatial resolution to 0.2 km spatial resolution domain centered over the DECUMANUS cities. CALMET model can reduce the computational cost of the two dynamical downscaling levels. CALMET, -as a diagnostic model-, does not produce “dynamics” as WRF-Chem model so all advection and diffusion processes are neglected. The Community Multi-scale Air Quality (CMAQ) modelling system has been also implemented [15]. The Air Quality (AQ) downscaling process over the cities is performed by running the CMAQ model over the specific cities with 1 km spatial resolution, using the WRF-Chem Europe scale model outputs as boundary conditions, -a procedure also known as off-line nesting-. We have used an adapted version of CMAQ for this task using “linear chemistry” which reduces on about 50% the total computational time. We will name CMAQL to the CMAQ model version with linear chemistry. The air quality downscaling procedure requires gridded emissions in the form of annual averages for six pollutants: NOx, NH3, PM, SO2, VOC and CO. The spatial resolution should be 1 km x1km. The EMIMO [16] model is an Emission Model which is capable to estimate-in a combined bottom-up and top-down approach-, the emissions of primary pollutants at 1 km spatial resolution and 1 hour temporal resolution. The final refinement from 1 km to 200m is developed with an interpolation tool called Cressman objective analysis [17].

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 indifferent scientific papers. 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 y0 is the baseline incidence rate of the studied health effect, β is a parameter which define the mortality effect estimation from epidemiological studies, ΔC is the change of the exposure variable (future minus present). Our system calculates 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 β parameter of the C-R function, they publish the relative risk (RR) associated with a given change in the exposure variable, but β and RR are related following the Equation 2 [19].

$$\beta = \frac{Ln(RR)}{\Delta c} \tag{2}$$

III. EVALUATION

Results of the modelling system have been evaluated using data from the local meteorological an 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

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 6, December 2015

statistical evaluation, Table 1, of the pairing of the gas species outputs (SO_2, NO_2, CO, O_3 and PM10) and meteorological parameters, Table 2, (temperature, wind and precipitation)in time (hourly) between WRF/Chem-CALMET-CMAQL outputs and monitoring stations datasets is shown in the next tables. There are three metrics, Normalized Mean Bias NMB), Root Mean Standard Error (RMSE) and the correlation coefficient (R2).

Table 1: Statistical evaluations of WRF/Chem-CALMET-CMAQL outputs in comparison to observations from air quality urban networks.

Air quality Monitoring Station (Avg stations)		NMB (%)	RMSE (ug/m3)	R2
Madrid	SO2	1.07	4.68	0.54
	NO2	1.21	31.23	0.43
	CO	-1.12	186.48	0.57
	O3	1.89	18.80	0.78
	PM10	-1.03	16.17	0.24
Antwerp	SO2	2.52	3.46	0.22
	NO2	1.66	23.69	0.52
	CO	-1.67	137.10	0.57
	O3	-1.55	19.44	0.69
	PM10	-1.80	16.08	0.48
Milan	SO2	-1.29	2.98	0.31
	NO2	1.34	36.05	0.51
	CO	-1.21	513.85	0.69
	O3	-1.14	20.38	0.85
	PM10	-1.00	25.77	0.65
Helsinki	SO2	-1.29	2.70	0.38
	NO2	1.36	16.51	0.39
	CO	1.83	106.49	0.49
	O3	1.58	18.48	0.57
	PM10	1.08	15.24	0.27
London	SO2	1.09	2.32	0.17
	NO2	1.27	44.02	0.33
	CO	-1.76	124.57	0.40
	O3	1.71	20.46	0.66
	PM10	1.46	13.52	0.48

Table 2: Statistical evaluations of WRF/Chem-CALMET-CMAQL outputs in comparison to observations from meteorological stations.

Meteorological Monitoring Station (Avg stations)		NMB (%)	RMSE	R2
Madrid	Wind Speed	129.78	1.83	0.65
	Temperature	-1.02	1.36	0.98
	Precipitation	-10.82	0.13	0.52
Antwerp	Wind Speed	20.49	1.39	0.80
	Temperature	-7.72	1.99	0.94
	Precipitation	-24.14	0.18	0.37
Milan	Wind Speed	53.21	1.35	0.50
	Temperature	-9.87	2.60	0.96
	Precipitation	-27.88	0.17	0.68
Helsinki	Wind Speed	25.53	1.97	0.74
	Temperature	-8.74	2.31	0.94
	Precipitation	4.11	0.17	0.58

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 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 O_3. Generally we have found a slight overestimation of the modelled 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.

A evaluation study has been completed to get more information about the availability of the system to downscale climate information. The goal of this study is to assess in detail the ability of different downscaling techniques (diagnostic and dynamical) to reproduce local values of meteorology and air pollution from global modelling data. We want to compare two different approaches, approach 1 (dynamical downscaling): full dynamical downscaling process is applied over Madrid domain up to 4.6 km spatial resolution (level l1), 0.92 km (level l2) and 0.184 km spatial resolution (level l3) with a prognostic meteorological model. This approach is more accurate than approach 2 but it also is more expensive from a computational point of view (mucho more CPU hours). Approach 2: diagnostic downscaling processes are applied over Madrid domain with diagnostic model with 0.184 km spatial resolution (level l3). The IC's (initial conditions) and BC's (boundary conditions) to run the diagnostic model are from 23 km (level l0), 4.6 km (level l1) and 0.92 km (level l2). CALMET model needs initial guess fields. This is less accurate but it is cheaper than approach 1. Air pollution concentrations are calculated with an air pollution model on level l3 (0.184 km).

Results from two different simulations (dynamical downscaling and hybrid downscaling) are compared against meteorological and air pollution monitoring data. The model results obtained within this study are compared against hourly surface (temperature, wind speed, ozone and particle) data from Retiro monitoring station for meteorological analysis

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 6, December 2015

and E. Aguirre monitoring station for air pollution analysis Retiro station is the only meteorological station of the Spanish National Meteorological Agency included in the simulation domain. Madrid municipally air quality monitoring network has many monitoring station but E. Aguirre location was chosen because there was ozone and particles data and it is the closet station to the Retiro . Also it is a background station, which has the most representative data. The rest of stations are very street urban stations. The model performance is evaluated for all simulations with the different downscaling methods (dynamical (WRF-CMAQF (full chemistry) and with CALMET-CMAQL (linear chemistry)). The results are summarized on the Table 3.

Table 3: Performance statistical parameters: Normalized Mean Bias (NMB), , Root Mean Square Error (RMSE) and Pearson Correlation Coefficient (R).

TEMPERATURE				
	S3: CALMET FROM WRF-CHEM 23 KM	S2: CALMET FROM WRF 4.6 KM	S1: CALMET FROM WRF 0.92 KM	S0: WRF 0.184 KM
NMB (%)	-20,13	-16,01	-14,94	-5,42
RMSE (ºc)	3,74	3,16	3,05	1,51
R^2	0,93	0,94	0,94	0,98
WIND SPEED				
	S3: CALMET FROM WRF-CHEM 23 KM	S2: CALMET FROM WRF 4.6 KM	S1: CALMET FROM WRF 0.92 KM	S0: WRF 0.184 KM
NMB (%)	53,06	72,38	79,74	52,17
RMSE (m/s)	2,01	2,59	2,81	1,81
R^2	0,06	0,03	0,02	0,27
O3				
	S3: CALMET-CMAQL FROM WRF-CHEM 23 KM	S2: CALMET-CMAQL FROM WRF 4.6 KM	S1: CALMET-CMAQL FROM WRF 0.92 KM	S0: WRF-CMAQF 0.184 KM
NMB (%)	34,72	24,17	22,77	18,14
RMSE (ug/m3)	21,61	20,08	20,14	15,39
R^2	0,7	0,61	0,6	0,74
PM10				
	S3: CALMET-CMAQL FROM WRF-CHEM 23 KM	S2: CALMET-CMAQL FROM WRF 4.6 KM	S1: CALMET-CMAQL FROM WRF 0.92 KM	S0: WRF-CMAQF 0.184 KM
NMB (%)	-54,03	-55,81	-37,37	-57,57
RMSE (ug/m3)	19,13	19,57	20,12	19,00
R^2	0,45	0,40	0,15	0,61

The best simulation is always the simulation S0 (full dynamical downscaling), S1 simulation is the closer to the S0 of the diagnostic downscaling simulations. Poor results are obtained for wind speeds due to high overestimation of WRF results, recent studies revealed a rather systematic tendency of the WRF model to overestimate the 10-m wind speed over complex topography. Very good results are obtained for temperature (R^2 from 0.93 to 0.98). Ozone is over predicted from 34.72% on 23 km with CALMET-CMAQL to 18.14% on 0.184 km with WRF-CMAQF. CMAQL does not simulate the full chemistry reactions related with the ozone only lineal transformations from NOx, it is the main reason to explain the higher bias with CMAQL. The general over predictions can be explaining by over prediction of the ozone precursors (NOx and VOCs). From a correlation point of view all systems obtain good performance results because for this statistical parameter the meteorology is most important that the chemical reactions. PM10 is under predicted around 50 %, the uncertainty of the local PM10 emissions may help explain some of the under predictions in the PM10. No good correlation is obtained to PM10 with CMAQL because CMAQL does not implement any aerosol chemistry module. CMAQF increase R up to 0.61, which is an very good value for urban PM10 comparisons. Only the NMB for temperature, O3 and PM10 shows clear decrease when CALMET/CMAL system is applied for downscaling from higher resolution WRF fields. For the wind speed the effect is the opposite.

IV. RESULTS

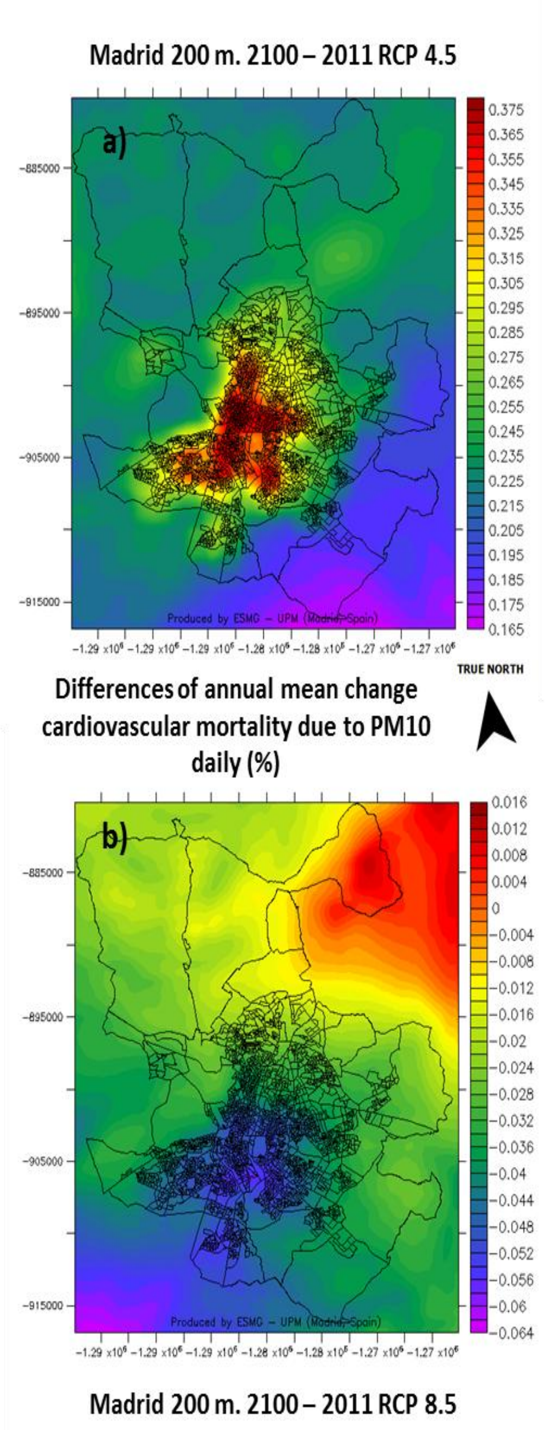
In this section we show results of the spatial distribution of the forecasted health impact for the 2100 year under the two IPCC climate scenarios (4.5 and 8.5) over the five European cities: Madrid (Fig. 2a and 2b), Helsinki (Fig. 3a and 3b), Milan (Fig. 4a and 4b), Antwerp (Fig. 5a and 5b) and London (Fig. 6a and 6b) for different health outcomes.

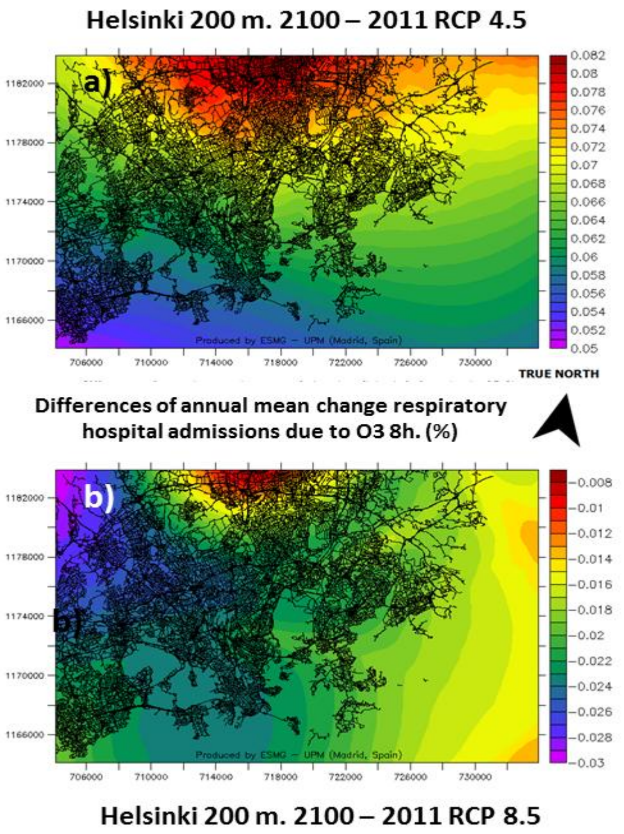
Fig. 2 Year 2100, differences (%) of annual mean changes short-term cardiovascular mortality due to PM10 daily average concentrations over Madrid (200 m.) under RCP 4.5 (a) top) and RCP 8.5 (b)bottom) climate scenarios respect to 2011.

Fig. 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 centre (area with high population density) but opposite effect is expected under 8.5 scenario, Fig. 2b, with ligliy

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 6, December 2015

reductions in the city centre.





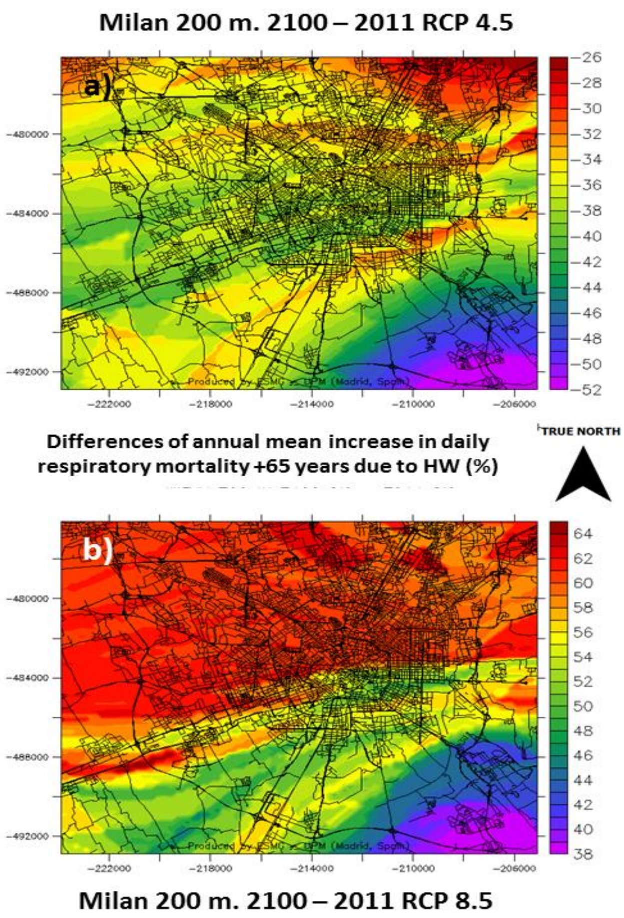


Fig. 3 Year 2100, differences (%) of annual mean changes short-term respiratory hospital admissions due to O3 8 hours average maximum concentrations over Helsinki (200 m.) under RCP 4.5 (a) top) and RCP 8.5 (b) bottom) climate scenarios respect to 2011.

Fig 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.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 6, December 2015

Fig. 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.

Fig 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.

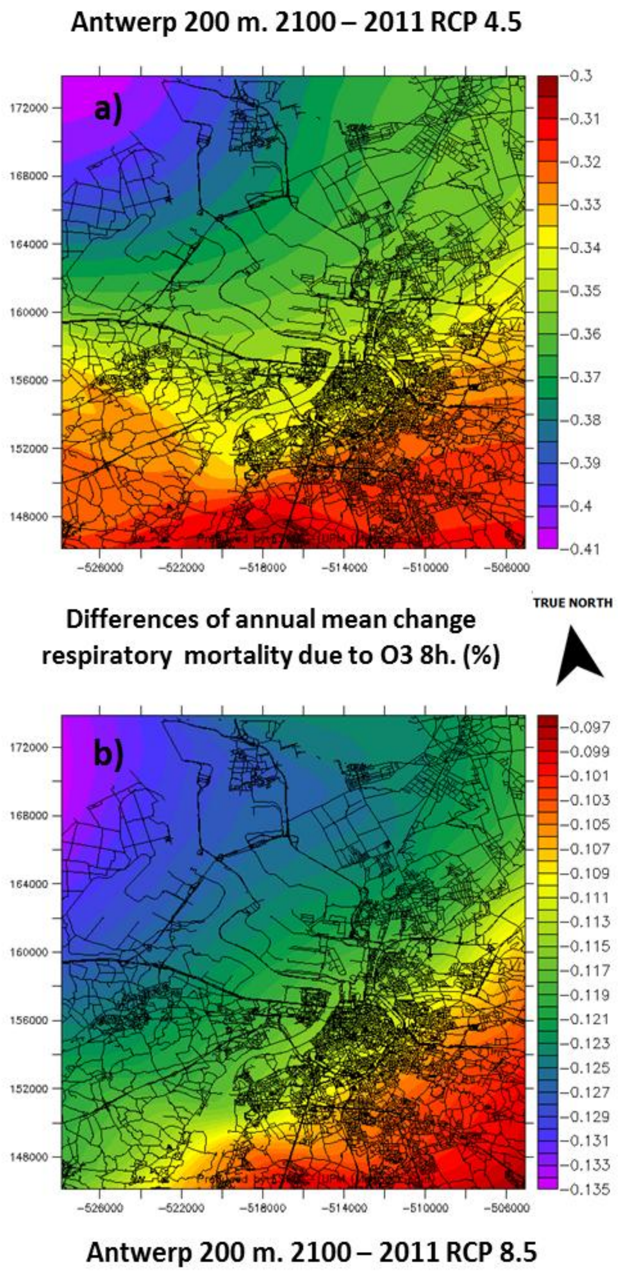


Fig. 5 Year 2100, differences (%) of annual mean changes short-term respiratory mortality due to O3 8 hours average maximum concentrations over Antwerp (200 m.) under RCP 4.5 (a) top) and RCP 8.5 (b) bottom) climate scenarios respect to 2011.

Fig. 5a and Fig 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 are expected in the South of the city under the RCP 4.5 scenario.

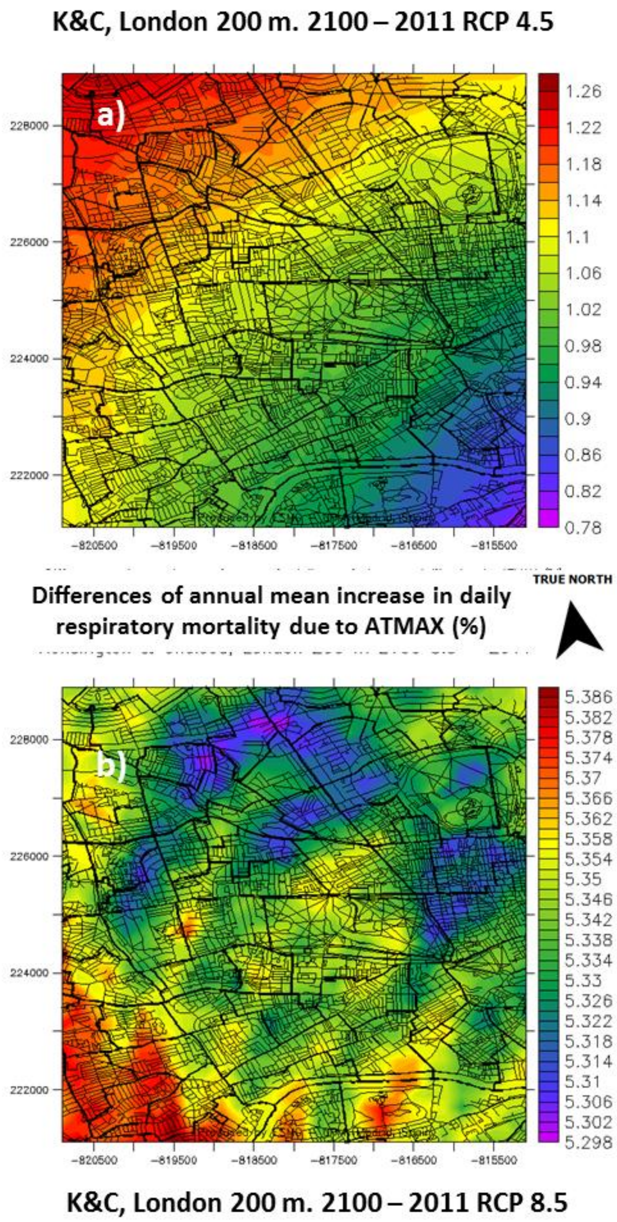


Fig. 6 Year 2100, differences (%) of annual mean changes short-term respiratory mortality due to maximum daily apparent temperature (AT) over Kensington and Chelsea (London) (200 m.) under RCP 4.5 (a) top) and RCP 8.5 (b) bottom) climate scenarios respect to 2011.

Fig. 6a and Fig 6b show that in case of the Kensington 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 %.

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, especially 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, especially 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.

V. CONCLUSION

A very high resolution climate, air pollution and health assessment tool was proposed and applied to study the impact of the future climate over European cities. The modelling system uses a hybrid downscaling tool, dynamical-diagnostic, that produces information that can be used for designing mitigation strategies with feasible computational costs (CPU time). The system includes the regional WRF/Chem model and the CALMET plus CMAQ model for the urban scale.

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. We have compared the meteorological and pollution concentration results obtained from two downscaling method. The reference method is called WRF-CMAQF simulation S0 and it is the state-of-the-art in numerical mesoscale modelling. The simplified and faster method used to produce meteorological and air pollution results over the very high spatial resolution model domain (l3) is the diagnostic meteorological model CALMET and the linear chemistry CMAQ version (adapted by our laboratory for this experiment). It is showed that all simulations are able to capture the variability of the observational data. CALMET model introduces more variability on the wind vectors over the area where the topography is more complex. Temperature from WRF is more detailed because it uses NOAH land surface model and the Urban Canopy Model (UCM). Downscaling from 23, 4.6 or 0.92 km does not make big differences.

The CALMET-CMAQL downscaling technique produces reasonably good results compared with the WRF-CMAQF simulations. However; the computational cost is much lower than in the case of WRF-CMAQF. Although the statistics are slightly better in the case of WRF-CMAQF, the computational cost is becoming a very important issue when long runs and several domains have to be produced and the cost does not justify the improvement on the statistics, using classical high performance hardware architecture. CALMET is 3547.7 times faster than WRF. So, the CALMET-CMAQL is a very reliable tool with a realistic cost and can be used for many climate applications to simulate different alternatives and scenarios (i.e. RCP climate scenarios) for many test years. WRF-CMAQ and WRF/Chem are confirmed as very accurate tool for producing meteorological and pollution fields but the computational cost at very high spatial resolution can be prohibited.

The results have shown an example of the health impact assessment of the impact of global climate change on urban areas. The information can be used for local decision makers and stakeholders in order to developing strategies to reduce these impacts. In this analysis, we have isolated the effect of climate change by holding local emissions and urban morphology over time, all simulations use data from current assumptions 2011. 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.

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. Ordnance Survey data for London: © Crown copyright and database rights 2015 OS 100021668.

REFERENCES

[1] Mickley, L. J., Jacob, D. J., Field, B. D., and Rind, D.: Effects of future climate change on regional air pollution episodes in the United States, Geophys. Res. Let., 31, L24103.

[2] United Nations, World Urbanization Prospects, the 2014 Revision. 2014. Available from: http://esa.un.org/unpd/ accessed March 2015

[3] Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N., and Rafaj, P., "RCP 8.5 – a scenario of comparatively high greenhouse gas emissions," Climatic Change, 109, 33–57, 2011.

[4] Valari, M. and Menut, L., "Does an increase in air quality models' resolution bring surface ozone concentrations closer to reality," J. Atmos. Ocean. Tech., 25, 1955–1968, 2008.

[5] Knowlton, K., Rosenthal, J. E., Hogrefe, C., Lynn, B., Gaffin, S., Goldberg, R., Rosenzweig, C., Civerolo, K., Ku, J.-Y., and Kinney, P. L., "Assessing ozone-related health impacts under a changing climate, " Environ. Health Persp., 112, 1557–1563, 2004.

[6] Riahi, Steven Rose, Paul Runci, Ron Stouffer, Detlef van Vuuren, John Weyant, Tom Wilbanks, Jean Pascal van

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 6, December 2015

Ypersele, and Monika Zurek., 2008. Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies. Intergovernmental Panel on Climate Change, Geneva, 132 pp.

[7] Rao, S. & Riahi, K. 2006. The role of non-CO2 greenhouse gases in climate change mitigation: Long-term scenarios for the 21st century. Multigas mitigation and climate policy. The Energy Journal. 3 (Special Issue), 177–200.

[8] Smith, Ronald J. Stouffer, Allison M. Thomson, John P. Weyant1 & Thomas J. Wilbanks, 2010. The next generation of scenarios for climate change research and assessment. Nature 463: 747-756. doi:10.1038/nature08823

[9] Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, R. Richels, 2007. Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Energy, Office of Biological & Environmental Research, Washington, 7 DC., USA, 154 pp.

[10] Wise, MA, KV Calvin, AM Thomson, LE Clarke, B Bond-Lamberty, RD Sands, SJ Smith, AC Janetos, JA Edmonds. 2009. Implications of Limiting CO2 Concentrations for Land Use and Energy. Science. 324:1183-1186.

[11] Grell GA, SE Peckham, R Schmitz, and SA McKeen, G Frost, WC Skamarock, and B Eder. 2005. Fully coupled 'online' chemistry in the WRF model. Atmos. Environ., 39:6957-6976.

[12] Bukovsky MS, Karoly DJ (2009) Precipitation simulations using WRF as a nested regional climate model. J Appl Meteor Climatol 48:2152–2159. doi:10.1175/2009JAMC2186.1

[13] Grell GA, SE Peckham, R Schmitz, and SA McKeen, G Frost, WC Skamarock, and B Eder. 2005. Fully coupled 'online' chemistry in the WRF model. Atmos. Environ., 39:6957-6976.

[14] Scire, J.S., Strimaitis, D.G., Yamartino, R.J., 2000b. A User's Guide for the CALMET Meteorological Model (Version 5). Earth Tech, Inc., Concord, MA. Available at: http://www.src.com/calpuff/download/CALMET_UsersGuide.pdf.

[15] Byun, J. Young, G. Gipson, J. Godowitch, F. Binkowsky, S. Roselle, B. Benjey, J. Pleim, J.K.S. Ching, J. Novak, C. Coats, T. Odman, A. Hanna, K. Alapaty, R. Mathur, J. McHenry, U. Shankar, S. Fine, A. Xiu, C. Lang, Description of the Models-3 Community Multiscale Air Quality (CMAQ) model, in: Proceedings of the American Meteorological Society 78th Annual Meeting Phoenix, AZ, January 11–16, 1998, pp. 264–268.

[16] San Jose R, Juan L. Perez, Jose L. Morant, Rosa M. Gonzalez, European operational air quality forecasting system by using MM5-CMAQ-EMIMO tool, Simulation Modelling Practice and Theory, Volume 16, Issue 10, The Analysis of Complex Systems, November 2008, Pages 1534-1540, ISSN 1569-190X, DOI: 10.1016/j.simpat.2007.11.021

[17] Cressman G. P., 1959. An operational objective analysis system. Mon. Weather Rev. 87, 367-374.

[18] Bell ML, Peng RD, Dominici F.,"The exposure–response curve for ozone and risk of mortality and the adequacy of current ozone regulations," Environ Health Perspect 114:532–536, 2006.

[19] U.S. EPA (U.S. Environmental Protection Agency), "BenMap: Environmental Benefits Mapping and Analysis Program User's Manual, Appendix, " Research Triangle Park, NC:U.S. EPA, Office of Air Quality Planning and Standards, 2010.

AUTHOR BIOGRAPHY

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.

Libia Perez is graduate in Engineering in the Technical University of Madrid and he is a professor of Numerical Analysis in the Department of Language and Systems and Software Engineering of the Computer Science School of the Technical University of Madrid (UPM).

Rosa M. González is an associate professor of Physics and Numerical Analysis in the Department of Geophysics and Meteorology of the Faculty of Physics of the Complutense University (UCM).

Antonio Garzón is project manager of the INDRA company. More than 25 years of experience. He has expertise in expertise in Remote Sensing, Geoinformatics (GIS), Cartography.