

Chapter 30

The Impact of Heat Waves and Urban Heat Island on the Production of Ozone Concentrations Under Present and Future Climate Conditions for the Belgian Domain

A.W. Delcloo, F. Duchêne, R. Hamdi, J. Berckmans, A. Deckmyn and P. Termonia

Abstract Due to a strong urbanization in Belgium, a lot of areas can be considered as particularly vulnerable to heat waves due to the urban heat island (UHI) effect. However, little information exists on the interaction between the urban heat island effects during heat waves and their interactions under present and future conditions. The heat wave definition and heat stress index chosen in this study are based upon the warnings issued by the Public Health of Belgium for the Brussels Capital Region. For this study, regional simulations were performed using the limited area model ALARO, coupled with the Town Energy Balance scheme. The offline air quality simulations are calculated using the CHIMERE model. Results from our observations and climate simulations indicate that for the present climate conditions night time UHI is enhanced during heat waves which affects also urban and rural surface energy balance differently. The projected climate change under scenario A1B for 2050 leads to an increase of the number and duration of heat waves. More specifically, for rural (urban) areas, climate change increases the intensity of heat waves more during the day (night). We will also look more closely to the effect these changes have on air quality when taking the present and future climate scenarios under consideration. There is a significant increase in the number of days for which ozone concentrations exceed the warning threshold during heat waves. Besides the urban scale we will also investigate the impact of this configuration on air quality for the rural scale under present and future climate conditions.

A.W. Delcloo (✉) · F. Duchêne · R. Hamdi · A. Deckmyn · P. Termonia
Royal Meteorological Institute of Belgium, Brussels, Belgium
e-mail: Andy.Delcloo@meteo.be

R. Hamdi · P. Termonia
Department of Physics and Astronomy, Ghent University, Ghent, Belgium

J. Berckmans
Plant and Vegetation Ecology (PLECO), University of Antwerp, Antwerp, Belgium

30.1 Introduction

Previous research indicates that human mortality is impacted by both meteorological conditions and atmospheric pollutant levels, such as the high temperatures and high levels of ozone experienced during the 2003 heat wave that had a substantial effect on human health (Vautard et al. 2005). Stedman (2004) suggests that between 21 and 38% of the excess deaths observed during the summer 2003 European heat wave were attributed to ozone and PM10 pollutants. In this study, the chemical transport model (CTM) CHIMERE (Vautard et al. 2001) has been coupled to the climate simulations.

Three different simulations were considered as following: (i) 4 years with ERA-INTERIM driven experiment (2005–2008), (ii) current climate (1990–1999), and (iii) future climate (2046–2055), following the A1B scenario. For all the simulations, the same emissions from TNO/GEMS (2004) were used (Visschedijk et al. 2007). This will allow us to verify if the changes in climate conditions will actually lead to a change in ozone concentration, especially during heat wave events.

To validate the skills of our ALARO-CHIMERE system, the simulations for the time period 2005–2008 have been validated using observational data (PM10 and O3) from IRCÉLINE. In Delcloo et al. (2014a), it has already been shown that the use of the Town Energy Balance parameterization in the land surface scheme of ALARO have significantly improved the modelling of PM10 and ozone in the urban areas. When comparing the time series of observed and modelled PM10 data for the station of Uccle during the time period 2005–2008, a correlation coefficient (R) of 0.72 and a bias of $1.7 \mu\text{g}/\text{m}^3$ are found. The intercomparison statistics for ozone show a negative bias of $-9.3 \mu\text{g}/\text{m}^3$ with a correlation of 0.86, which elucidates that the model underestimates some of the observed ozone peaks. Since the station of Uccle is situated in a suburban area, the observed ozone time series show more elevated maximum ozone concentrations during ozone peaks, due to less influence by titration by NO. This chemical reaction favors the destruction of ozone and happens typically on locations which are much more exposed to traffic emissions (Beekmann and Vautard 2010).

30.2 Results and Discussion

30.2.1 Urban Micro-climate

From previous work it is shown that while the Brussels Capital Region warms substantially for the 2050s horizon, climate change will have a neutral impact on the annual mean urban heat island (UHI) intensity. The biggest and statistically significant change of nocturnal (daytime) UHI is noted during winter (summer) season with an increase (decrease) of $+0.2 \text{ }^\circ\text{C}$ ($-0.1 \text{ }^\circ\text{C}$). During summer, the decrease in daytime UHI is directly connected to soil drying over rural areas, while

the increase in nocturnal UHI during the winter can be explained by the projected decrease of wind speed (Hamdi et al. 2014).

The projected climate change under scenario A1B for 2050 leads to an increase of the number and duration of heat waves. More specifically, for rural (urban) areas, climate change increases the intensity of heat waves more during the day (night).

30.2.2 Air Quality

For the policy maker, it is interesting to know how these changes in heat wave intensity/events will have an impact on air quality by looking at how the number of exceedances will evolve in the future climate scenarios. To evaluate these changes, we have verified the number of days in which ozone concentrations exceed the warning thresholds of $180 \mu\text{g}/\text{m}^3$ during a heat wave event in the present and future climate simulations.

Table 30.1 shows results for some stations, which clearly indicate an increase in exceeding the warning threshold for ozone in the future climate. It is important for the interpretation of these results to take into account that the emissions that have been used are more representative for the first half of the time period 2000–2010 instead of the 90s. A strong reduction in NO_x and NMVOCs has been observed since then (Wilson et al. 2012). From the results in Table 30.1 we can deduce that for the city climate, the increase is higher when compared with the results from stations, located in a more rural area. However, we also observe that for stations, located in more forested area (Vezin, Offagne), the increase in ozone concentrations is even more elevated.

Table 30.1 The relative change in number of days in which ozone concentrations exceed the warning threshold of $180 \mu\text{g}/\text{m}^3$ for the future climate simulations compared to the present climate simulations for some stations under consideration

Station	Type	Relative change in number of exceedances (%)
Ukkel	Suburban	138
Destelbergen	Suburban	110
Houtem	Rural	58
Moerkerke	Rural	60
Offagne	Rural	453
Vezin	Rural	360
Dessel	Rural	142

30.3 Conclusions

The projected climate change simulations under scenario A1B for 2050 show that this will lead to an increase of the number and duration of heat waves. More specifically, for rural (urban) areas, climate change increases the intensity of heat waves more during the day (night).

The effects of these changes on air quality elucidate that in the future climate more exceedances of the warning threshold for ozone will take place. Especially for the suburban and more forested regions this seems to be the case. Since the intensity of the heat waves will increase for the future climate, a significant impact on the ozone burden is to be expected.

Acknowledgements The authors would like to thank IRCELINE for providing the observational data.

Question and Answer

Questioner: Richard Derwent

Question: You did not provide any projections of future ozone levels for the Offagne station in the forested region of Southern Belgium. Have you any results?

Answer: New results have been added for the Offagne and Vezin station in the Southern part of Belgium within this work.

References

- Beekmann M, Vautard R (2010) A modelling study of photochemical regimes over Europe: robustness and variability. *Atmos Chem Phys* 10: 10067–10084. doi:[10.5194/acp-10-10067-2010](https://doi.org/10.5194/acp-10-10067-2010)
- Delcloo A, Hamdi R, Deckmyn A, De Backer H, Forêt G, Termonia P, Van Langenhove H (2014a) A one year evaluation of the CTM CHIMERE using SURFEX/TEB within the high resolution NWP models ALARO and ALADIN for Belgium. In: Air pollution modeling and its application XXIII, NATO science for peace and security series C: environmental security, pp 495–498. doi:[10.1007/978-3-319-04379-1_81](https://doi.org/10.1007/978-3-319-04379-1_81)
- Hamdi R, Van de Vyver H, De Troch R, Termonia P (2014) Assessment of three dynamical urban climate downscaling methods: Brussels's future urban heat island under an A1B emission scenario. *Int J Clim* 34(4):978–999. doi:[10.1002/joc.3734](https://doi.org/10.1002/joc.3734)
- Stedman JR (2004) The predicted number of air pollution related deaths in the UK during the August 2003 heatwave. *Atmos Environ* 38:1087–1090
- Vautard R, Beekmann M, Roux J, Gombert D (2001) Validation of a deterministic forecasting system for the ozone concentrations over the Paris area. *Atmos Environ* 35:2449–2461
- Vautard R, Bessagnet B, Chin M, Menut L (2005) On the contribution of natural Aeolian sources to particulate matter concentrations in Europe: testing hypotheses with a modelling approach. *Atmos Environ* 39:3291–3303

- Visschedijk AJH, Zandveld PYJ, Denier van der Gon HAC (2007) A high resolution gridded European database for the EU integrate project GEMS, TNO-report 2007-A-R0233/B
- Wilson RC, Fleming ZL, Monks PS, Clain G, Henne S, Kononov IB, Szopa S, Menut L (2012) Have primary emission reduction measures reduced ozone across Europe? An analysis of European rural background ozone trends 1996–2005. *Atmos Chem Phys* 12(437–454):2012. doi:[10.5194/acp-12-437-2012](https://doi.org/10.5194/acp-12-437-2012)