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Object : Review of habilitation thesis of Dr. Peter Huszar

This Habilitations thesis, untitled "Impact of urbanization on climate and atmospheric chemistry"by Peter Huszar, contains a set of eight peer-reviewed papers in international journals, published from 2014 to 2021, preceded by a contextual framework associating them and concluded by a short summary. This impressive work focuses on the regional scale effects of urbanization in the troposphere. Research activities are carried out by a numerical modelling approach focusing over central Europe, characterized by medium urban density. Dr. P. Huszar is particularly interested by the inclusion in mesoscale models of urban canopy models to better parameterize the small and microscale processes specific to the urban environment. The main originality of that work is to account for the forcing (called UCMF) that the urban canopy layer acts on the meteorological variables over urbanized areas, reducing wind speeds and increasing vertical mixing of pollutants. Dr. P. Huszar convincingly demonstrates that, as air quality is strongly tied to meteorological conditions, the UCMF leads to modifications of air chemistry and transport of pollutants and provides estimates of those effects. Most of the studies reported in the publications are based on a set of experiments using the regional climate model RegCM4, including surface parameterizations that have been extended with the SLUCM or the CLMU urban canopy models. RegCM4 is generally online or offline coupled to the CAMx chemistry-transport model. In the last papers, the numerical approach is also extended to other regional climate-chemistry models : offline WRF-CAMx and online WRF-Chem. To distinguish the individual effects and to facilitate the understanding of the underlying processes acting to modify urban gas and aerosol concentrations, a very appropriate cascading experimental approach is used.

Chapter 1 is a good synthesis of the individual pathways and the general interactions between emissions, atmospheric chemistry and climate. It provides a clear and general overview of the direct and indirect impacts of urban areas on the atmospheric chemistry and meteorology, including the impact of UCMF on atmospheric chemistry.

In Chapter 2, the impacts of cities and urban surfaces on meteorological conditions and climate in central Europe are quantified. A statistically significant impact of urbanized surfaces on meteorological variables is found with enhancements of temperatures and boundary layer heights, and decrease of surface winds, humidity and summer precipitation rate. The use of the urban parameterization improves the representation of the diurnal temperature variation in the regional climate model. The distant influence of the cities over rural areas without major urban surfaces is also shown.

Chapter 3 quantifies the impacts of urban emissions from central European cities on the present-day regional air quality. A significant O_3 titration is found over cities, whereas O_3 is produced over rural areas. There is evidence of a significant contribution of urban emissions to concentrations of NO_x, SO_2, $PM_{2.5}$ in cities ($50 - 70\%$), but also over rural areas ($10 - 20\%$). Finally the interference between large cities in terms of air quality is found to be negligible.

The objective of Chapter 4 is to assess the present-day (2001-2010) and future (2046-2055) regional impacts of SLCF (aerosols and ozone) from urban emissions in Central Europe on climate. The impacts of present-day emissions from cities on climate are statistically significant but small, with decreases of surface radiation, temperature (≈ -0.03 K) and boundary layer height (≈ 5 m) noticed mainly over cities. Those effects are mostly ascribed to the radiative (direct and indirect) effects of aerosols, with a minor contribution from ozone titration. The impacts of future urban emissions are estimated to be even smaller since the future emissions themselves are assumed to be smaller. The main point here is that the modulation effects of SLCF emitted from cities on central European climate can be considered as minor compared to direct urban canopy meteorological effects caused by urban surfaces.

Chapters 5 and 6 investigate the impact of the urban canopy induced meteorological changes on the long-term summer photochemistry (Chapter 5) and surface fine aerosol concentrations (Chapter 6) in Europe. The presence of urban surfaces lead to large enhancements of urban surface temperature ($\sim 2 - 3$ K) and of vertical turbulent diffusion ($60 - 70$ m^2 s^{-1}) and reductions of humidity ($-0.4 - 0.6$ g kg^{-1}) and wind speed (-1 m s^{-1}). Wind- and temperature-related effects on ozone are of considerably smaller magnitude than those caused by urban canopy induced turbulence. The result of increased downward vertical mixing supported by reduced chemical loss lead to significant ozone increase (5 ppbv) over cities, NO_x reduction ($-2 - 3$ ppbv) and HNO_3 enhancements (1 ppbv) at the surface. Except humidity whose effect was found minor on aerosols, each of those individual modifications translates into significant changes in aerosol concentrations, not only at the surface. They lead to decreases of $PM_{2.5}$ over urban areas (by -2μg m^{-3}) in the case of urbanization-induced temperature (mostly nitrates) or turbulent changes (mainly primary BC and OC) and to increases of $PM_{2.5}$ (by $1 - 2\mu$g m^{-3}) when wind changes are considered (mostly primary BC and OC). Those studies demonstrate that including the urban canopy meteorological effects, especially turbulence, in chemistry simulations clearly improves model performance.

Chapter 7 investigates the uncertainty of vertical eddy diffusion arising from different representations in numerical models and how this uncertainty propagates to the final species concentrations as well as to the changes due to the UCMF. Urbanization has always a pronounced influence on vertical eddy diffusion, the largest impact being obtained for the turbulent kinetic energy based methods. This propagates to a range of O_3 increases by $5 - 10\%$ and $PM_{2.5}$ decreases up to $30 - 40\%$, explaining most of the impact of all meteorological modifications due to the UCMF. The effect of vertical diffusion hence counterbalances the opposing effects of other components of this forcing (temperature, humidity, wind), regardless of the resolution chosen and the season of the year.

In Chapter 8, Dr. P. Huszar analyses urbanization-induced extreme meteorological modifications and the resulting effect of UCMF on long-term extreme air pollution in central Europe for present-day climate conditions. Extreme values of meteorological variables (temperature, PBLH, winds) can respond to UCMF much more than average values. The impact on extreme values of NO_2 and $PM_{2.5}$ can also be significantly larger (2 times) than that on daily averages for both pollutants. This is of great policy interest.

Chapter 9 constitutes a study of the impact of urban areas emissions (UEI) in central Europe on air quality at local and regional scales and how this impact is modulated by the UCMF for present-day climate conditions. It is shown that urbanization contributes to increase NO_2 mixing ratios by $4-6$ ppbv ($40-60\%$), increase $PM_{2.5}$ concentrations by $4-6\mu$g m^{-3} ($20-40\%$) and decrease O_3 mixing ratios by $2 - 4$ ppbv ($10 - 20\%$) over cities. The UEI is overestimated by $\sim 60\%$ if urban canopy effects are not taken into account. Both the impact of UEI and its modulation are much stronger in the case of extreme pollution events. The urbanization-induced modification of vertical eddy diffusion turns out to be the main cause of the modeled decrease in the UEI whether the effects of UCMF are considered.

Finally Chapter 10 summarizes the results from those studies. Key messages from Dr. P. Huszar research activities are of great interest. His studies demonstrate that disregarding the urban canopy induced meteorological effects, and in particular turbulence, in air quality oriented modeling studies can lead to erroneous results in the calculated species concentrations. Those meteorological changes resulting from urbanization have to be included in regional model studies if they intend to quantify the regional footprint of urban emissions. Ignoring these meteorological changes can lead to the strong overestimation of UEI.

The thesis totally fulfills the requirements expected for a habilitation. Both the methodology and the scientific results are clearly described. The manuscript is well written and I have not found any serious scientific misconduct regarding plagiarism. The high percentage of coincidence in the plagisrism check is not relevant as mostly due to the fact that the dissertation is a collection of eight reprints of papers co-authored by Dr. P. Huszar. The results achieved represent valuable contributions to climate and atmospheric chemistry modelling and are, in my opinion, of high quality. I, therefore, recommend that it is accepted by the university to get the Habilitation degree.

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