

The urban canopy meteorological forcing and its impact on ozone and PM2.5: role of the vertical turbulent transport

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Dear Referee,

We appreciate the detailed and constructive criticism the reviewer raised in his throughout review. We considered all the comments in our revised manuscript and our point-by-point response follows. Moreover, we prepared the revised manuscript with highlighted changes with respect to the original version to facilitate the reviewers/editors decision how to proceed with the review process.

Referee #1's comments:

COMMENTS TO THE AUTHORS: The manuscript "The urban canopy meteorological forcing and its impact on ozone and PM2.5: role of the vertical turbulent transport" has been reviewed in great detail. The reviewer recognizes the great work carried out by the authors and the potential of the manuscript. However, although the manuscript is well-structured it is not very well-written. Statements are often not link to each other and just reported as "dot sentences" but without dots. The terminology used by the authors, mainly when referring to wind engineering and urban physics aspects, is not adequate and also inexact. Moreover, grammar errors (e.g. singular/plural and/or verb tens) have been found throughout the whole manuscript. Figures are clear and consistent to the body text but the font size of the labels is often too small and unreadable. From a scientific and methodological point of view, the manuscript has a great potential and the reviewer believes that it will be an important contribution for the whole scientific community, but the text should be largely improved, and the text made much more fluent both for an expert (e.g. a reviewer) and a non-expert audience. In conclusion, the reviewer's opinion about this manuscript is that it is not suitable to be published in the present form and an extensive work should be done to make the text understandable, unambiguous and scientifically robust for the audience. In order to help the authors in improving the manuscript the reviewer provided them with some comments/suggestions related to the main sections. However, the reviewer suggests to the authors to write again the manuscript and take care to the aspects raised below.

Authors' response: We appreciate that reviewer's recognition of our work and his potential for publication and we admit that it lacks some exactness and un-ambiguousness to communicate its message in a much clearer way towards the scientific community. We went trough the whole text and reformulated many paragraphs to meet the requirements of the reviewer. This concerns especially the use of some scientific terms which were not exact and better wording had to be used, mainly where the topic touches the field of wind engineering.

Abstract: In general this section is very detailed but also too long to be an abstract. Furthermore, although the scope of the manuscript is well highlighted in the first lines, it is not mentioned at all what the knowledge gap in the literature is. Therefore, the reviewer suggests to the authors to add one line about the "knowledge gap" and try to take out from this section some less important details however already included in other sections.

Authors response:

We added further sentences to clearly formulate the "knowledge gap" in the literature, which our manuscript is trying to fill. Further we shortened the abstract a bit ,however, we still would like to include in the abstract the most important aspects of both the design of the model simulations and the results and given their amount, we were limited in reducing the abstract's length.

Another important comment related to this section and to the whole manuscript as well is about the use of the terminology that can be inappropriate and ambiguous for the wind engineering and urban physics community to which this document is also addressed. Definitions as for example “urban meteorological changes”, “model experiments”, “urban canopy meteorological forcing” are not commonly used. The reviewer’s suggestion is to revise the whole document carefully and check in the literature the terminology usually adopted by publications dealing with similar topics.

Authors response:

We revised the use of the mentioned terms including others regarding on the urban canopy. We clearly defined what we meant under the formulation “the urban canopy meteorological forcing” and removed unambiguous terms as “urban meteorological changes”. Further we also removed the term “model experiments”, and rather replaced it with “model simulations” although in the atmospheric modeling community, “model experiments” is a rather accepted phrase denoting experiments conducted with model simulations when modeling is considered as experimental method.

At lines 3-5: The sentence “From an air quality . . . an important role too” is inexact and unclear. The wind, from the analytical point of view, can be decomposed into the “mean” and the “fluctuating” components which is also the turbulent part. An increased turbulence belong to a decreased mean wind speed. Furthermore, the reviewer does not understand what the authors mean by “wind stilling”. Please rephrase and make the sentence clearer for a reader.

Authors response: We reformulated these lines to be more exact highlighting the role wind and turbulence plays in the transport of pollutants in urbanized environment. The term “wind stilling” is commonly used regarding the influence of urbanized areas on the average windspeeds, e.g. Hou et al. (2013), Huszar et al. (2014) and refers to the decrease of windspeed due to increase drag over urbanized landsurface.

At line 6: what do the authors mean with “urban surfaces”? Do you mean urban city/area/environment? If so, please rephrase here otherwise try to explain exactly what you mean. Apply this comment throughout the whole manuscript whenever needed.

Authors response: Urban surfaces here mean urban landsurface type, i.e. surface changed from natural or rural to urbanized one with typical urban features as buildings, streets, parks etc. However, to be more precise, we replaced these terms with the term “urban canopy”, eventually the “urban canopy layer” if referring to the air in the urban canopy.

At line 11: please replace “the sensitivity to model grid resolution” with “the sensitivity of the numerical model to the grid resolution”.

Authors response: Changed.

At line 11: what do the authors mean with “model experiments are performed”? Experiments can be performed, experimental models can be used, but model experiments is no sense. It would be better to rephrase here to make the sentence unambiguous for a reader.

Authors response: If we accept the term “model experiment” (see above) as an experiment conducted with numerical model than “model experiments are performed” means the simulations performed. To avoid misunderstanding, we nevertheless changed this to “model simulations” are performed/conducted.

At line 12: the definition “urban canopy meteorological forcing” is not wrong but probably may be defined better and in accordance with the literature. It is well-known that obstacles composing cities (as buildings, bridges, trees, etc.) largely affect the wind flow field inside the urban canopy layer

(UCL) and many papers published in the last 30 years confirmed that the logarithmic profile (representative of neutral stability conditions) does not hold anymore in this layer. It means that the “local-scale forcing effects” on the wind flow inside this layer are mainly caused the “obstacles” than inflow conditions (the so-called “large-scale forcing effects”) imposed in the numerical model (for example by the nest of cascading models). Please refer to this comment also to modify the title, eventually.

Author’s response: it is well known that urban canopies large influence the air flow and the radiative and thermal conditions in the air which ‘fills’ the corresponding layer (urban canopy layer) but also above. Accordingly, in the revised manuscript we made it clear that the urban canopy meteorological forcing (UCMF) is the forcing that acts on the meteorological variables over urbanized areas. We have chosen the word ‘forcing’ as the presence of urbanized land-surface forces the air towards modified values of meteorological variables as temperature, windspeed, humidity etc (compared to the values if natural surface would be present).

Therefore we decided to keep this in the manuscript title as well.

At line 17: “near the surface”, to which surface are the author referring to? Please be more specific.

Author’s response: we refer to the urban canopy layer and clarified this in the revised manuscript.

At line 20: the definition “urban meteorological changes” is not widely used in the wind engineering and urban physics field. The meteorological changes happening at the scale of cities and/or urban districts can be included, according to the size of cities and districts, into the “microscale” and/or “local scale”.

Author’s response: we changed this to (at different parts of the manuscript) “urban canopy induced meteorological changes” which tells the reader that we refer to the changes of meteorological variables due to the introduction of urban landsurface (i.e. the UCMF has been imposed).

Introduction:

At lines 4-5, p2: The sentence “Urbanization . . . (Folberth et al., 2015)” is not clear, please rephrase and be more specific. The reference can help the reader in better understanding the meaning but the current manuscript (and all sentences) should stand alone.

Author’s response: we extended this sentence to be more clear for the reader without the direct requirement to look at the cited literature.

At lines 5-8, p2: the reviewer probably understood the intention of the authors and what they mean by this sentence but only after reading that few times. It would be better to rephrase here and make the sentence a bit more fluent.

Authors’ response: we rephrased the sentence to make it easier to understand and more fluent.

At line 9, p2: if the authors write “First of all” at line 5, the reader supposes that a second point follows soon and they would never expect an indentation when explaining the second aspect (“secondly”). Indentation here is not needed at all.

Author’s response: We agree and removed the indentation with a slight rephrasing too.

From line 12 to line 20, p2: this piece of text is very confused for the reviewer and it would also be unclear for a reader. Sentences, are not well-written in English and not very well-linked one to each other. Please rephrase and give to the whole piece of text a logical meaning.

Author’s response: here we intended to list the possible modifications of meteorological variables (within the UCMF) to help the reader to understand the the well known urban heat island (UHI) is not

the only change that occurs due to rural-to-urban transition but there are other ones too. We slightly rephrased this part of the text to make it more fluent and sentences to link to each other in a better way.

At line 21, p2: the sentence “Meteorological conditions are, thus, strongly perturbed over urbanized areas” states a concept very well-known since decades and assessed by many publications published in literature. You should cite or at least refer to the most important publications dealing with “urban canopy and boundary layers wind flow modeling”.

Author’s response: we added the reference to the well known BUBBLE experiment (Rotach et al., 2005) which encompassed a detailed investigation of the boundary layer on both city and street-level scale. This paper revealed most of the urban canopy induced changes we expected.

At line 22, p2: what do the authors mean with “urban induced modifications”?

Author’s response: We meant and changed the text to “urban canopy induced modifications of meteorological variables”

At line 25, p2: again, please correct the expression “urban meteorological forcing”. Moreover, what do the authors mean with “elements”? Please be specific and unambiguous.

Author’s response: We changed the “elements” to “components” referring to the components of the UCMF, i.e. the changes in temperature, windspeed, vertical turbulent diffusion etc.

At line 29, p2: please replace “the main contributor” with “the main contribution is given by”.

Author’s response: Replaced.

Experimental setup: The reviewer does not understand why the authors have titled here “Experimental setup” but they actually described different numerical models adopted to simulate. If this section, as well the next one, refer to numerical simulations there is no sense to talk about “experimental setup”. Please remove also the subtitle “Models”.

Author’s response: We changed this to “Methodology” which more fits the purpose of the section to introduce the scientific methods used to derive the conclusions of the study. We kept the subsection “Models used” as the used numerical models are key to the study and we think they deserve separate subsections.

RegCM4:

At line 15, p5: please replace “Internation . . . ” with “International . . .”.

Author’s response: Replaced.

At line 20, p5: what do the authors mean with “processes”? Please explain or be more specific and unambiguous. At line 20, p5: please as first time use the full name and the acronym in brackets “University of Washington (UW)”.

Author’s response: We meant the physical processes characteristic for the PBL, i.e. mechanical/thermal turbulence and interaction with the surface. We rephrased the sentence to be more specific. The acronym UW placed after the full name.

At line 23, p5: if more than two please replace “between” with “among”.

Author’s response: Replaced.

At line 29, p5: what do the authors mean with “landcover processes”? Please explain or be more specific and unambiguous.

Author's response: Here we mean the processes involved in the interaction of the land-surface and the boundary layer which includes the calculation of fluxes of heat, radiation, water and momentum. We clarified this in the revised manuscript.

At lines 30-31, p5: what do the authors mean with "classical canyon representation of urban geometry"?

Author's response: Here we mean the traditional view of urban geometry in the modeling community as an ensemble of canyons of different orientation, width and depth (height of the buildings on the sides of the canyon). The "urban canyon" concept was introduced by Oke (1987). See also Oke et al. (2017, page 19.).

At lines 3-4, p6: the sentence "Within the urban canyon, momentum fluxes are calculated using a roughness lengths and displacement height typical for the canyon environment" is grammatically wrong and scientifically inexact. How do you calculate the momentum fluxes using the roughness length and the displacement height? Moreover, both the roughness length and the displacement are characteristics of rough terrain or surfaces and not necessarily only of "canyons".

Author's response: Indeed, roughness length and displacement height are characteristic of all landsurface types in atmospheric models however here we described the urban canopy parameterization so we gave a reference how the heat and momentum fluxes are calculated in the urban canyon. We rephrased this sentence to be more correct: "Within the urban canyon, heat and momentum fluxes are calculated using the Monin-Obukhov similarity theory with roughness lengths and displacement heights typical for the canyon environment." The full description of the methods is given by the Technical Note on the urban canopy model in Oleson et al.(2010).

At lines 4-5, p6: it is important here to show some governing equations to make clear for a reader the numerical model used.

Author's response: The equations describing the fluxes of anthropogenic heat and air conditioning waste heat are rather complicated (see Oleson et al., 2010) and our manuscript is already lengthy, so we decided not to include any governing equation in the manuscript but placed appropriate reference for the reader if interested in the details.

Experimental setup and data: The title is wrong since the authors in this section are talking about numerical simulations and not experimental tests. Therefore, it is wrong to use refer to an "experimental setup". Moreover, to which "data" are the authors referring to? This is another error since they are not describing "results" or/and "databases" for example, for which commonly the word "data" are adopted. Similar errors have been repeated systematically throughout the whole section. Just some examples have been stressed by the reviewer below. The section should be probably re-written from scratch.

Author's response: As we already pointed out, numerical model simulations with the purpose of test some hypothesis can be regarded as experimental tool or these experiments as 'model experiments'. Consequently the configuration of such experiments, i.e. the 'experimental design' is in fact the model set-up . However, to avoid misapprehension, we changed the title to "Model set-up and simulations" which clearly states what follows (which includes also the model driving data, which are indeed not experimental data). We rewrote parts of the section to reflect this properly.

At line 15, p7: Please change "model experiments" with "experiments".

Author's response: replaced.

Moreover, please add one extra space between “resolution” and “(size . . .”. Moreover, if referring to computational grids, as it seems to be, please use a correct and proper terminology and replace “gridboxes” with “computational grids”. Please, apply this comment throughout the whole document whenever necessary.

Author's response: Indeed, we refer to the computational grid, but in particular these numbers refer to the number of gridboxes. There are three Cartesian computational grids with gridboxes as indicated by the numbers (in W-E and N-S direction). We rephrased and made the sentence more clear.

At line 16, p7: what do the authors mean with these numbers in brackets? This is not clear at all. Please add an extra space before each bracket.

Author's response: see above.

At line 16, p7: please rephrase the portion of the sentence “Each domain is centered over Prague”; make this concept clearer for a reader.

Author's response: This mean that the center of the domain matches the center of Prague. We rephrased the sentence appropriately.

At line 17, p7: what do the authors mean with “projection parameters”?

Author's response: we mean the parameters of the geographic projection used to project the Earth's spherical surface into a plane. We clarified this in the revised text.

At line 17, p7: the sentence “Accordingly, the three domain is denoted . . .” is grammatically wrong. Please rephrase here.

Author's response: we rephrased the sentence.

At line 18, p7: what do the authors mean with “The regional climate model simulations were performed over 23 vertical levels”? Please provide the reader with more details about the simulations performed to let him understand what you mean with “23 vertical levels”.

Author's response: In the revised manuscript, we explained in more detail the vertical layering of the models used, i.e. the depth of the model atmosphere and the depth of individual layers (which is a function of the number of layers).

At line 19, p7: the sentence “For the higher resolution ones” is wrong if the authors are referring to the grid having the “highest resolution”. Please rephrase here and make it clearer for a reader. Similar errors have been found also after line 19 but not reported extensively here.

Author's response: Corrected whenever occurred.

Result: The main title and two sub-titles have been used here without any reason. Please use the title to provide the reader with a “general picture” of the corresponding section. In this specific case the subtitle “Model validation” is too vague. You need to say what really has been done in this section.

Author's response: The model validation here means that the results of the models are validated against available observational data (surface measurements and sounding(included in the revision)). “Model validation” is a very common name when referring to such comparison so we think this title is not wrong, however we added a sentence just after it to make it clear what the section will include.

Conversely, the second subtitle “Model Climate” is completely useless. Once again, the terminology is not correctly and properly used and it may cause a large number of misunderstandings. The reviewer

does not understand why the authors switch continuously terminology to describe the same things. What do the authors mean with “observational data”? Do they mean “model climate” or what? And what do they mean with “simulated model results”?

Author’s response: We changed the “Model climate” to “Meteorology” as we validate here the meteorological variables (results from the simulations with the regional climate model RegCM). Similarly to the next subsection “Air-quality”, where we validated the chemical results (results from the simulations with the chemistry transport model CAMx). Observational data here means data directly observed, i.e. surface measurements or sounding data. The “simulated model results” are the outputs of model simulations which we compare to the measured/observational data. We rewrote this part to make it unambiguous and clear.

Another problem of this section concerns the “description” of results. The authors have provided the reader with a lot of observations without any reasonable explanation for these. The usage of an improper terminology makes this section unclear for a reader.

Author’s response: In the description of the results we focused strictly on the description only, without detailed explanation and interpretation of the results. This is done in the Discussion section further. We further reformulated many paragraphs of this section to reflect the reviewers concerns on the improper or unambiguous terminology.

Literature:

Hou, A., Ni, G., Yang, H., and Lei, Z.: Numerical Analysis on the Contribution of Urbanization to Wind Stilling: an Example over the Greater Beijing Metropolitan Area, *J. Appl. Meteorol. Clim.*, 52, 1105–1115, 2013.

Huszar, P., Halenka, T., Belda, M., Zak, M., Sindelarova, K., and Miksovsky, J.: Regional climate model assessment of the urban land-surface forcing over central Europe, *Atmos. Chem. Phys.*, 14, 12393-12413, doi:10.5194/acp-14-12393-2014, 2014.

Oke, T.: *Boundary Layer Climates* (2nd edition). Routledge, London and New York., 1987.

Oke, T., Mills, G., Christen, A., and Voogt, J.: *Urban Climates*, Cambridge University Press, <https://doi.org/10.1017/9781139016476>, 2017.

Oleson, K.W., Bonan, G.B., Feddema, J., Vertenstein, M., and Kluzek, E.: Technical description of an urban parameterization for the Community Land Model (CLMU). NCAR Technical Note NCAR/TN-480+STR, National Center for Atmospheric Research, Boulder, CO, 169 pp, 2010.

Rotach, M. W., Vogt, R., Bernhofer, C., Batchvarova, E., Christen, A., Clappier, A., Feddersen, B., Gryning, S.-E., Martucci, G., Mayer, H., Mitev, V., Oke, T. R., Parlow, E., Richner, H., Roth, M., Roulet, Y.-A., Ruffieux, D., Salmond, J. A., Schatzmann, M., and Voogt, J. A.: BUBBLE—an urban boundary layer meteorology project, *Theor. Appl. Climatol.*, 81, 231--261, 2005.