

Seasonal and diurnal variability in air pollutants and short-lived climate forcers measured at the Rwanda Climate Observatory

By DeWitt et al.

Upon second review of the manuscript, the manuscript has been improved, yet still requires major revision for publication in ACP.

Comments in green are unaddressed comments from the previous reviewer comment report and would be important to address before publication.

Reviewer general comments:

It is difficult for a mountain site to inform on the air quality in Kigali as well as on mitigation efforts within Rwanda, and even more so on the comparison between RCO and country averages. Yet this data set is important and merits publication. The story surrounding this data still needs work.

The discussion of PM_{2.5} in general should be removed as the study focuses on BC, O₃ and to some extent CO. These pollutants should also be added the title.

When and how often is RCO within the boundary layer compared to in the free troposphere? Line 134 does not adequately answer this issue. See the following references:

Nyeki, S., Li, F., Weingartner, E., Streit, N., Colbeck, I., Gäggeler, H. W., and Baltensperger, U.: The background aerosol size distribution in the free troposphere: an analysis of the annual cycle at a high-alpine site, *J. Geophys. Res.*, 103, 31749–31761, <https://doi.org/10.1029/1998JD200029>, 1998.

Zanis, P., Ganser, A., Zellweger, C., Henne, S., Steinbacher, M., and Stachelin, J.: Seasonal variability of measured ozone production efficiencies in the lower free troposphere of Central Europe, *Atmos. Chem. Phys.*, 7, 223–236, <https://doi.org/10.5194/acp-7-223-2007>, 2007.

Zellweger, C., Forrer, J., Hofer, P., Nyeki, S., Schwarzenbach, B., Weingartner, E., Ammann, M., and Baltensperger, U.: Partitioning of reactive nitrogen (NO_y) and dependence on meteorological conditions in the lower free troposphere, *Atmos. Chem. Phys.*, 3, 779–796, <https://doi.org/10.5194/acp-3-779-2003>, 2003.

Ozone chemistry, references still required:

Baier, B. C., Brune, W. H., Lefer, B. L., Miller, D. O. and Martins, D. K.: Direct ozone production rate measurements and their use in assessing ozone source and receptor regions for Houston in 2013, *Atmos. Environ.*, 114(Journal Article), 83–91, [doi:10.1016/j.atmosenv.2015.05.033](https://doi.org/10.1016/j.atmosenv.2015.05.033), 2015.

Geddes, J. A., Murphy, J. G. and Wang, D. K.: Long term changes in nitrogen oxides and volatile organic compounds in Toronto and the challenges facing local ozone control, *Atmos. Environ.*, 43(21), 3407–3415, [doi:10.1016/j.atmosenv.2009.03.053](https://doi.org/10.1016/j.atmosenv.2009.03.053), 2009.

Monks, P. S., Archibald, A. T., Colette, A., Cooper, O., Coyle, M., Derwent, R., Fowler, D., Granier, C., Law, K. S., Mills, G. E., Stevenson, D. S., Tarasova, O., Thouret, V., von Schneidemesser, E., Sommariva, R., Wild, O. and Williams, M. L.: Tropospheric ozone and its precursors from the urban to the global scale from air quality to short-lived climate forcer, *Atmos. Chem. Phys.*, 15(15), 8889–8973, [doi:10.5194/acp-15-8889-2015](https://doi.org/10.5194/acp-15-8889-2015), 2015.

Reviewer specific comments:

Title:

- I would again encourage the authors to specify which “air pollutants and short-lived climate forcers” they studied. I really think a specific title would benefit the visibility of the article. For example, **“Seasonal and diurnal variability in O₃, BC and CO measured at the Rwanda Climate Observatory”**

Abstract:

- Line 15: replace “air pollution is still largely unstudied in sub-Saharan Africa” to “Air pollution is understudied in sub-Saharan Africa”.
- Avoid parentheses. The information within them is important and should be part of the sentences.
- Season numbers are confusing. The seasons are much clearer now in the text, but it would be useful to use the month letters here in the abstract for clarity. The idea here is to make the abstract accessible to an international readership.
- Line 23: rewrite for clarity. For example, “Rwanda is [...] East Africa with less than 20% urbanization but is currently undergoing rapid development.”
- Line 26: give standard deviation on the 5 microg/m³ value.
- Line 36: are there only one or two rainy season(s)?
- Line 41: “that deserves immediate attention” – I would encourage the authors to either specify how or to omit this comment.

Introduction:

The introduction was streamlined and reads much better. However Figure 1 needs 2-3 more sentences of description to clarify the data points. I don't understand the x-axis. Are there really 1600 papers reporting an annual PM_{2.5} exposure (and why not concentration?) of 15 microgram/m³? I recommend using a few references to make the same point. For example compare O₃ and/or BC Paris, London, Beijing, LA, Mumbai, Johannesburg and add the new Rwanda data. Don't use PM_{2.5} if there is no PM_{2.5} data in the paper.

- Line 53: update reference to a more up-to-date reference.
- Line 55: astral should be austral

Methods:

- **Table 1: needs synthesized information. For example, additional columns could include minimum and maximum concentrations observed by each instrument, annual or seasonal average. Table 1 should be a quick reference for the community to see how this station compares to other mountain sites.**

- I recommend that the authors add a data processing section in their methods. How did they quality control the data?

Results and Discussion:

- Line 175-176: were the generator spikes often? The generator's influence could be substantially impacting the data, and it would be important to convince the reader of the trustworthiness of the data set.
- Black carbon concentrations are high enough to be reported in microg/m³.
- Figure 2: why is temperature constant at the beginning of the measurement period? Data quality control is incomplete still for BC (straight grey line around 9/1/16). Are the lighter colour traces averages, running averages, 8-h running averages? extrapolations? Specify.
- Figure 3: Absolute values are more meaningful to highlight an air quality problem. The authors can plot all traces on the same graph and have 3 different y-axis. The authors must be consistent in their graphing – each graph has different types of error representations and leads to confusion. Choose one and use throughout each panel for clarity.
- Figure 4: include a graph for RCO to effectively compare the three sites. Elaborate on the significant different in BC concentrations in DJF between Kampala, Addis and RCO. Nonetheless, comparing two urban sites with RCO is not so meaningful since they are affected by local sources to highly different extents. The authors could also remove this graph entirely.
- Figure 5: MODIS data should not be presented in the rainbow color scale. I recommend using **a two colour bar so that it is clearer whether the FRP is low or high (like the blue-red color bar)**. *The authors answer that they have changed the color, but the submission version likely has a mistake as it still contains the rainbow color scale.* The excellent match between FRP and BC concentrations is highly significant and should be further discussed in the paper. This comparison is striking!
- Figure 11: I have issues with the meaning of this figure. The comparison is problematic. Rwanda's bar on the figure is from ONE SINGLE SITE, a regional site **whereas the comparison to other countries is an average of a MANY**, and does not add value to the context. BC data could be compared to other background and mountain sites – but cannot between countries. Furthermore, if the authors want to highlight a pollution problem, **then a better approach could include highlighting maximum daily pollutant levels (and/or exceedances) instead of averages from different sites.**
- Figure 10: it is difficult to compare between panels. Place all graphs on one x-axis labelled Day 1-Day4 and then colour code with the different dates. Could the authors use microg/m³ instead of ng/m³?
- Section 3.3.3 – the discussion about PM_{2.5} in Addis Ababa and Kampala are outside the scope of the study. This analysis does not bring more understanding to Rwanda, particularly since no PM_{2.5} are being reported in this study.
- Line 467 – PM_{3.5} ;)

- The MOZAIC campaign discussion could be better placed under an ozone section.

Conclusion:

Point 1: The use of PM2.5 in this study is inconsistent. There is no PM2.5 data presented, yet Figure 1 and Figure 10 focus on PM2.5. The PM2.5 discussion is therefore misleading. Why not stick to BC discussion only? It would streamline the discussion.

Point 2: Higher emissions do not equate to higher ozone.

Point 3: excellent

Point 5: Care should be taken in using this first-ever data set for Rwanda to speculate on improving emission inventories and mitigation issues.

Reviewer technical corrections:

There are important changes that the authors can make to improve the quality of the writing and thus the efficiency of their communication. I would like to point out the following grammar and syntax recurring issues in the manuscript:

1. The word “this” should be followed by a noun. “Despite this,” and “This is” is incorrect/inaccurate syntax in scientific writing (see line 47, line 218, line 538).
2. Sentences longer than 2-3 lines of text need to be revised for syntax and conciseness. (see lines 94-99)