

Interactive comment on “Retrieval and validation of O₃ measurements from ground-based FTIR spectrometer at equatorial station: Addis Ababa, Ethiopia” by S. Takele Kenea et al.

S. Takele Kenea et al.

samueltake@yahoo.ca

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Response to Referee #2 comments and suggestions

We would like to thank the referee for useful comments and inputs that we have used to improve the manuscripts substantially. We appreciate the positive recommendations and understanding of the relevance of our work on FTIR observation of O₃ and its comparisons with satellite observations. In the following, we will address issues raised and recommendations by the referee in detail.

Referee #2 General comment: This paper presents the first results of the FTIR spec-
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trometer at the new measurement station in Addis Ababa, Ethiopia. This station is the first site at the African continent, where FTIR observations are performed regularly, and the third site within the tropics, a region which is poorly constrained by measurements and of great importance for the global atmosphere. This station is very important for validation of satellite retrievals and for the understanding of simulations of atmospheric chemistry and physics, and fills a gap in the global network of ground-based remote sensing stations. Because of that, this paper is important to publish and appropriate for this journal, even there are major revisions needed. I would recommend to publish this paper after major revisions.

It seems that the paper haven't been prove-read, there are many typing errors, the references are not consistently formatted throughout the paper, some references are missing (I assume that the author did not meant to copy a whole paragraph from the PhD thesis of A.K. Petersen without citing it...). Some sentences are grammatically incorrect. I refer to the commented version of the other referee and recommend to give a revised version to be read by the coauthors before the next submission. The intercomparison with the satellite observations is very repetitive, the technical descriptions of the satellites are too long and do not draw the interest of the reader. My suggestion is to show the satellite observations all together with the FTIR observations and give one overall discussion about the results. The FTIR observations do not need a validation by satellite, usually the FTIR observations are used to validate satellite retrievals. The measurement technique of FTIR spectroscopy have been used at many occasions and do not need a validation by satellite, but the FTIR observations can be compared with satellite observations. To my opinion, the paper would significantly improve by including a comparison with model simulations of ozone and/or in situ observations (if available), and by addressing scientific questions e.g. the high ozone during March 2009. I would recommend to show a time series of the FTIR measurements from 2009 to 2011 (not overlaying all years), showing the date on the x-axis (not day-of-the-year). The high O₃ during March 2009 should be addressed (what can be the reason for these high O₃?). The satellites observations can be shown (all together) in the same figure. The paper

describes the first FTIR observations at the site of Addis Ababa. The paper would improve by including a further discussion of the site: Where are the air masses coming from (it might be interesting to look at back trajectories)? Are there differences between the seasons? Is the ITCZ moving over this site, so does the site belongs sometimes to the Northern Hemisphere, and sometimes to the Southern Hemisphere, or is the ITCZ always south of Addis Ababa? Other existing publications about FTIR measurements in the tropics need to be cited.

I would recommend to change the title. The paper is not showing a validation, neither of the FTIR observations nor of the satellite observations. I would call it: First ground-based FTIR observations of O₃ at the African equatorial station Addis Ababa, Ethiopia, or something like that.

Response

We are grateful to the referee comments. We have accepted and addressed the referee's general comment which is also reflected more or less in some specific comments shown below. Typo errors, reference format and citations as well as missing references are now corrected in the updated version of the manuscript. The grammatical errors are carefully corrected as much as possible with contribution of all coauthors.

The technical descriptions of the satellites are indeed too long. This was also a comment from referee #1. Therefore, the descriptions are now short, clear and are given in Section 4 of the updated manuscript. The intercomparison with satellite was not compact enough in old version of the manuscript. We have now made rearrangement and the corresponding discussions are accordingly adjusted while maintaining their content as given under new Sections 5.1 and 5.2 entitled "Profile intercomparison" and "Column Amount Intercomparison" in line with the reviewer comment. It is true that FTIR does not need validation but intercomparison to build confidence in the FTIR and to use FTIR for validation of other satellites in the future.

We believe that comparison with additional data including those from model simulations

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could build confidence in the data. Model simulation can not serve as validation data for FTIR observations due to a lot of uncertainty in nearly all chemistry-transport (CTM) models. The FTIR observations can be used to tune model in a sensitivity numerical experiment and process studies. However, this is beyond the scope of this paper which addresses ozone observations at a new tropical site. We hope to extend this work in the future in the direction suggested by the reviewer.

We have also made substantial rearrangement as per the suggestion of the reviewer. We have created Section 5.2 on ozone VMR intercomparison and Section 5.3 on column amounts intercomparison. The previous discussions in these regard are coherently rearranged. This rearrangement has resulted in renumbering of figures etc as shown in the updated manuscript.

The title of the updated version of paper is "Retrieval and satellite intercomparison of O₃ measurements from Ground-based FTIR Spectrometer at Equatorial Station: Addis Ababa, Ethiopia."

Specific comments:

1. Why is it important to do measurements in the tropics? Cite all papers of tropical ground-based FTIR observations.

Response

There are several reasons to do measurements in tropics; Apart from the reasons stated in the introductions, often observations are confined with satellite or model simulations which have their own limitations particularly in providing accurate measurements of tropospheric gases since their sources are at the surface. So tropics are poorly constrained by ground based instruments such as FTIR. This instrument is so versatile that we can address different scientific issues.

We included these references for tropical FTIR based stations:

1. Petersen, A. K.: Atmospheric Trace Gas Measurements in the Tropics, PhD dis-

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sertation, University at Bremen Fachbereich für Physik und Elektrotechnik Institut für Umweltphysik, Germany, 2009.

2. Petersen, A. K., Warneke, T., Lawrence, M. G., Notholt, J., and Schrems, O.: First ground-based FTIR observations of the seasonal variation of carbon monoxide in the tropics, *Geophys. Res. Lett.*, 35, doi:10.1029/2007GL031393, 2008.

3. Petersen, A. K., Warneke, T., Frankenberg, C., Bergamaschi, P., Gerbig, C., Notholt, J., Buchwitz, M., Schneising, O., and Schrems, O.: First ground-based FTIR observations of methane in the inner tropics over several years, *Atmos. Chem. Phys.*, 10, 7231–7239, 2010

4. Rinsland, C. P., Goldman, A., Murcray, F. J., Murcray, F. H., Blatherwick R. D., and Murcray, D. G.: Infrared Measurements of Atmospheric Gases Above Mauna Loa, Hawaii, in February 1987, *J. Geophys. Res.*, 93(D10), 1260712626, doi:10.1029/JD093iD10p12607, 1988.

2. Rewrite the introduction as it is copied more or less word by word from the PhD thesis of A.K. Petersen.

Response

We have rewritten the part of introduction and also cited reference as follows: “The study of atmospheric trace gases has a great role in terms of global climate change and atmospheric chemistry. The increase in population growth, accompanied by industrial development and deforestation, has altered the environment of the tropics. The impact of these changes on atmospheric composition and climate are not fully known due to poor understanding of the physical and chemical processes that govern tropical atmosphere (Petersen, 2009 and references therein). The previous studies showed that no significant ozone loss is observed over the tropical stratosphere (Fishman et al., 2005 and references therein); however, it is very important to get a clear understanding about this region because this layer determines the concentration of many short lived

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species that are entering into the stratosphere. There is also limited understanding of the tropical tropopause.” 3. Is biomass burning really important for Ethiopia? Is this important, if looking at CO or CH₄ (as in Petersen) but for O₃?

Response

Observing biomass burning event is important for Ethiopia since it is more significant during agricultural activities on seasonal basis. Thus, the production of CO and CH₄ would be directly linked with the source of tropospheric ozone through photochemical process. So, it is crucial to observe the variation ozone amount over this site. There is MSc thesis by G. Sufa (2010) which clearly links biomass burning as a precursor to tropospheric ozone.

4. Why are the O₃ columns high in March 2009? Where is it coming from? Trajectory analysis?

Response

We would like to thank the reviewer for pointing this point to us. We have investigated this period which is May-June 2009, not March as stated by the reviewer. We have found that there is some inconsistency in the ADC (Analog to Digital Converter) counts during the two months as revealed in our metadata records. This period was also the beginning of our FTIR observations which is likely linked with instability in the measurements as we tried to set it up. However, we are still examining if there are isolated processes that were captured by FTIR but missed by the satellites. As far as our current information reveals, it is likely to be an artifact. Therefore, we have removed measurements with low ADC counts as a matter of precautions.

5. Are there differences between the seasons? Is the ITCZ moving over this site, so does the site belong sometimes to the Northern Hemisphere, and sometimes to the Southern Hemisphere, or is the ITCZ always south of Addis Ababa?

Response

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We added in section 2.1 the last paragraph “Our measurement site is located in the region of annual migration range of the Inter-Tropical Convergence (ITCZ) which characteristics for wet and dry seasons over this region. In December and June, ITCZ is occurs on the south and north of Addis Ababa respectively.”

6.Are the satellite observations altitude corrected? The FTIR site is at a high altitude, so by comparing with satellite observations with a bias swath, and not completely collocated, the altitude difference needs to be taken into account?!

Response

We have considered the altitude difference during comparison between FTIR and satellite observations. The ozone observations from satellites are extracted from altitude range above the station altitude level.

7.What means “coincident” here? Same time? Or only same day? Shown are daily averages?

Response

The considered temporal coincidence criterion is the “same day”, not the same time. So we have taken the daily average measurements for comparison.

8.Show also standard deviations of the daily averages of the FTIR observations to show the variation of O₃ during the day.

Response

This could be misleading as the number of observations from one day to the other is not uniform. Moreover, in some cases, the numbers of daily observations are very small.

Section3/Page 6771: -Discussion of the possible offset due to the spectroscopy?

Response

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Errors in the HITRA spectroscopic data have been discussed in the updated version of the manuscript.

Page 6769/Figures: It is mentioned, that the microwindow at 1000cm⁻¹ is best suited for O₃ retrievals, but due to the limited amount of MCT measurements, the InSb measurements are used in this publication. As the microwindow around 1000cm⁻¹ is best suited, it would be interesting to compare the MCT measurements with the the InSb measurements and show them together in one figure and discuss the possible differences. This would perfectly fit in this paper, as it is more a technical paper about retrieval and to the journal.

Response

Regarding MCT measurements, we just have a few measurements. We added this statement in line Page 6769, 20, “but we do not prefer to use it because the quality of the KBr beam splitter is not good.” We have also DC signals of InSb detector to check for clouds

Page 6767, line 5: does the FTIR spectra are recorded automated or by manual operation? How is it be assured, that clear sky conditions apply? By eye of a researcher/ technician or with a diode?

Response

This is done by the researcher/s through visual inspection.

Line14, 15: give the website/source of the automailer system and of NCEP

Response

We included website <http://www.cdc.noaa.gov/data/gridded/data.ncep.reanalysis.html> in the manuscript.

Line 18/19: which retrieval method is used in this paper? Are the others are tested for this site/the O₃ retrieval?

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Response

We have used Tikhonov-Phillips regularization method for the retrieval of O₃. We have not used methods such as the one based on apriori covariance matrix. The performance of such method depends on establishment of accurate apriori covariance matrix which we do not have for this region.

Page 6768, line 25: coadding the spectra for high signal to noise ratio

Response

Coadding of the spectra is done for 10 scans which is already described in the manuscript in Section 2.2.

Page 6769, line 20: how are the microwindows determined? With ALFIP software? cite Show the MCT measurements and compare with the retrieval performed with the microwindows used here

Response

We have obtained microwindows from ALFIP software (Notholt et al., 2004), we have added this phrase in Page 6769, line 20 "which are determined from ALFIP software". Regarding MCT measurements, we have already indicated reason for not using it.

Page 6770, line 2: "Figure 1 shows [an] example...", but is it also a typical spectrum?

Response

Yes, the examples shown in the manuscript are since other spectral fits are as good as this one.

Page 6771, line 1 and 2: what has the high tropopause of the tropics to do with the degree of freedom?

Response

This statement is rephrased as indicated in Section 3, paragraph 4.

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Line 16: I do not understand this sentence: why is there a bias if the averages are calculated on the basis of log retrievals? What does this mean? What is then the advantage of log retrieval? Better do it on a different way? Section 4: all satellite descriptions: "...we used the recommended parameters for screening the : : : data for the target trace gas of O₃" What does this mean? Recommended by whom? What are these parameters?

Response

The reasons for possible bias are indicated in a journal paper by Funk and Von Clar-mann (2012) for water vapor and CO both of which has very high vertical gradients. In our case, this has to be checked. Therefore, we have only indicated the potential for the occurrence of such biases.

Many repetitions, I would recommend to shorten this section. It is not well written and not interesting to read. One possibility would be to put the satellite descriptions in a supplement. Page 6772, line 26:

Response

We have removed some unnecessary details from the descriptions of the satellite instrument and have rewritten all sections. In the new manuscript, Section 4.1 has now be reduced to 16 from 36 lines. Similarly, Section 4.2 reduced from 31 to 15 lines; Section 4.3 is reduced from 30 to 11 lines; Section 4.4 is reduced from 35 to 14 lines; Section 4.5 is reduced from 34 to 9 lines; and Section 4.6 is reduced from 31 to 14 lines.

Moreover, we have made substantial rearrangements while retaining the substances of our discussion in the relevant rearranged sections (Sections 5.2 and 5.3) as shown in the updated version.

Technical corrections: There are so many formatting, spelling and grammatical errors, that I would recommend first to prove-read the article before sending to the reviewers.

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I refer to the commented version of the other reviewer for corrections.

Response

All above are changed according to the referee comments and suggestions.

In general, the reviewer's comments and suggestions were very much useful to improve the quality and readability of the manuscript.

Interactive comment on Atmos. Meas. Tech. Discuss., 5, 6763, 2012.