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Atmospheric Measurement Techniques Discussions

Interactive comment on "Ozone profiles above Kiruna from two ground-based radiometers" *by* Niall J. Ryan et al.

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General comments:
First, we would like to thank the reviewer for their feedback. We found it useful and believe that the paper has been improved as a result.

In addition, a small bug was found in the code assigning coincidence based on position relative to the vortex. After correcting this code, the number of coincidences for KIMRA and MLS increased, and the specific set of profiles selected has changed somewhat due to KIMRA having measurements in the vortex edge over the measurement time period. There was also a small increase/change in selected profiles for the MIRA 2 and MLS coincidences. No significant difference is seen in the comparison of the profiles, except for the number of measurements, and a small change was found in the column

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comparison differences.

A distinction is now made between standing waves (waves that are set up within components of instruments) and baseline waves (wave structures that are present in the baseline of spectra).

Response to Reviewer:

General comments

This is an interesting paper on the validation of the two microwave radiometers KIMRA and MIRA 2 based in Kiruna, Sweden. KIMRA and MIRA 2 are compared to each other when at the same location, to ozone profiles measured by radiosonde (RS) launched from Sodankylä, and to simultaneous measurements by MLS.

The effects on the ozone profiles of a unsolved problem of standing wave in the KIMRA measured spectrum are described. This is leading to a low bias of KIMRA towards MIRA 2, RS and MLS around 22 km.

7 and 5 months mean profiles for the 2012-2013 winter are first compared, then a comparison with RS using regression is performed with the distinction between measurement inside and outside the vortex. Finally, a 5 winters climatology of KIMRA is used to assess the presence of a dip in the arctic winter ozone profile at 35 km. A qualitative explanation for the presence of this dip in the ozone profile is given and the necessity of further investigations is mentioned.

The paper is clear and well written with good quality figures. The scientific contribution is relevant for publication and lies within the scope of AMT. The methods used for the comparisons are valid, and the related work is referenced. The paper will make a good contribution to AMT, provided that the following comments are addressed.

P1, line16: "KIMRA is low-biased with respect to the ozonesonde data due to a

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general low bias in the KIMRA profiles around 22 km altitude," A low bias due to a general low bias looks redundant. Please, modify in order to make clear that KIMRA is low biased with respect to radiosonde, MIRA 2 and MLS.
Agreed, thank you. The abstract has been edited and now states: "KIMRA has a correlation of 0.82 but shows a low bias with respect to the ozonesonde data, and MIRA 2 shows a smaller magnitude low bias and a 0.98 correlation coefficient. Both radiometers are in general agreement with each other and with MLS data, showing high correlation coefficients, but there are differences between measurements that are not explained by random errors."

P2, line25-26: To what extent is the inversion procedure presented here different from the older one? Were the older KIMRA spectra showing a similar standing wave? Was the older inversion setup able to deal with that? Please, describe shortly the changes with respect to the previous retrieval setup.
The goal for this work was to develop a retrieval scheme that could be applied as consistently as possible to both instruments. The previous retrieval methods for KIMRA and MIRA 2 employed variations on the OEM and are described in the references given in the text. Also, a different ozone transition has been used for the KIMRA retrievals. As noted in Raffalski et al. (2005), there were standing waves present in older spectra measured by KIMRA and a careful selection of the spectral region was also used to minimize the impacts of these standing waves.

P3, line12: The authors mentioned the two FFTS of KIMRA but only the characteristics of the narrowband FFT are mentioned. What are the characteristics of the second FFTS? Please add.
As noted in the response to Reviewer 1, information has been added to the section, reading: "The narrow-band FFTS, installed in 2007, is often centered on a nearby CO line and has been used in retrieving CO between 40 and 80 km (Hoffmann et

al., 2011), and the broadband FFTS, installed in 2012, has been used to measure atmospheric spectra in the region of 230 GHz. The data from the AOS are presented here as its time series extends back to 2002 and the spectrometer is the same model as the MIRA 2 spectrometer."

P3, line 13: "Narrowband often centered": please, mention that the FFTS can be moved to another frequency here instead of later in the text at p3, line 29-33.
This has been clarified in the text with the following addition. "KIMRA operates in the frequency range between 195 GHz and 233 GHz. The instrument has the capability to measure many species by tuning within this frequency range but, due to baseline issues, has only been used to measure O_3 and, since 2007, carbon monoxide (CO)."

P5, line 8: Is the uncertainty estimation of 1 ppmv constant for the whole altitude range? The standing wave on the wings of the spectrum should affect only the bottom of the profile? Please, describe the variation of the 1 ppmv uncertainty with altitude.
The estimates of the errors were made using sensitivity tests and so do not provide information about the altitude structure of "real" baseline waves in the spectra. The text has been modified to clarify this: "These error estimates are based on results of sensitivity tests and do not provide information about the vertical structure of errors caused by "actual" baseline waves in the spectra."

P5, line12: Oscillations in the baseline are due to reflections along the quasi-optic path. The distance of the reflection to the horn can be deduced from the oscillation frequency. Were the authors able to determine in which of the components of KIMRA the reflections are set?
This has been attempted but the origin is still unclear for KIMRA. Oscillations in the baseline do not only come from reflections in the quasioptical path, but can also be

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due, for example, to impedance mismatching in any part of the system. In looking at the KIMRA spectra, there appears to be a combination of more than one signal.

A recent servicing of the AOS has eliminated the visible oscillation in the MIRA 2 spectra. This was likely an artifact produced by a laser diode at the end of its life.

This information has been included in Section 3.2 and 7.

Sec. 3.2: "The clearly visible structure in the baseline of the MIRA 2 spectra (seen in Figure 1) has been eliminated during recent servicing of the AOS. This structure was likely an artifact produced by a laser diode at the end of its life."

Sec. 7: "A recent servicing of the MIRA 2 AOS has eliminated the visible oscillation in the MIRA 2 spectra."

P5, line 22 and Figure 2: The measurement contribution (MC) is 140% at 45 km and 120% at 18km. Can such deviations from 100% be explained? Please, explain the high MC values.
Higher than 100% measurement response is due to the averaging kernel for that altitude having an area greater than 1. The concentration at an altitude is not only sensitive to variations at that altitude, but also to concentrations at other altitudes because of the vertical resolution of the retrieved profile being lower than the retrieval grid. This is often seen for ground based instruments (e.g. Palm et al., 2010, Hoffmann et al., 2011) and to some extent for satellites (e.g. MLS data quality documents – e.g. Livesey et al., 2013).

The values are relatively high here and are likely because the altitude resolution of the retrieved profile at those altitudes is coarser than the altitude resolution of the retrieval grid.

As the MC is the sum of the surfaces of the AVK, the shape of the envelope of

the AVK should correspond to the shape of the MC profile. This is not the case in Figure 2. Please comment.

The shape of the measurement response generally does not follow the envelope of the averaging kernels. To make an example, one very broad averaging kernel may follow the envelope but have a relatively high area. This is also true for satellites and can be seen in the ozone averaging kernels for MLS (MLS data quality document v4.2; Livesey et al., Version 4.2x Level 2 data quality and description document, Tech. Rep. JPL D-33509 Rev. B, Jet Propulsion Laboratory, Pasadena, Calif., 2016).

P6, line15 and Figure 3 Measurement error of KIMRA resp. Mira 2: the whiskers are the 1 standard deviation of the differences. Are the dashed blue lines, the observation errors which are related to the measurement covariance matrix? In that case, the errors should be minimum in the middle part of the profile where the SNR is maximum? What is exactly the dashed blue line? Please modify in order to clarify what the "the sum of the average measurement error" is.

Measurement error does refer to error from the measurement noise covariance matrix. This has been clarified in the text: "The regression coefficients (slope and intercept) are calculated for two cases of KIMRA/MIRA 2 partial column error estimates. The first case includes only the measurement error on the profile: the error due to the statistical noise on the spectrum (Rodgers, 1990), to which an offset has been added to account for short scale waves in the spectral baseline (see Section 3.2)."

The minimum in the relative error for KIMRA and MIRA 2 does occur in this region. This minimum in the absolute (ppmv) error does not, in general, have to occur where the concentration of the trace gas is a maximum. An example is the CO profile which increases strongly with altitude in the mesosphere and has higher absolute errors at these altitude (Hoffmann et al. 2011).

As noted in the response to Reviewer 1, the measurement error has been removed from the profile comparison figures as there is no real value in comparing the systematic bias with the measurement error. It was more for a quick comparison of value. This error has been used in Figures 4,5,9, and 10 instead.

Does considering the standard deviation/sqrt(n) instead of the standard deviation of the n differences change the conclusions of section 4.2? Same comments for Figure 7 and 8 and conclusions of section 5.3. Please comment.

Agreed. The error bars on the profile comparisons (Figures 3, 7, and 8) have been changed to include the standard error of the mean, as suggested by both reviewers. The standard deviation of the differences between profiles is also still included as it represents the space in which one instrument's profile is likely to lie in relation to another instrument's.

P9, line 22-23 and Figure 5: Is the number of coincidences influencing the regression coefficient? The statement of higher correlation for MIRA 2 and RS is done on 25 coincidences for KIMRA vs RS and 13 coincidences for MIRA 2 vs RS. Please comment.

In theory, the sample size does not affect the regression coefficient. This is not true in practice, in the case of error, and the value obtained will change according to the sample that is taken from a dataset. Increasing the sample size does, however, change the goodness of the fit. The standard errors on the slope are now included with the estimates of the slope and shown on the figures. MIRA 2 shows a larger standard error on the fit than KIMRA does in the case of the sondes.

The reader cannot deduce from the good r coefficient of MIRA 2 vs RS that the bias ($\pm$ the standard deviation) of the differences between RS and radiometers is within the range of the sum of the measurement errors from RS and MIRA 2. The regression plot and factors without an estimation of the errors are not sufficient to establish the good correspondence between MIRA 2 and RS, please

add errors bars to figure 5 or show the profile of the difference.
Error bars are now included on all column comparison plots and the corresponding text has been modified accordingly. A comparison with measurement error is not made.

P12, line 20-21 : The authors emphasized that the arctic winter dip in ozone at 35 km is not a result of the biases in KIMRA ozone profiles, but an issue could be : to what extent the bias in KIMRA ozone profiles, bias related to the presence of the standing wave in the measured spectra, is enhancing the ozone dip at 35 km or the maximum intensity at 27 km?
It is agreed that this point should be emphasized, as well as the fact that the bias in KIMRA can obscure a local minimum in the profile. In comparing to MLS in Figure 12, in early 2013, KIMRA appears to enhance, and in instances create, a minimum in the profile. In late 2013, KIMRA obscures a minimum that is seen in the MLS profile. It will be challenging to accurately separate the two with KIMRA data alone. Text has been modified/added to this effect: “As the location in altitude of this local minimum can change throughout the winter, due to descent of air for instance, the oscillatory bias in the KIMRA profile can either enhance or obscure its presence. Thus, it will be challenging to accurately identify a local minimum feature with KIMRA data alone.”

Do the authors have any suggestions? Is it possible to correlate the intensity of the ozone dip with the opacity of the troposphere or with the intensity of the standing wave? How is the standing wave in winter 2008, when the ozone dip is not as clear?
A good question. It would be interesting to try to correlate the intensity of the O_3 profile at 27/22 km (i.e. the baseline wave signal) with atmospheric opacity. It is possible that that could work to identify a variation in the inversion, and, in the long-run, try to account for some of the bias on an individual profile basis. However, this is speculative and is outside the scope of the work presented in this paper.

It is difficult to quantitatively say what the baseline (or standing wave signal) looked like, but the spectra in 2008 are similar to the spectra in other years.

A reiteration must also be made here that the local minimum is present in the stand-alone MLS data, as shown in Figure 12 for 2013.

MLS show the ozone dip in Figure 12. Are the MLS profiles AVK smoothed by KIMRA? What is the influence of the smoothing by KIMRA AVK on the ozone dip intensity measured by MLS? Please describe the eventual effects of AVK smoothing of MLS ozone profiles by KIMRA AVK on the ozone dip measured by MLS.
The MLS data is not smoothed in Figure 12. The caption has been modified to indicate this. The un-smoothed MLS average profile is now included in the profile comparisons in Figure 7 and 8 to show the effect of the smoothing with the averaging kernels of the ground based instruments. The dip is more obviously seen in the average of the MLS profile (non-smoothed included) than in the ground based profiles, but this is only for 2013.

Technical comments

Figure 4, righthand side: up left panel: in the text p6, line 29: slope=0.81, in the figure: slope=0.9; down left panel: in the text p6, line 32: slope=1.0, in the figure, slope=1.07.
Please make it consistent.
Thank you. This has been done.

P8, line 10: Livesey (2008) is not in the reference list
This has been added.

P10, line9: "...shows better agreement with MLS." Please, mention here a reference to Figure 8.
Done.

P10, line 14: it should be Figure 4 instead of Figure 3
This has been changed.

P13, line 27: Calisesi (2003) is not cited in the text
It has been removed from the references.

P16, line 6: Palm(2010) should go to P17, line 22
Done.

P17, line 17: Nash(1996) is not cited in the text
It has been removed from the references.

P19, Figure 2 left and middle: please add a vertical dashed line at MC=100%
A vertical line has been added at 80% MC to illustrate the cutoff.

P20, Figure 3, legend: a priori "used" for the Inversion
Edited.

P20, Figure 4, p26 Figure 12, p27 Figure 13: why ppv instead of ppmv? Please adapt for similarity with the others figures.
They have been changed.

P25, Figure 10, legend: should be "as Figure 9" instead of "as Figure 10"
Done. Thank you.

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