Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2016-86-AC1, 2016
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Atmospheric Measurement Techniques
Discussions
Open Access

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

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Received and published: 19 July 2016

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

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:

This is a nice validation paper which focuses primarily on the 2013 period when MIRA and KIMRA were both deployed at Kiruna. The validation information is encompassed primarily in two sets of figures. Figures 3, 7, and 8 show comparisons between average profiles from the instruments, and point-by-point coincident comparisons are presented in Figures 4, 5, 9, and 10. It is therefore important that these figures are as informative as possible in order to provide for the basis for interpretation of the validation.

For Figures 3, 7, and 8, it is unclear what the blue "measurement error" refers to. Is this systematic error? This is unclear in the associated text as well. If the point of these figures plot is to discuss systematic biases, and I think it is, then the appropriate error bars here should be sigma/sqrt(n), not sigma as is shown. Given the number of data points here (e.g. 177 in Figure 3) error bars should then be much smaller. In fact, if the error bars are retained at their current large form, some of the statements made in the conclusions cannot be drawn. The variability and random error comparison for which the larger error bars would be appropriate is best left to Figures 4, 5, 9, and 10.
Measurement error refers to the error due to statistical noise on the spectrum, but this has been removed from the profile comparison figures as there is not a real value in comparing the systematic bias with the measurement error. It was more for a quick comparison of value. The measurement error has been used instead in Figures 4,5,9, and 10, as suggested.

The error bars on the profile comparisons have been changed to include the standard error of the mean, as suggested. 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.

Text has been added when describing the plots: "The standard error of the mean difference is also shown but is small due to the sample size".

For Figures 4, 5, 9, and 10 it is important to clearly define how exactly the x and y errors are determined. To what extent are the slopes sensitive to reasonable variations in the error estimates? A similar study was conducted by Nedoluha et al. [1997], where it was found that different error estimates gave significantly different slopes, but because of the smaller geophysical variations in that study the sensitivity of the slopes to the error estimates may have been much higher. In any case, an estimate of the uncertainty in the slopes based upon an uncertainty in the error estimates should be given. If the slopes are not, within the uncertainty of these estimates, equal to 1, then there is a significant difference in the variations observed by the instruments and this should be discussed. If not, then the appropriate conclusion is that they agree within reasonable uncertainties.
Agreed. Accordingly, some changes have been made to these plots:

First, a mean of the error on the columns in an altitude range was previously being used for all points in that range. This has been changed so that the error for each measurement is properly represented.

The slope is now calculated for two cases. The first case includes only the measurement error (the error due to the statistical noise on the spectrum), which has been estimated as in Section 3.2. The second case includes the sum of 130% measurement error and the mean of the error on the columns. The idea here is to increase the

individual measurement errors to try to account for other errors that might vary statistically, and to include a constant error that does not change over time or depend on the measurement error. The error bars are now included in the plots and the standard error on slopes is also shown, as defined in York et al. (2004). Some discussion of the results is provided in each section as below.

Sec. 4.2: "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 second case is the sum of 130% measurement error and the mean of the measurement errors on each partial column: the former increase is to try to account for other errors that vary statistically (such as errors in the temperature profile), and the latter is to include an error that does not change in magnitude over time or depend on an individual observation. The idea here is that this will help to capture some the variation in the measurements that is neither truly random nor systematic in nature, such as a baseline error. While not based on it, the larger error estimate appears justified when one considers the bias shown in Figure 3. The limits of these slopes and their standard errors define a range that should contain the value of 1 if the measurements agree. A similar approach was used by Nedoluha et al. (1997), in which case the standard deviation of the satellite measurements being compared was added to the errors of the ground-based measurements.

The results for KIMRA and MIRA 2 are plotted in Figure 4, showing the correlations and the slopes and intercepts of the lines of best fit in each case. The correlations between the partial columns are high, even for layers containing the altitudes with poor profile correlation (Figure 3 (right)), with 36 - 46 km having the highest value of 0.97. A value of 1 lies within the range of the slopes calculated for the two lowermost columns, albeit just barely for the 16 – 26 km column. The 26 – 36 km columns agree for both cases of error estimation. A value of 1 does not lie in the range of slopes for the two higher partial columns, with MIRA 2 showing a larger range of O_3 values in both cases. A value of 1 for the slope does lie in twice the standard error range of the higher error estimates, but for the 46 – 56 km partial column this error is likely an overestimation as the error bars are larger than the variation of the points from the line of best fit."

Sec. 5.3: "Lines of best fit were calculated accounting for errors in X and Y. The correlations between KIMRA and MLS (Figure 9 (lower)) vary between 0.66 and 0.80, and slopes of best fit for the partial columns vary between 0.81 and 0.96, for the case of the lower error estimate. Only for the lowermost column does a value of 1 lie in twice the standard error range of the calculated slopes but it should be noted that the slopes for the lower error estimate all lie within 19% of 1. The correlations between MIRA 2 and MLS (Figure 10 (lower)) are high, between 0.88 and 0.94, and a value of 1 lies in the range of calculated slopes for the two lowermost columns. It can be seen from the two 46 – 56 km panels in Figure 10 that MIRA 2 is low-biased in the case of high O_3 columns at these altitudes.

In most instances for the comparisons with MLS, the higher error estimate has a small change (< 0.03) on the value of the calculated slopes, but a large change is seen for the two highest columns in the KIMRA and MLS comparison in Figure 9 (lower). This is likely due to the smaller natural variation in O_3 at these altitudes and the presence of outliers in the KIMRA data. MIRA 2 in general shows better agreement with MLS, compared to KIMRA."

Page 2 - "With a likely upcoming gap in observations from profiling satellite instruments, ground-based instruments will represent the predominant source of atmospheric measurements needed to maintain a long-term O3 profile record." While I don't dispute the importance of ground-based instruments, it seems unlikely that there will be a true gap in profiling satellite instruments in the near future. Admittedly MLS may stop operating in the next few years, but OMPS-LP and SAGE III are both likely to be operating for some time, and the OMPS nadir

instrument certainly does provide some profile information. Perhaps it would be best to just rephrase this as "With the decrease in observations from profiling satellite instruments, ground-based instruments will represent an increasingly important source . . ."

Yes, thank you. This line has been edited to state: "With the decrease in observations from profiling satellite instruments, ground-based instruments will represent an increasingly important source of measurements needed to maintain a long-term stratospheric O_3 profile record."

Page 3 - "as well as two Fast-Fourier-Transform spectrometers (FFTS)." There's only discussion of what is done with the narrowband FFTS. What about the other one?

The text has been modified to: "The narrowband 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 is presented here as it extends back to 2002 and the spectrometer is the same model as the MIRA 2 spectrometer."

Page 5 - "Attenuation of the signal due to the troposphere is accounted for by including the Millimeter wave Propagation Model MPM93 H2O continuum (Liebe et al., 1993) in the inversion." Does this mean that ARTS is not run in the troposphere (i.e. it is run only in the middle atmosphere)? Or does it mean that something is added to ARTS in the tropospheric levels?

ARTS is run in the troposphere as well as the stratosphere and the water vapour continuum is included in the model. In an effort to be clearer, this line has been changed to: "Attenuation of the signal due to water vapour, mainly in the troposphere, is accounted for with the Millimeter wave Propagation Model MPM93 H_2O continuum

(Liebe et al., 1993), which can be included in the forward modelling with ARTS."

Figure 2 - Please put a dashed or thin line at 0.5 ppmv/ppmv (=100% measurement response) to make it easier to estimate the measurement response.
To better show the measurement response cutoff, a line at 0.4 ppmv/ppmv has been included and the shading removed. And a line of text has been added stating: "The mean measurement response for KIMRA dips just below 0.8 at 35 km due to some negative values in the corresponding averaging kernel but the inversion is still defined as useable here."

Page 8 - "Either way, the choice of time criterion did not have a substantial effect on the presented results (there was a slight increase in standard deviation)." So there was an increase in standard deviation both for tighter and loser coincidence criteria?
It was for a looser criterion. The text has been modified to read: "Either way, the choice of time criterion did not have a substantial effect on the presented comparison results (there was a slight increase in standard deviation of the differences for a looser time coincidence)."

Page 9 – "Both the ozonesonde and MLS profiles were smoothed using the averaging kernels." How were the ozonesonde profiles smoothed with averaging kernels given that their highest altitude is in the middle of the KIMRA/MIRA2 vertical range?
Good point. The ozonesonde profiles were extended using a scaled KIMRA/MIRA2 a priori profile. This information is now included in this section. "Because the ground-based measurements have some sensitivity to O_3 at altitudes higher than the reach of the sondes, the sonde profiles were extended above their maximum altitudes prior to performing the smoothing calculation. This was done using the a priori concentrations

(Section 3.1) scaled to match the sonde data at its highest altitude."

It seems surprising that KIMRA shows so much less variation than the sondes in Figure 5, but in other figures that show 16-26km data KIMRA shows more variation the MIRA2 . Any comments on this?
Both KIMRA and MIRA show less variation compared to the sondes than to MLS, but particularly KIMRA, and the reason is unclear. Identification of a cause falls outside the scope of this work and we would not like to make a conjecture.

Figure 10: The caption says "same as Figure 10". Presumably it should say "same as Figure 9".
The text has been changed.

Page 12 – The only reasonable explanation for the double peak structure is the last one given, beginning with "A possible explanation for the observed shape is the combination of downward motion of air within polar vortex, and transport of extra-vortex air into the middle to upper stratosphere". A lot of the discussion leading up to this (chemical ozone depletion, mini-holes, . . .) should be eliminated since it clearly isn't relevant.
The text has been modified to exclude some of the information.

All information explaining the ozone mini-holes has been deleted. Only reduced information about the measurements in 2002/2003 is retained because it concerns the observation of a structure in the ozone profile that is similar, and therefore relevant, to the structure seen in this work. Also, discussion of chemical ozone depletion and variation of the vortex edge has been retained as these are possible causes that need to be eliminated through this discussion.

Sec. 6.1: "The O_3 dip is present for some period of time in each year and disappears in late February or March. It is persistent up to the end of March in 2009. It is very unlikely that this feature is caused by chemical ozone depletion as ozone loss resulting from heterogeneous reactions in the lower stratosphere has never been seen extending to this altitude in the Arctic (e.g., Manney et al., 2003, 2015; Kuttippurath et al., 2010; Livesey et al., 2015). A strong O_3 dip (most similar to 2010 presented here) has been observed previously with KIMRA in the winter of 2002/2003 (Raffalski et al., 2005). This coincided with ozone mini-holes between 4 and 11 December 2002, as reported by the European Ozone Research Coordinating Unit (EORCU), but the KIMRA measurements presented for that winter still show the structure of an O_3 dip throughout most of December. The latitudinal extent of the polar vortex has been shown to vary with altitude (e.g., Schoeberl et al., 1992; Manney et al., 1995; Harvey et al., 2002), which could explain an occurrence of a local minimum/maximum, but such a feature would not remain stable long enough to account for the observations shown here."

Page 12 – "An oscillatory bias was identified in the KIMRA data, present in the comparison with all three instruments." According to Figure 3, 7, and 8 in their current form with their very large error bars, this bias would appear to be insignificant, so it is not clear that this conclusion can be drawn. If the error bars were changed to sigma/sqrt(n) then this conclusion would probably be appropriate.

Figures 3, 7, and 8 have been modified to show the standard error of the mean.

The text in this section has been edited to: "An oscillatory bias was identified in the KIMRA data: There is a low bias of 1 ppm at 22 km, and a high bias of 1 ppm at 28 km, both with a halfwidth of 5 km."

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