Answer to Referee # 2

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Dear Referee, thank you for carefully reading our paper and for your comments and suggestions. They will help to improve the article. To answer your comments we will always print your comment first and then our answer to it.

Generally, it would be helpful to report also relative differences (%) and not only absolute differences (ppmv). This makes cross checks with other studies easier.
Done.

The introduction is missing an overview of the actual state of research on middle atmospheric water vapor with a focus on how ground based mw radiometers contribute.
We changed the first part of the introduction as follows:
Water vapor plays a key role in the Earth's radiative budget as it is the most important natural greenhouse gas in the troposphere. In the stratosphere water vapor is important as it has, through cooling by infrared emission, an effect on stratospheric temperature which itself influences surface climate as shown in [17] and references there in. Water vapor has chemical effects on ozone in the stratosphere [2] as well as in the mesosphere [9].
In the stratosphere and mesosphere water vapor has a long photochemical lifetime with respect to dynamical processes and it is therefore a valuable tracer. It enters the stratosphere from the troposphere through the tropical transition layer which acts as a cold trap rendering the middle atmosphere extremely dry. The seasonal cycle in tropical tropopause temperature leads to an annual cycle in water vapor mixing ratio near the tropopause [5]. These variations propagate upward through the tropical stratosphere, following the Brewer-Dobson circulation, exhibiting the so called tape recorder [11]. Oxidation of methane is the dominant formation mechanism of middle atmospheric water vapor leading to a positive vertical vmr gradient throughout the stratosphere. Photo-dissociation due to the absorption of solar Lyman α is the relevant sink of water vapor in the middle atmosphere, leading to a negative vertical VMR gradient throughout the mesosphere. Effects of the Lyman α irradiance varying with the solar cycle can be observed in the upper mesosphere [13, 6, 14]. Besides the tropical stratosphere strong seasonal variations are also found in the polar to mid latitudinal mesosphere with high water vapor vmr in summer and low vmr in winter [15]. An accepted theory is that upwelling in summer transports humid air from altitudes around the stratopause towards the mesopause while downwelling in winter has the opposite effect, e.g. dry mesopause air is transported towards the stratopause [7]. In polar region middle atmospheric water vapor

profile measurements have been used to determine timescales of mesospheric and stratospheric vertical transport [4, 8] and to investigate meridional transport during sudden stratospheric warmings [16, 3].
Water vapor in the upper stratosphere and mesosphere is mainly observed by passive remote sensing instruments, either space borne or ground based. Satellite instruments, such as MLS on EOS/Aura [18], MIPAS on ENVISAT [10], SMR on ODIN [12] and FTS on ACE [1] provide the vertical as well as the horizontal distribution of water vapor and other trace gases and are therefore important for the monitoring of the evolution of the composition of the Earth's atmosphere on a global scale which is crucial for climate research. However, the lifetime of a satellite is typically limited to less than a decade and therefore the creation of meaningful long term observational time series from these data requires careful checking of the consistency between different instruments.
Ground based radiometers observing middle atmospheric H_2O provide vertical profiles at a single location and are characterized by long operational lifetimes and a temporal resolution in the order of hours to days. A network of ground based instruments allows detecting biases between satellite experiments, helps to find geographical dependency in these biases and plays a key role in the merging of satellite data sets. In addition the long term data sets are used to study trends, seasonal and longer term variations in stratospheric and mesospheric water vapor. Alongside this network of ground based instruments having a high temporal resolution is used for dynamical studies such as the investigation of horizontal and vertical transport. However this requires that the network itself is consistent and that the temporal resolution of the instruments is optimized. Examples for middle atmospheric research using ground based radiometers are given above.

Change title to "Description of the instruments"
Done.

P3364/l27 replace "to avoid" with "to minimize"
Done.

P3367/l14 Use an other letter for the equivalent transmission, as t is already used for time in Equation 5.
We changed t to tr.

P3369/l20 The use of a noise diode should also be mentioned in "Calibration Methods".
We agree that it is better to mention the internal calibration load earlier in the paper. We decided, however, to do it in the "Description of the instruments" as it is not directly related to the calibration of the spectrum, but is an integral part of the correlation receiver of MIAWARA-C.
The output of MIAWARA-C's correlation spectrometer was proportional to T_{line}-T_{colfet} and we originally hoped to be able to total power calibrate the spectrum, given the noise temperature of the COLFET is known and stable. This proved to be difficult to impossible due to nonlinearities of the spectrometer. Therefore we changed to the balancing calibration now applied. With this calibration scheme we basically calibrate the COLFET 'away' and it 'only' influences $T_{sys,c}$. For this reason we changed the correlation receiver to a dual-

polarization receiver.

P3370/l5 Give the reader some more information, how this result is achieved. Derivatives are built with respect to $\mathbf{V}_{hot}$, $\mathbf{V}_{cold}$, $\mathbf{V}_{sky}$ and $\mathbf{V}_{ref}$ and the uncertainty in these variables are given by Equation 5 with a = 1. It should also be stated, that proportionality between signals ($\mathbf{V}_{hot}$, ...) and $\mathbf{T}_{sys}$ has been used.
We changed this small section to:
The actual σ of each radiometer is determined using Gaussian error propagation

$$\sigma_F = \sqrt{\left(\frac{\partial F}{\partial x_1} \cdot \sigma_1\right)^2 + \left(\frac{\partial F}{\partial x_2} \cdot \sigma_2\right)^2 + \cdots}$$

on Eq.1 for MIRA 5 and cWASPAM3 and on Eq. 2 for MIAWARA - C. Derivatives are built with respect to V_x where $x = sky, line, hot, cold$ and proportionality between signals V_x and temperatures T_x is assumed. The uncertainty, σ_x, in these variables is given by Eq. 5 with a=1. This results in:
We believe that if we write it that way we do not explicitly use the proportionality between signals (V_{hot}, ...) and T_{sys}. This is why we do not mention it.

Equation 10 and 11 are supposed to be estimates of the noise, corrected for tropospheric attenuation and for the airmass (σ^*). However, if error propagation has been applied to equation 1 and 2, this estimate refers to the uncorrected noise. This has to be clarified.
You are right. This was a mistake. We changed the position of Equation 6 and the introducing sentence to the beginning of page 3371. The correction to zenith direction and for tropospheric attenuation has no influence on the determination of the sensitivity factor 'a' but only matters when actually comparing noise levels. This means we changed σ^* to σ in the following positions on page 3370: line 2 and equations 9, 10 and 11.

P3370/l13 ".. As described above" refer to equation 9 here.
Done.

P3370/l20 Is the "simulated Gaussian noise of a total power spectrum" given by equation 5 with a=1? If so, please refer to the equation. If not, explain how these values have been calculated. In caption of figure 2, a Monte Carlo simulation is mentioned. Explain where, how and why a Monte Carlo simulation has been performed.
Thanks for pointing this out. You are absolutely right that the "simulated Gaussian noise of a total power spectrum" given by equation 5 with a=1. The 'simulated Gaussian noise of a total power spectrum' and also the 'Monte Carlo simulation' mentioned in the caption of figure 2 are 'leftovers' from the search for the most elegant way to determine the sensitivity factor a.
We changed line 20 to:
The experimental values for a, shown as circles, are obtained by dividing the measurement noise of the one day integrated spectra, acquired between 2 April 2009 and 22 April 2009, by σ_{TP} (Eq. 5 with a=1), with an estimated value for $T_{sys,sky}$.
and the caption of figure 2 accordingly to:

Sensitivity factor a calculated by Gaussian error propagation on the calibration equations (lines) and from measurements compared to the uncertainty of a total power measurement σ_{TP}, with an estimated value for $T_{sys,sky}$.

Section 4.3 P3376/l27 Explain, how calibration load temperature and pointing (which influences the cold load temperature estimate) are taken into account for MIAWARA-C.
We added this to Table 4 and the according caption.

Table 1: Estimates of the errors in relevant forward model parameters. For MIAWARA-C the uncertainty in T_{hot} and in pointing, influencing τ_z and T_{cold} are considered in the calibration error which is given in % of factor for the tropospheric correction.

Parameter	Instrument	Estimated uncertainty
Temperature profile		5 K
Calibration	cWASPAM3	1 K on either calibration load, 0.5° in pointing
	MIRA 5	1 K on either calibration load, 0.5° in pointing
	MIAWARA - C	3% of factor for the tropospheric correction (3 K on T_{hot}, 0.2° in pointing $\rightarrow$ 2.5% on τ_z and 0.5 K on T_{cold})
Line intensity S		$6.81 \cdot 10^{-21}$ m^{2}Hz
Air broadening γ_{air}		1014 Hz/Pa

P3377/l20 This is not clear. Do the authors want to conserve the column density?
Yes this is the goal and it is now mentioned like this in the paper.

Section 5 P3378/l3 This is not clear. Are the gaps due to the weather conditions? In what sense is the measurement noise "inconsistent"
Yes, the gaps are due to the weather conditions. We changed this sentence in order to make it more clear:
The data of MIAWARA - C is noisier in winter than in spring which is an effect of to the measurement gaps due to bad weather conditions leading to a measurement noise strongly varying from day to day. The varying noise level leads to differences in the influence of the apriori profile on the retrieved profile.

Section 6.3 Here, the authors should give new estimates of the noise level for comparison with the values in table 2 and make a comment how these improvements do or will affect the retrieval, i.e. altitude range.
We added an additional column to Table 2 (here Table 1) showing the values for MIAWARA-C after the improvements. In addition we changed Section 6.3 as follows:
With all these changes it was possible to decrease the measurement noise of MIAWARA - C significantly, as shown in Table 2 and in Fig. 11. Given an opacity of 0.078 and an observation angle of 15° the noise level is improved by a factor

of 3.6 thanks to the changes in the receiver and calibration. If considered that during the ARIS campaign MIAWARA-C observed at an elevation angle of 35° for τ=0.78 the noise level is even improved by a factor of 9. For the profiles this means that MIAWARA-C does now cover an altitude range of approximately 5 to 0.02 hPa for an integration time of 1.5 hours given an opacity of 0.78.

MIAWARA - C	15° /0.007	35° /0.078	15° /0.078	15° /0.078 after optimizations
a	2 (0.6)	2 (2)	2 (2)	1 (1)
t_{int} [% of t]	19 (1.6)			37 (1.2)
$T_{sys,corr}$ [K]	230 (5.8)	245 (2.5)	270 (2.7)	200 (20)
$c_{trop,bal}$	0.41 (1.4)	1.62 (4.2)	0.59 (1.5)	0.59 (1.5)
$\sqrt{B}\sigma_{bal}$ [K/$\sqrt{s}$]	1.45 (7.5)	6.0 (31.8)	2.4 (12.6)	0.66 (3.5)

Table 2 Explain t_{tot}.
t_{tot}=t. We changed the name accordingly in the table and added the following sentence to the caption:
t_{int} is the effective integration time on line given in % of measurement time t.

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