Response to the referee #2

June 22, 2016

We are very grateful to referee #2 for the careful reading of our manuscript and for providing constructive comments which helped to improve the manuscript. This document includes all the referee's comments as well as our replies to every one of them.

General comments from the referee

The paper presents an inter-comparison campaign of tropospheric temperature profiles measured by three different instruments at the same site. The instruments are: The new temperature radiometer TEMPERA, operating at the low frequency flank of the oxygen band between 50 and 70 GHz developed at IAP. The commercial available Humidity And Temperature PROfilers radiometer (HATPRO), RPG
Radiosondes with in situ instruments
The paper is very interesting, well written and describe the potential of the new TEMPERA radiometer. When the comments below are considered my opinion is that the paper fulfil the requirements for publication in "Atmospheric Measurement Techniques" Except from the remarks from Anonymous Referee #1, that I agree with, I add the following comments.

Specific comments

1. **Comments from the referee:** In equation 1 (page 3/ line 24) the zenith angle is used but in the rest of the paper elevation angles are used to describe the vertical pointing. I suggest that equation 1 is reformulated to use elevation angle as well.

   Author's response:
   We agree with the referee that can be more clarifying to indicate the dependency with the elevation angle in equations 1 and 2. Both equations have been reformulated in the manuscript.

   Author's changes in the manuscript: p. 6, line 11

   Under the Rayleigh-Jeans approximation ($h\upsilon << kT$) the radiative transfer equation is expressed as

   $$Tb(h_0,\theta) = T_0 e^{-\tau(h_1,\theta)} + \int_{h_0}^{h_1} T(h) e^{-\tau(h,\theta)} \alpha \frac{1}{\sin(\theta)} dh \qquad (1)$$

   where $Tb(\theta)$ is the brightness temperature **at elevation angle θ,** T_0 is the brightness temperature of the cosmic background radiation, $T(h)$ is the physical temperature at height h, h_0 is the altitude at ground, h_1 is an upper boundary in the atmosphere, α is the absorption coefficient and τ is the opacity. The opacity is defined as

$$\tau(h,\theta) = \int_{h_0}^{h} \alpha(h') \frac{1}{\sin(\theta)} dh' \qquad (2)$$

2. **Comments from the referee:** Glancing through the technical description of HATPRO at `http://www.radiometerphysics.de/download/PDF/Radiometers/General_documents/Manuals/2015/RPG_MWR_STD_Technical_Manual_2015`. It looks like some information about the HATPRO beam can be found on page 11

   Author's response:

   We thank the editor for pointing out that there was information about the antenna pattern in the HATPRO's manual. According to this information, we consider that the small Half Power Beam Width (HPBW) of this radiometer with values between 1.8 and 2.2 at the V-band frequencies has a very small impact on the brightness temperature as it was shown in Figure 9. For this reason we consider that the assumption of a pencil beam to characterize the antenna pattern for HATPRO is good enough and the possible changes of considering a Gaussian beam as antenna pattern would be negligible.

   Anyway we have clarified this point in the manuscript.

   Author's changes in the manuscript: p. 10 line 2-3

   The measured Tb from HATPRO radiometer was also compared with the ones simulated using RS measurements. For this new comparison the ARTS model was set with the radiometer instrument characteristics from HATPRO. The seven frequencies (51.26, 52.28, 53.86, 54.94, 56.66, 57.30 and 58.00 GHz) and the six elevation angles (90.0, 42.0, 30.0, 19.2, 10.2 and 5.4) of HATPRO were used as inputs of the forward model. **The simulations were performed considering a pencil beam since the HPBW at the V-band frequencies for HATPRO is small (<2.2°).** In this study, the shape of the filter bandwidth is idealised to a rectangular function with the width specified by the manufacturer (230 MHz for the 4 most transparent channels, 600 MHz at 56.66 GHz, 1 GHz at 57.30 GHz and 2 GHz at 58 GHz).

3. **Comments from the referee:** I think the "than" shall be excluded in the sentence "The temperature comparison between HATPRO and RS under clear conditions shows almost identical values in the lowest part (from ground to 3 km) than for all weather conditions" at page 14/ line 8-9.

   Author's response:

   We consider that "than" is appropriated in the sentence, since we are comparing the results under clear conditions with the ones with all weather conditions.

4. **Comments from the referee:** I believe that the same line types are used in figure 8 as in figure 7 (dash-dotted for mean and solid for std) but this has to be clarified in figure 8 either in the caption or in the legend.

   Author's response:

   According to the referee's suggestion we have clarified this point in the caption of both figures.

Author's changes in the manuscript: p. 14 and 16

Figure 7. Mean **(dash-dotted lines)** and standard temperature deviation **(solid lines)** between HATPRO/TEMPERA radiometers and RSs for all weather conditions (a) and clear skies (b).

Figure 8. Mean **(dash-dotted lines)** and standard temperature deviation **(solid lines)** between HATPRO/TEMPERA radiometers and RSs during day (left) and night time (right) under clear conditions.

5. **Comments from the referee:** It is an interesting approach to simulate the brightness temperatures from the radiosonde data to be able to compare them with the measured brightness temperatures from the two radiometer systems. A comparison of the different temperature profiles from the three instruments is also presented. I would like the authors to expand upon the two different comparisons. Can for example the observed differences in the direct temperature comparison explain the differences in the comparison of the brightness temperatures?

Author's response:

We agree with the referee that the comparison of brightness temperature and physical temperature using different techniques can be an interesting approach to assess instrumental and methodological aspects of this measurement technique. We have tried to remark this point in the manuscript and we think that the larger deviations found for the TEMPERA retrievals when all the channels are used (12 channels) can be explained by the larger discrepancies found in Tb for the most transparent channels.

Next we indicate the different sentences where it has been addressed in the manuscript.

Page 14, lines 15-17 (discussion about physical temperature retrievals):

"These results also evidence a better agreement between RS and TEMPERA when only 8 channels are used in the inversion algorithm although only clear cases have been selected. It could be explained for the larger Tb bias found for the most transparent channels under clear conditions."

Page 15, lines 17-20:

They found a non-zero behaviour as a function of height with opposite sign between both datasets. It is important to note that the temperature bias values found in that study for HATPRO were lower than the one observed in this work. It could be explained because they applied a Tb offset correction to that analysis.

Page 20, lines 6-12 (Conclusions):

"It is worth to point out the better agreement observed for TEMPERA when only the 8 more opaque channels were used in the temperature retrievals even under clear conditions. It could be due to the large deviations observed in the most transparent channels, which are also observed in other studies which used different radiative transfer models. In this sense, future efforts should focus on the identification of the error sources of these uncertainties and in this way improve the performance of these most transparent channels. Instrumental characteristics as the beamwidth

and the bandwith have been shown to have an important effect in the most transparent channels of the V-band, reaching values of up to 3 K in the case of the bandwidth. Other possible explanation could also be that spectroscopy is not yet fully understood."

In order to clarify in the conclusions that the deviations in the most transparent channels are regarding the brightness temperature (Tb) we have explicitly added it.

Author's changes in the manuscript: p. 20, lines 6-8

It is worth to point out the better agreement observed for TEMPERA when only the 8 more opaque channels were used in the temperature retrievals even under clear conditions. It could be due to the large **Tb** deviations observed in the most transparent channels, which are also observed in other studies which used different radiative transfer models.

Additional changes in the manuscript

We would like to point out that a new project has been mentioned in the acknowledgments section. It now reads as:

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