# Answers to the referees (AMT-7-2013-327)

## Referee 1

GENERAL COMMENTS

The paper AMT-2013-327 by Navas-Guzman et al. describes the results of an experimental set up for investigating the effects of clouds on the retrievals of temperature profiles from a ground-based microwave radiometer. It is an interesting analysis that may help improving the temperature profile retrievals from ground-based microwave radiometers.

1) However, I think the authors miss to give credits to previous work when they state (introduction, conclusions) that "so far, clouds have not been properly treated in the forward models". In fact there are several algorithms which include clouds in the forward model, both of statistical (Solheim et al., 1998; Ware et al., 2003) and physical (Löhnert et al., 2004; Hewison, 2007; Cimini et al., 2009) types. The authors should explain careful what they mean with the above sentence.

We agree with the referee's comment and we have changed this part in order to evidence that this is not the first study that deals the incorporation of the clouds to the retrievals. New references have been included. The corresponding paragraph in the introduction section read now as:

**"Many studies have addressed the characterization of the temperature in the troposphere using microwave radiometer measurements (Basili et al., 2001; Stähli et al., 2013; Löhnert and Maier, 2012). However, despite the presence of clouds in many atmospheric observations, only few studies have dealt the incorporation of clouds in the temperature retrievals (Löhnert et al., 2004; Solheim et al. 1998; Ware et al., 2003). A better knowledge on the cloud characterization as well as on the assessment of its effect on the temperature under different cloudy conditions is still needed. The work presented here addresses the characterization of clouds and its incorporation in the temperature retrievals for almost one year of measurements."**

And in the conclusions:

**"This work presents a study about the cloud effect on temperature profiles retrieved from microwave radiometry. So far, few studies have treated the clouds in the forward models and big errors are found for some cloudy conditions. Cloud characterization was carried out using different instrumentation ...."**

SPECIFIC COMMENTS

2) page 1309, line 4-6: the following sentence is not exactly true and should be understated: "The elevation angle of the ceilometer has been set to 40 deg to guarantee the observation of clouds in the same direction as TEMPERA is measuring."

We agree with the referee's comment and we have rewritten the sentence in order to be more precise. It reads now as:

**"The elevation angle of the ceilometer has been set to 40 deg to guarantee the observation of clouds inside of TEMPERA field of view."**

3) page 1309, line 9-10: the radiometer is pointing south east, while the radiosonde are launched west of Bern. What is the expected contribution for this mislocation?

To be more precise Payerne is located at 40 km South-West of Bern, this clarification will be indicated in the manuscript. From this mislocation we expected that the biggest temperature differences between radiosonde and microwave radiometer were found in the lower layers (inside the Planetary Boundary Layer, PBL). It is in the lowest part of the troposphere where the temperature could be more affected by ground conditions. However, the temperature differences found between radiosondes and microwave radiometer were small (around 1 K of average for the 60 cases in the first kilometre, Fig. 8). For this reason we consider that the thermal structure in Payerne and in Bern were quite similar.

4) page 1310, line 21: I think that K=dF/dx is usually called Jacobian, while weighting function is WF=dF/dxdh

Following the notation of Rodgers's book (Inverse methods for atmospheric sounding) the term K=dF/dx can be called as weighting function or Jacobian.

5) page 1311, line 1-3: Why not using the TROWARA IWV to scale a standard WV profile?

We use an exponential water vapor profile scaled to the surface water vapor density because we consider that it is the most general procudere to obtain a reasonable water vapor profile in all the locations. The water vapor density at the surface is a variable that is measured by any weather station while the IWV should have to be measured with other microwave radiometer. In fact, we have moved TEMPERA radiometer to MeteoSwiss station in Payerne 3 months ago and the water vapor profile is calculated as we have indicated before. Moreover, we would like to point out that TROWARA is not pointing at exactly the same direction than TEMPERA (the elevation angle of TROWARA is 40 degrees), so it could also introduce some uncertainties.

Anyway, we have compared the IWV from TROWARA with the values obtained from the integration of the water vapour profiles used in the retrievals for the three cases presented in section 4.1 (see table). From this comparison , we can observe that in the three cases the IWV values from TROWARA were larger that the ones used in the retrievals (35% on 21-Nov, 18% on 14-Nov and 2% on 26-Oct).

| date | IWV-trowara [mm] | IWV-retrievals [mm] |
|---|---|---|
| 21-Nov-2012 | 18.22 | 11.72 |
| 14-Oct-2012 | 17.76 | 14.60 |
| 26-Oct-2012 | 16.71 | 16.35 |

In order to evaluate how these discrepancies affect the temperature profiles we have compared the retrieval obtained using a water vapor profile scaled to the TROWARA IWV as the referee suggest with the one obtained using the water vapor profile described in our manuscript. The case shown in Figure 1 corresponds to 21 November 2012, when the difference in IWV was largest. We can observe that the differences in the temperature profiles were negligible, with changes smaller than 0.1% in the whole range. Therefore, the results evidence that there is not an improvement in the temperature profiles when the water vapor profile is scaled to the TROWARA IWV.

6) page 1312, line 12-13: The authors say the method is not sensitive to the chosen constant LWC within the cloud. This may be counter intuitive, since LWC and ILW together determine the cloud thickness. Could the author show convincing examples (e.g. adding a line using different LWC to Figures 5-6-7)?

Following the referee's suggestion we have used different LWC values for the temperature retrievals of the three cases presented in section 4.1. The chosen LWC values have been very different, checking the retrievals with a very low value (0.06 $g/m^3$) typical of fog or cirrus and very high

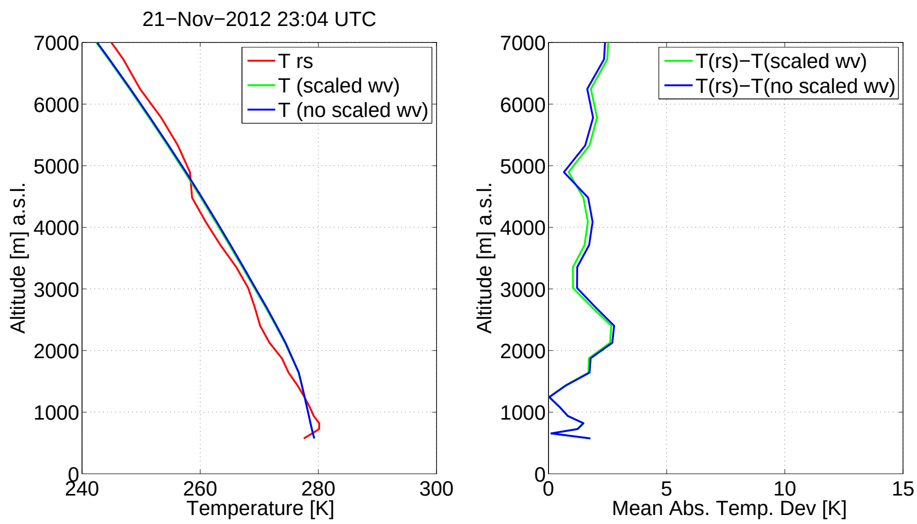


Fig. 1: Temperature profiles and absolute temperature deviation on 21 November 2012 when different water vapor profiles are used in the retrievals.

(1 $g/m^3$) typical of cumulonimbus. Table 1 shows the ILW for each case and the cloud thickness derived when different kind of clouds are considered. We can observe that the cloud thickness can be very different for the same amount of liquid water when different kind of clouds are considered (different LWC).

| date | ILW [mm] | cirrus thickness [m] | stratus thickness [m] | cumulus thickness [m] |
|---|---|---|---|---|
| 21-Nov-2012 | 0.47 | 7770 | 1665 | 466 |
| 14-Oct-2012 | 0.03 | 505 | 108 | 30 |
| 26-Oct-2012 | 0.13 | 2246 | 481 | 134 |

Table 1: ILW and cloud thickness for the different kind of clouds used in the retrievals.

Figure 2 shows the temperature retrievals obtained considering different LWC in the three cases presented in section 4.1. These plots evidence that the temperature retrievals are not very different when the LWC is changed, despite the cloud thickness are very different. The biggest discrepancies were always below 1 K. We have chosen the LWC value of 0.28 $g/m^3$ which it is typical of stratus because these are the kind of clouds more common in our study. As the referee suggest we will include these results and discussion in the final manuscript.

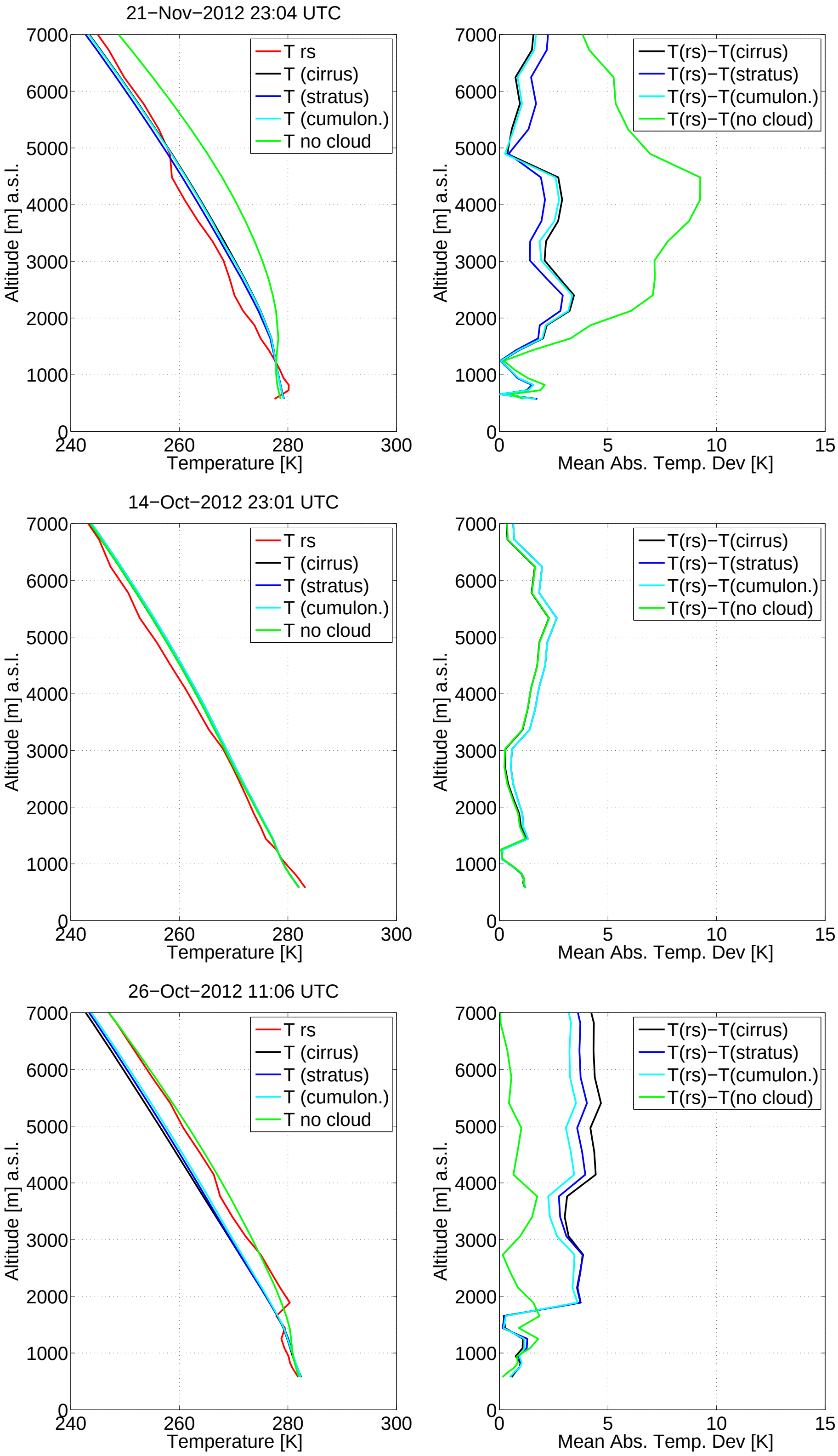


Fig. 2: Temperature profiles and absolute temperature deviation for the three cases discussed in the manuscript. Different LWC values are used to characterize the clouds (LWC: 0.06 $g/m^3$ for cirros, 0.28 $g/m^3$ for stratus and 1 $g/m^3$ for cumulonimbus).

7) page 1313, line 8-10: Why not also using all channels? The effect should be even more evident; also it would have broader interest, as most of commercial MWR use the whole 51-58 GHz range, regardless of clouds. In addition, this choice may generate ambiguity. For example, in Figure 5-7 one cannot tell if the differences are due to the cloud in the forward model or simply to the different channel sets.

We would like to point out that we checked again the retrievals and we have realized that there is a mistake in our statement. For all the retrievals of this study we have actually already used all channels, so the whole range has been covered (51.25 to 57 GHz). We apologize for this misleading statement. This point will be clarified in the reviewed manuscript.

8) page 1313, Section 4.1: in addition to physical thickness, the authors should report the cloud optical thickness (in terms of ILW) for each and all the study cases.

We will add the ILW for each case presented in section 4.1 in the revised manuscript in order to characterize better every case. We are not sure if this is the cloud optical thickness to which the referee relates. In case that we are wrong, please could you clarify what you mean with cloud optical thickness in terms of ILW?

9) page 1314, line 23-end: The discussion here is weak. The authors should try to explain in detail why the far range affects one retrieval more than the other. In addition, the LWC profile was assumed to have negligible effect (see my earlier comment), so it cannot be blamed now to be the reason for the discrepancies.

We would like to point out that we did not conclude that the LWC profile is negligible but that the LWC constant value used to define this profile did not affect too much the inversions when values for different kind of clouds were used. In fact it is clear that the LWC profile is not negligible since this is the only difference between the inversion with and without clouds and as we can observe the differences in the retrievals are important. As we state in the manuscript we consider that the differences could come from the difficulty of characterizing the low clouds (in altitude and thickness) since the variability of these clouds is larger. Moreover, the greater sensitive of the retrievals in the near range could increase the differences in the case of a wrong LWC profile was provided.

10) page 1315, line 13-15: The bigger discrepancies are due primarily to the fact that the used channels have low sensitivity to high elevation levels and thus the retrieval rely on the climatological mean.

As we indicated in previous comments all the channels were used for the temperature retrievals. We consider that the discrepancies were bigger in the far range due to the lower resolution of the microwave radiometer.

11) page 1317, Conclusions: The reason of unclear results may be that the retrieval with no clouds does not use channels lower than 53 GHz (see one of my earlier comments). I suggest to perform the retrievals with no clouds using all channels and compare the results with the other two. This may help in clarifying the conclusions. Also, the discussion on the cloud base altitude effect is rather poor.

See previous comment about the channels used. Regarding the cloud base altitude effect we have extended a little bit more this discussion, this paragraph in the conclusion read now as:

**The study also showed a different behaviour in the retrievals depending on the cloud base altitude. For cloud base altitudes below 1000 m (agl) and above 3000 m (agl) there was not a clear improvement using the clouds information in the retrievals. The difficulty of char-**

**acterizing the low clouds due to their larger variability in the near range and the shift of the radiosonde and high altitudes could be the reason of this unclear results. However, the results were better for those cases with cloud base between 1000 and 3000 m (agl). This situation corresponded to almost the 50% of the cases.**

12) page 1318, line 2-5: This conclusion is maybe not too surprising, as clouds with ILW<0.1 mm have likely little impact on TB. To show this and help the discussion, it would be very useful to show 3 types of clouds in Figures 3 and 4, as representative of the 3 case studies presented here.

With Figure 3 of the paper we just wanted to show that the clouds have a important influence in the absorption coefficient in the frequency range from 51 to 53 GHz. The absorption coeff. profiles were calculated with radiosonde data from Payerne on 19 January of 2009. We have calculated the absorption coefficient for the three cloud cases presented in section 4.1. Figure 3 shows these three profiles. We observe that there is a slight dependency with the altitude, observing larger absorption at higher altitudes. Anyway, it seems that this dependency with the altitude does not explain the discrepancies observed in our study and they would be more related with the ILW of each case and the possible differences observed with the radiosondes.

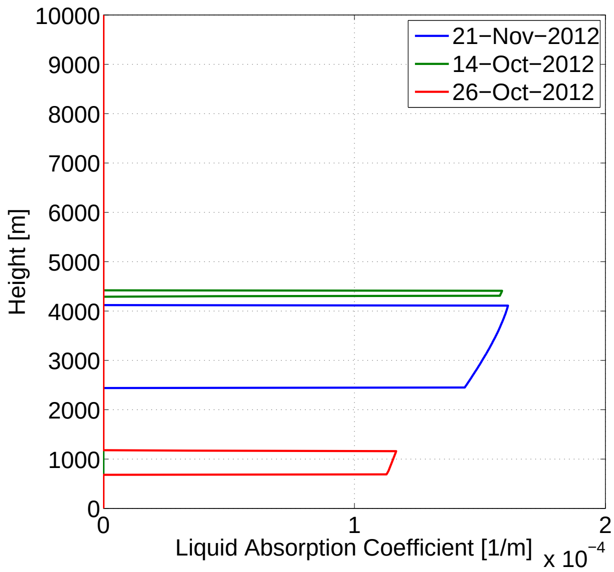


Fig. 3: Liquid absorption Coefficient for the three cloudy cases presented in section 4.1.

In Figure 4 of our paper we show the shape of the LWC profile. The only thing that changes for the different cases is the thickness and the altitude of the clouds. For this reason we have marked a grey box in the Figures 5, 6 and 7, indicating the altitude and the thickness of every cloud. It seems that these boxes can not be seen if you read the manuscript from the browser but there are not problems if you open with adobe acrobat.

TECHNICAL CORRECTIONS

13) page 1309, eq.1: the authors should mention the frequency dependence of TB, tau and alpha

As the referee suggest we have included the frequency dependency in equation 1:

$$T_B(h_0, \upsilon, \theta) = T_0 e^{-\tau(\upsilon, h_1)} + \int_{h_0}^{h_1} T(h) e^{-\tau(\upsilon, h)} \alpha(\upsilon) \frac{1}{cos(\theta)} dh \quad (1)$$

14) page 1311, line 5-6: Not clear; please rephrase. Following the referee's suggestion we have rephrased this sentence. It reads now as:

**For other species like oxygen (O2) and nitrogen (N2) we used standard atmospheric profiles for summer and winter (Anderson et al., 1986) which are incorporated into ARTS2.**

15) page 1315, line 26: radisonde -> radiosonde

Done.

16) page 1316, line 1: correspond -> corresponds

Done.

FIGURES

17) Figure 3: The authors should state the ILW and the boundaries of the cloud used for obtaining this figure. Is this the one in Figure 4? To help the discussion, I'd suggest to show 3 kind of clouds in Figures 3 and 4, resembling the 3 case studies presented later.

See comment 12.