Answer to reviewer 1

We would like to thank both reviewers for their thoughtful and constructive comments. As the comments were not numbered in both reviews, we have broken them into what appears to us to be logical units.

General comments

The paper is well written and the authors provide a good description of the background of microwave radiometry. The originality of the paper should be the operation of the radiometer "in truly complex terrain". Other studies have already investigated the water vapor in strongly structured terrain (Black forest: Kneifel et al., 2009; GRSL; Corse: Adler et al., 2015) using microwave radiometers that reveal the spatio-temporal variability of water vapor caused by surface processes and circulations at different scale.

Indeed, the purpose of our overall work is to examine the operation of the radiometer in truly complex terrain. When using a radiometer in complex mountainous terrain (i.e. steep valleys such as the Inn valley) where microwave radiation may not only originate from 'the sky' we indeed think that an assessment of the instrument's measurement principle itself is in order. Apparently we haven't made this point clear enough in the original manuscript. We adopt the reviewer's comment by adding the following text to Section 1. :
(p.2266, l. 25) Overall, a thorough assessment of a passive temperature profiler in complex terrain using close-by radiosondes seems to be missing. Furthermore, operation of a passive microwave profiler in a deep valley raises the question as to what the potential impact of slopes in the immediate surrounding of the profiler might be. While the atmospheric temperature profile is variable in time (what is, of course, the target of the observations) the ground has usually a larger thermal inertia than air thus potentially degrading the statistical retrieval algorithm of the profiler. (p. 2267 l. 17) Given that microwave radiation may not only originate from 'the sky' but also from the surrounding mountains and that all retrieval methods assume horizontal homogeneity of the atmosphere, which is not satisfied in an alpine valley, it is necessary to assess the performance and accuracy of the ground-based radiometer in complex terrain

Unfortunately this paper only investigates the quality of the vertical distribution of temperature and humidity assuming horizontal homogeneity within the valley.

The two cited papers deal with water vapor inhomogeneity, both retrieved by microwave radiometers. However, we focus in this paper on temperature profiles whose importance in studying the boundary layer development is particularly relevant. We cannot provide a 3D-temperature field (i.e., scans in different azimuth directions), since the instrument would soon 'hit' the mountains if we pointed under lower elevation angles towards north or south.
We have added some clarifying sentences in Section 1.
(p. 2267 l. 19) Unfortunately, scans in different azimuth directions needed for obtaining a 3D-temperature field are not possible in the present environment, since the instrument would soon have the nearby mountains in its direct optical path if it pointed under lower elevation angles towards north or south.

The paper mainly deals with retrieval development using well established statistical procedures via simple regression algorithms. There is no surprise that the algorithm developed by the authors on the base of high resolution, day and night radiosondes performs better than an all year algorithm based on low resolution and night soundings only.

Indeed the reviewer is right – if one considers the operation of the instrument just as such. However, as pointed out by the reviewer above, the topic of our study is the operation of the HATPRO profiler in complex terrain, and we think it is indeed a novel contribution to demonstrate that standard procedures to improve the retrieval also yield better results - despite the potential perturbation through terrain. Even more, we could demonstrate that we obtain the same quality of retrieval. Apparently we haven't made this clear enough in the original manuscript. We have therefore added the following in Section 4.2.
(p.2275 l.9) This improved performance is very encouraging given the fact that Löhnert and Maier (2012) used a significantly larger radiosonde dataset (of about 12 000 high resolution radiosondes during both daytime and nighttime) for their retrieval, providing a more robust diurnal cycle but also more robust statistics in general than we had at our disposal. Moreover, and probably more importantly, the obtained performance being equal (or even slightly better) than from less complex terrain, demonstrates that microwave radiation originating from nearby slopes (or terrain in general) is not likely to deteriorate the quality of vertical profile information. Hence, the use of HATPRO for the continuous monitoring of the boundary layer (and beyond) in a mountain valley is possible and promising – at least if the scanning mode is performed in along-valley direction as in the present case.

The importance of a representative training data set has been pointed out in the literature since decades (cf. Güldner, 2013; AMT) – same for the classification into seasons.

Thank you for pointing us to this reference. We have inserted this reference in Section 1 together with the following text.
(p.2266 l.6) Other training data have been proposed. For example, Güldner (2013) introduced a new approach for retrieval development, namely using data from the COSMO numerical weather prediction model (Steppeler et al. 2003). He showed that with this approach retrieved profiles almost reach the quality of those based on a radiosonde training data set. Additional advantage of such an approach is that data for retrieval are available 'always and everywhere' (at each grid point of an operational model). However, using model data introduces additional uncertainty especially in complex terrain due to grid resolution and steep(er) slopes.

In this context, the authors claim that the poor performance in the presence of elevated inversions (P2276, line 10) is due to their limited occurrence in the training data. However, the reason is the poor vertical resolution of the microwave radiometer as the information gathered in most channels comes from a broad range of altitudes. This can easily be seen from the weighting functions for the individual channels or averaging kernels (i.e. retrieved temperature change compared to the true one - see Fig. 7, Löhnert and Maier, 2012). In fact, the major problem with the radiosonde training data sets is that not the full diurnal cycle is considered.

We agree, but we believe that the reason is twofold, as we have written in the text (p.2276 l.10): poor vertical resolution as well as the limited occurrence in the training data. The first is indeed a problem for passive microwave observations. The vertical resolution is poor from 1 km above ground since the observations under different elevation angles don't add any more information. The problem with the full diurnal cycle is evident, but we do not have any other data for training. However, we believe that if a more robust historical data set were available, the statistics may slightly improve the poor resolution. For clarifying the concept, we have modified the corresponding text in Section 4.2.
(p.2276 l.10) This is likely due to the height of the inversion, which is higher than the atmospheric layers that benefit from the scanning mode (see e.g. Crewell and Löhnert, 2007), hence the radiometer information is not sufficient to resolve it. Possibly, a much larger number of cases in the training data set showing an elevated inversion of this type (note that in the current training data set, this number is quite limited) might slightly improve the statistics but clearly will not overcome this problem of poor resolution aloft.

The only original idea in the paper is the consideration of additional measurements as could be gathered from neighbouring mountain slopes and tops. However, this idea needs to be developed in more detail in particular about the representativeness of the measurements for the vertical profile as for example surface heating on hill slopes might cause deviations. What is the correlation among different heights, different sides of the valley, etc.? I would strongly encourage the authors to further pursue this line of work.

We would like to thank the reviewer for the encouragement (even if we do not quite agree that this is 'the only original idea'). We take the reviewer's advice to add more specific considerations concerning the representativeness of 'slope profiles' for the vertical profile in the valley atmosphere and spatial variability. The following has been added to Section 4.4.

(p.2279, 14) The additional regressors used in the present 'proof of concept' are the actual temperatures at various heights in the valley atmosphere. The best one can possibly have at disposition, however, even in complex mountainous terrain with steep slopes and nearby peaks are surface based observations, e.g. along a slope or on peaks of different heights. Some decades ago a number of comparisons between slope profiles and free air temperature profiles (even for the Inn Valley) were performed (e.g., Brehm and Freytag 1982, Dreiseitl 1988). Clearly, a slope observation is influenced by nearby terrain and thus a slope profile will not, in general, be equal to that in the valley boundary layer. More recent simulations using meso-scale numerical models and idealized topography (e.g., Wagner et al. 2014) show that isentropes are not horizontal in a valley atmosphere (at least under convective conditions as in their case) due to the local baroclinicity of the flow. Thus, the slope profile will not detect an elevated inversion at the correct height – but likely at a consistently different height. Numerical simulations using idealized terrain might suffer from over-idealization, i.e., in the present case the (assumed) symmetry with respect to solar insolation on the slopes. Matzinger et al. (2003) have shown that net radiation (essentially providing the energy to heat the slopes) can be up to a factor of three different at different positions in a north-south oriented valley in mid-latitudes under convective conditions and the surface heat fluxes vary correspondingly (Rotach et al 2008). Turbulent mixing and the resulting

cross-valley, thermally driven circulation, however will have a tendency to alleviate these contrasts. Laiti et al. (2013) have used spatial interpolation techniques to obtain cross-valley temperature distributions based on airborne observations (for a small valley in the Italian alps). Clearly, the isentropes are not horizontal for many of their flights and cross-sections but they appear to be 'sufficiently uniform' to at least make it plausible that a slope-based profile might add some additional information to improve the retrieval if included in the algorithm.

In this sense, it can be hypothesized that a slope-based profile will exhibit the gross features of elevated inversions (such as in Fig. 10) and is likely to considerably improve the overall performance of the retrieval. This approach is currently being tested on the basis of actual slope profiles in the vicinity of our profiler – and results will be detailed in a later contribution.

There are many interesting questions that the authors already could easily address with their data set:
- How strongly differ the temperature profiles derived from scans in the two directions?

We do not have any measurements pointing in different azimuth directions. Therefore, we cannot address this question. Moreover, it is not possible to perform scans in all directions, due to the vicinity of mountain slopes.

- Is there a dependence on the weather type / stability?

This evaluation is beyond the scope of the present article. The dependence on weather type/stability has been already evaluated in literature (for example, Löhnert and Maier (2012)).

- How does the temperature distributions develop in a situation with low synoptic influence? Especially, the authors should exploit the continuous observations, as this is the major advantage of microwave radiometer compared to satellite.

We agree, the continuous observations are by far the most relevant potentiality of microwave radiometry. Originally, we considered the influence of synoptic scales on radiometer performance to be beyond the scope of the present paper. However, we absolutely follow the suggestion by reviewer 1 and we add Figure 11 and the following new section (Section 4.5: Boundary layer dynamics).

(p.2279, l.19) In order to demonstrate the potential of a microwave radiometer for describing the boundary layer dynamics in an alpine valley, the daily cycle of temperature for the night where we found a strong elevated inversion around 1500 m (cf. Figure 10) is displayed in Figure 11. The inversion (Fig. 10) starts to grow around 3 UTC and develops throughout the morning hours and results in an almost isothermal (i.e. stable) valley atmosphere before noon. The surface heating in the afternoon produces a shallow layer of nearly neutral stratification near the ground while the remainder of the valley atmosphere remains stable ($\partial T/\partial z \approx -0.003 Km^{-1}$) throughout the afternoon. Above the crest height the somewhat weaker stratification of the large-scale flow persists throughout the day. Apparently, the flow interaction between the free troposphere and the valley atmosphere is largely constrained by the surrounding topography under the wintertime

conditions of Fig. 11. For more convective conditions, numerical simulations using idealized terrain (Wagner et al. 2014) suggest that – depending on the dimensions of the valley – the stability characteristics of the valley atmosphere can be confined to below crest height or extend up to much higher altitudes. The example of Fig. 11 demonstrates both, the potential of a microwave temperature profiler to resolve the temporal development much better than a sequence of soundings could – and this is of course not specific for mountainous terrain - as well as the necessity to optimally resolve elevated inversions in this type of environment.

Reference:

Wagner, J.S., Gohm, A., and Rotach, M. W.: The impact of valley geometry on daytime thermally driven flows and vertical transport processes, Quart J Roy Meteorol Soc, DOI: 10.1002/qj.2481, 2014.

Specific comments

P2265, line 26: Vertical resolution comes from observing spectral features. Therefore exchange infrared "radiometer" with "spectrometer" and two lines later.

Thanks for the suggestion. We have modified Section 1.
(p.2265, l.26) Unlike infrared spectrometers that are able to produce vertical profiles only under clear sky conditions due to strong liquid water absorption, a microwave spectrometer operates under almost all conditions.

P2268, line 16: Do not cite PhD thesis but standard textbooks (Petty, Jansen..) or review articles (Westwater) for theory.

We have substituted the reference in Section 2.1.
(p.2268, l. 16) Janssen (1993)

P2270, line 10: Why 0.35 K noise? For all channels the same?

A noise of 0.35 K for the oxygen channels is the first guess noise for the basic retrieval. After the optimization of the retrieval to the field terrain, the noise has been changed to 0.20 K, as pointed out in Table 2-3 and stated at p. 2280, l.7.

P2272, line 8: Also the assumption for water vapor to be horizontally homogeneous (over the path of the beam never holds. For temperature the more optical thick channels receive information within a much narrower region.

We agree and hence we have modified the text as follows:
(p.2272, l.8) In addition, the assumption for water vapour to be horizontally homogeneous is rarely valid.

P2272, line 21: Scanning in zenith direction? You mean time series ?

We mean operating the radiometer in the zenith direction. To be more precise, we have changed the text in Section 3.2.

(p.2272, l. 21) The radiometer operates in both Z and S modes every 5 min.

P2275, line 25: Note, that Löhnert et al. 2009 used synthetic data – no real measurements

We have added this clarification to the text (section 4.2).
(p.2275, l. 25) Taking into account that the results by Löhnert et al. (2009) were obtained using a more sophisticated optimum estimation technique and were based on synthetic data, our results for humidity profiles can be considered very satisfying.