Responses to Review of Referee 1 (AMTD-8-1-2015)

We would like to acknowledge to Philip W.Rosenkranz for his useful remarks and comments which have helped to improve the manuscript. All comments have been addressed as detailed hereafter in blue.

The paper extends work reported in previous papers by Staehli et al.(2013) and Navas-Guzman et al.(2014) on the TEMPERA instrument, which produces simultaneous retrievals of tropospheric and stratospheric temperature. The present report extends the possible measurement range to altitudes above 50 km by incorporating the Zeeman effect in the radiative transfer calculation, and presents some preliminary measurements of brightness temperature. The Zeeman effect needs to be accurately modeled so that the measurements can be corrected for it. The paper demonstrates this agreement between the model and measurements in Fig. 11.

Here are a few comments:

1. To put this work in a larger context, the introduction could mention that ground-based measurements of the atmosphere with good temporal resolution can provide complementarity to satellite measurements which may be limited by revisit times, depending on the instrument and the orbital parameters.

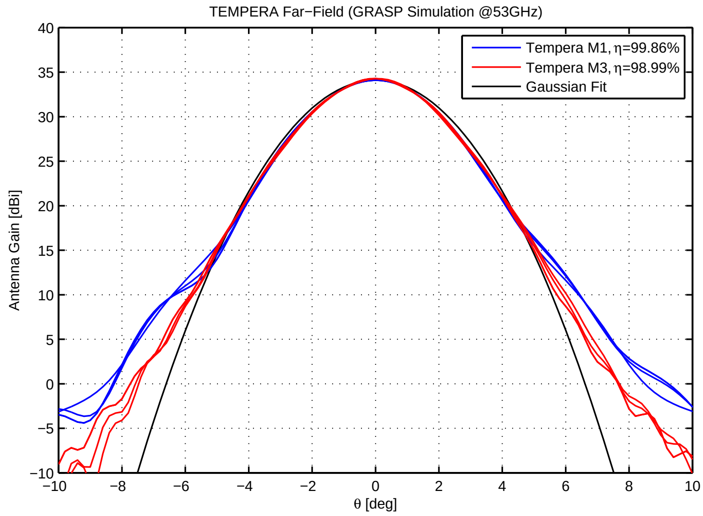
We agree with the referee's comment and this point has been highlighted in the introduction. The paragraph reads now as (lines 62-70):

"The measurements were possible using a Fast Fourier Transform (FFT) spectrometer with 1 GHz of bandwidth to measure the whole oxygen emission line centered at 53.07 GHz and a narrow spectrometer (4 MHz) to measure the center of the line with a very high resolution (1 kHz). These measurements have been compared to a model which includes the Zeeman-splitting effect. The incorporation of this effect to the forward model will allow to extend the temperature retrievals beyond 50 km. This improvement in the forward model will be very useful for the assimilation of brightness temperatures in numerical weather prediction (NWP) models. It is also important to note that ground-based measurements of the atmosphere with good temporal resolution complement satellite measurements, which are temporally limited by their satellite's orbital parameters."

2. What is the antenna beam efficiency? With the beam being reflected three times as shown in Fig. 6, is a correction for stray radiation into the far sidelobes of the antenna necessary and if so, how was it done?

There was no need to correct for the far sidelobes and straylight in our setup because the TEMPERA optics consists of a corrugated feed with low sidelobes and oversized reflectors. The blue beam tube in Fig. 6 corresponds to the -20dB contour of an Gaussian beam. The attached figure shows Physical Optics antenna simulations with GRASP. Configuration M1 includes only the first reflector after the feed. In this case the simulated spillover at the reflector is about 0.14%. For the routine observations and the Hot/Cold calibration of TEMPERA only this reflector is used. Configuration M3 corresponds to the three mirror setup described in the paper. In this case the accumulated spillover is about 1%. This will introduce a small positive continuum bias on the observations with this setup, but since this bias is independent of the frequency and azimuth angle it can be neglected for this publication. In both cases the antenna pattern are well represented by the fitted Gaussian.

3. In connection with Fig. 5, it may be helpful to the reader to note that given the magnetic field



orientation at Bern, and observing at an elevation angle of 60 deg., the direction of propagation is nearly parallel to the Earth's magnetic field at the azimuth angle of 181 deg., resulting in minimal difference between vertical and horizontal polarization at that position.

We thank to the referee for noticing this interesting point. We have included this comment in the manuscript. The text now reads as (lines 206-211):

"It is also interesting to note from Fig. 5 and 6 that the differences between horizontal and vertical polarization are very small close to the 181º azimuth angle. This is in good agreement with theory, as this direction corresponds to measurements of radiation which has been propagated along the magnetic field towards TEMPERA. This parallel propagation results in minimal differences between linear polarizations."

4. Equations 4 and 6 are inconsistent as written. I understand the authors' meaning, but clarity would be improved if in line 5 on page 11, p is defined as [1 1 0 0] L(chi), and that paragraph is joined to the next one. Then eq. 6 would read:

$T_b^p = [1100]L(chi)s'$

We agree with the referee's comment. In order to solve this inconsistent we have reformulated Equation 4 including the term $L(chi)$ which was missing before.

5. A missing relevant reference is J. W. Waters, "Ground-based measurement of millimetre-wavelength emission by upper stratospheric O2," Nature vol. 242, pp. 506-508, 1973. Thus, the present work is not the first ground-based measurement of Zeeman broadening at 53.07 GHz (as said on page 4, lines 3-4 and page 16, lines 13-14), since Water's fig. 3 clearly shows that effect. However, it would be correct to say that this is the first measurement of polarization for that line (or more precisely the variation of polarization with azimuth angle) since Water's measurement was not sufficiently sensitive to measure the polarization.

We agree with the referee that this important reference was missing in the paper. We have included it and some paragraphs have been modified in the manuscript in order to put it in a correct context. The modified lines are:

- Abstract (lines 8-10):

"Moreover, a high resolution spectrometer (1 kHz) was used in order to measure for the first time the polarization state of the radiation due to the Zeeman effect in the main isotopologue of oxygen from ground-based microwave measurements."

- Introduction (lines 35-37):

" Observation of the Zeeman effect from ground-based measurements was first performed by Waters (1973) for atmospheric O2 at 53 GHz. Pardo et al. (1995) were able to measure the Zeeman substructure for atmospheric 16O18O at 233.95 GHz."

- line 42:

"**The observation of this effect for ^{16}O has also been possible from satellite measurements.**"

and lines 59-61:

"In this work we present an experiment where the Zeeman broadening of the oxygen emission line at 53.0669 GHz is observed and the polarization state of the radiation due to this effect is detected for the first time using a ground-based microwave radiometer."

and finally also in the conclusions (lines 380-383):

This work presents an experiment where the Zeeman broadening of the oxygen emission line at 53.0669 GHz is observed and the polarization state of the radiation due to this effect is detected for the first time using a ground-based microwave radiometer.

6. In the reference Rosenkranz(1993), typesetting has garbled the name of the publisher and location. This reference is out of print, but it is available on the Web at http://hdl.handle.net/1721.1/68611, which could be added at the end of the citation.

This reference has been corrected. It reads now as:

"Rosenkranz, P. W.: Absorption of microwaves by atmospheric gases, in Atmospheric Remote Sensing by Microwave Radiometry, edited by M. A. Janssen, Wiley, New York, NY, 1993. (Available on the Web at http://hdl.handle.net/1721.1/68611)."