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Geoscientific Instrumentation Methods and Data Systems Discussions

Interactive comment on "Neutral temperature and atmospheric water vapour retrieval from spectral fitting of auroral and airglow emissions" *by* Joshua M. Chadney and Daniel K. Whiter

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We would like to thank the reviewer for their constructive comments and provide the following responses. The reviewer's comments are shown in blue. Additions in the manuscript text are in bold font.

The major problem for me is lack of retrieved parameters and their validation against other methods or measurements. I think it should be included in manuscript in order to show how well the method performs and what are the advantages.

The aim of this paper is to describe the novel spectral fitting and parameter retrieval method and to quantify the dependence of uncertainties on the atmospheric parameters that determine the components of a spectrum.

Comparing results against other observations is thus beyond the scope of this study. Furthermore, for many of the atmospheric parameters that we measure there is no other observation against which to directly compare our results. Validation is therefore not a simple task and deserves a paper in its own right. Indeed, we have planned a follow-up study that will compare the OH(8-3) temperatures that we measure, to temperatures measured from a slightly different vibrational band OH(6-2) by the Silverbullet instrument that is co-located with HiTIES. We will also be comparing with OH temperatures observed in two different wavelength channels by the TIMED/SABER instrument.

We have added the following text to the end of the conclusion to advertise this upcoming paper:

"*In a number of follow-up studies, we will make use of the spectral fitting and temperature retrieval methods demonstrated here to explore trends in upper atmospheric neutral temperatures in the HiTIES dataset.* ***As a first step, we shall compare OH(8-3) temperatures measured by HiTIES with OH(6-2) temperatures from the Silverbullet instrument operated by the University Centre in Svalbard (UNIS) (e.g., Sigernes et al., 2003; Holmen et al., 2014), also located at the Kjell Henriksen Observatory, and with OH temperatures derived from the SABER instrument onboard the TIMED satellite.***"

Other comments: 1. It would be good to add short Description/justification of Monte Carlo method as well as the convergence assessment. Why did you use 50 000 synthetic spectra in Fig. 6-7 and 10000 in Fig 9 and 10?

Further justification of the need to run a Monte Carlo simulation has been included

by better distinguishing between uncertainties on the parameters retrieved from a particular spectrum from the aim of the Monte Carlo simulations to determine parameter ranges over which our method is useful and to estimate the magnitude of the errors expected.

The following paragraph has been added to the end of Sect. 4:

"***Considering that the main source of noise in a given spectrum is shot noise, we determine the uncertainties on the fitted line intensities (e_I) using the following:***

$$e_I = \sigma_{residuals} \times \sqrt{N_{pixels}}, \quad (1)$$

where $\sigma_{residuals}$ is the standard deviation of the residuals and N_{pixels} is the number of pixels on the detector contained in the FWHM of the emission line. In this way, we can obtain uncertainty estimates on the parameters retrieved from each particular spectrum. However, we would also like to determine the ranges of parameters over which the fitting process produces accurate results. For this reason, we carry out a Monte Carlo simulation in Section 5.

And the beginning of Sect. 5 has been amended to read:

"*In order to estimate **expected** errors on the fitting and parameter retrieval process described in Sect. 4, we have performed a Monte Carlo simulation. **Such a simulation also provides information on the region of parameter space over which the fitting method is valid.***"

The first four paragraphs of Sect. 5 then describe the Monte Carlo simulations performed.

The convergence of the mean and standard deviation of the fractional errors on each retrieved parameter is shown in Fig. 1 of this response. It can be seen that, at high values of N (the number of synthetic spectra included in the Monte Carlo simulation), the quantities converge to a constant value. The standard deviation on the fractional error of T_{N2} (in red in the middle panel of Fig. 1 of this Author's Comment) requires the

largest number of Monte Carlo simulations to reach convergence. Thus, when considering all of the retrieved parameters, as in Fig. 6, 7 of the paper, we take N=50,000. In Fig. 9, 10 of the paper, where we tested the effect of using different OH transition probabilities and energy levels, we are just interested in the OH temperatures. Therefore, we only require N=10,000 synthetic spectra, since convergence of the distribution of fractional errors of TOH is reached for lower values of N (as seen in the left panel of Fig. 1 of this response).

We prefer to leave the details of convergence in this Author's Comment and add the following sentence to the end of the second paragraph of Sect.5:

"*In all, 50,000 synthetic spectra are produced and run through the fitting and temperature retrieval process. **This number is sufficient to ensure convergence of the Monte Carlo simulation.***"

2. The standard deviation in Fig 8 does not increases slightly with PWV but doubles. What is the reason behind it?

That is true, we have removed the word slightly. The standard deviation on the PWV error shown in Fig. 8 does indeed double between values of PWVin of 0 - 20 mm. However, note that it is the absolute error (PWVret - PWVin) that is shown here. In relative terms, the standard deviation on the error decreases with increasing PWV. This makes sense since it is easier to detect a stronger water vapour absorption signal.

3. What is the reason behind the overestimation of means PWV values?

The distributions of Δ PWV shown in the left panel of Fig.8 are skewed, whereas the median value is near 0mm, there appears to be a tail at high positive Δ PWV. The reason for this is unclear.

4. The abstract is too short, it should maybe advertise the result a bit more

The abstract now reads:

"*We have developed a spectral fitting method to retrieve upper atmospheric parameters at multiple altitudes simultaneously during times of aurora, allowing us to measure neutral temperatures and column densities of water vapour. We use the method to separate airglow OH emissions from auroral O^+ and N_2 in observations between 725 – 740 nm using the High Throughput Imaging Echelle Spectrograph (HiTIES), located on Svalbard. In this paper, we describe our new method and show the results of Monte-Carlo simulations using synthetic spectra which demonstrate the validity of the spectral fitting method as well as provide an indication of uncertainties on the retrieval of each atmospheric parameter.* ***We show that the method allows retrieval of OH temperatures with an uncertainty of 6 % when contamination by N_2 emission is small. N_2 temperatures can be retrieved with uncertainties down to 3 – 5 % when N_2 emission intensity is high. We can determine the intensity ratio between the O^+ doublets at 732 nm and 733 nm (which is a function of temperature) with an uncertainty of 5 %.***"

5. Section 2 should be joined with section 3. Section 2 has been lengthened in response to a comment from reviewer 1 to include more information on how the instrument is operated and so we believe it should appear in a separate section to the description of the atmospheric emissions detailed in Sect. 3.

6. Conclusions are more like Discussion and conclusions. Some parts of the conclusion are simply results analysis and method description (example, Sec. 7: line 7-14.)

The paragraph from the conclusion discussing noise has been moved to a new sub-

section, Sect. 5.6.

7. Line 22 '..past studies of OH temperatures have not been able to obtain measurements..' - add reference

Second and third paragraph of the introduction now read:

"*In this way, neutral temperatures have been determined from observations of airglow emissions from the OH layer located near the mesopause (e.g. French et al., 2000; Phillips et al., 2004; Suzuki et al., 2010; Holmen et al., 2014; Chadney et al., 2017). It has also been possible to measure rotational temperatures from N_2^+ ions, observed during aurorae (e.g Koehler et al., 1981; Jokiaho et al., 2008).*

One difficulty with these measurements is that emissions from different species often occur at the same wavelengths. For example, past studies of OH temperatures ***(such as those listed above)*** *have not been able to obtain measurements during periods of auroral activity, when auroral emissions contaminate the OH spectrum.*"

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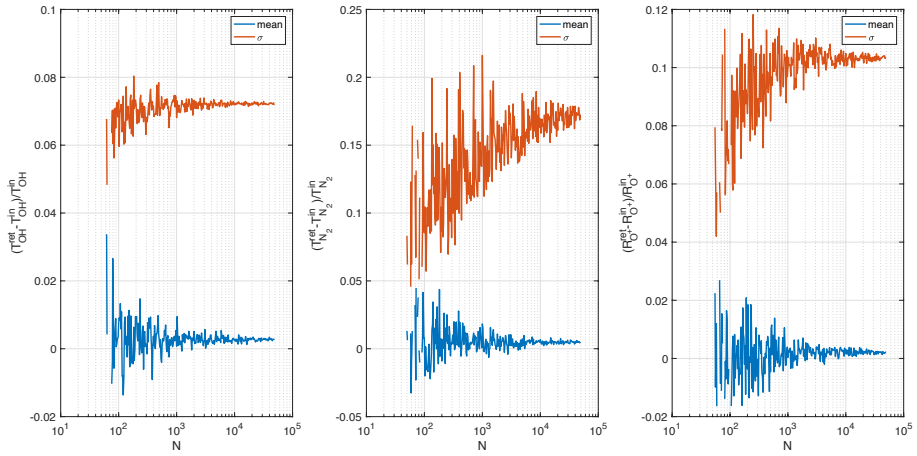

Fig. 1. Convergence of the mean and standard deviation fractional errors in TOH, TN2, and RO+ as a function of the number of Monte Carlo simulations, N.