Atmos. Meas. Tech. Discuss., 5, C2466–C2481, 2012
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Atmospheric Measurement Techniques Discussions

Interactive comment on "First middle-atmospheric zonal wind profile measurements with a new ground-based microwave Doppler-spectro-radiometer" *by* R. Rüfenacht et al.

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Reply to comments from referee #3

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- blue: referee's comments
- green: author's replies

General Comment:

The method of measuring middle atmospheric winds observing the ozone spectrum in the microwave regime has been already proposed by Dewey Muhleman in the late eighties. This publication shows the first implementation of such a measurement system providing zonal winds on a routinely basis. The paper addresses relevant scientific questions within the scope of AMT.

Specific comments:

5113 Line 23: “This leads…”. No! The line shape depends mainly on the vertical profile of ozone and it does not matter whether the line intensity is high or not (since the line is not opaque in the cases considered here). Different tropospheric

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transmissions do not significantly change the line shape (create or not steep line wings, etc.)

5113 Line 24: "...in terms of signal to noise ratio." I see no relationship between steep line wings and SNR. What counts is only the ratio of brightness of the line and rms noise.

Our wording seems to be confusing. The terms "line intensity" and "line shape" and "signal to noise ratio" were probably not used in a consistent way. For this reason we will rephrase the paragraph in the final manuscript. What we tried to express is that the random error in the determination of the center frequency of a calibrated spectrum, and hence in the retrieved wind speed, is proportional to the ratio between the slope (in K/MHz) of the line wings and the instrumental noise (in Kelvins). Within our error simulations this proportionality has also been shown (page 5124, line 13ff). To illustrate our statement spectra with steeper and flatter line wings, both overlaid by the same noise, are plotted in the figure 1 appended to this document. The center frequency of the blue spectrum can be determined more accurately than the one of the red spectrum.

5114 Line 24: "The radiometer is operated in the lower sideband...". How is it possible to operate a double sideband radiometer just in the lower sideband? You probably mean that the LO tuning is such that the ozone line appears in the lower sideband. Please clarify!

This sentence is maybe misleading and will be modified. The instrument as used for this experiment is indeed a double sideband radiometer with the frequency of the LO being such that the ozone emission line lies in the lower sideband whereas the upper sideband adds a nearly frequency independent signal to the total spectrum on the IF.

5115 Line 25: Why not using one frequency reference (e.g. the GPS signal reference) for all oscillators? A good design should consider this option.

Oscillator stability has been assessed during the development process of the instrument. The ability of the instrument to observe the signal from opposite viewing directions (within one minute in the operational setup) ensures that possible frequency offsets and long term frequency drifts do not significantly affect the quality of our wind data as described on page 5115 line 20-29.

5117 Line 7: Since the elevation angle is rather small, small errors in the knowledge of the angle may produce large errors in airmass assumptions and wind speeds. Therefore a number for the accuracy of this angle in your system should be given.

Indeed, errors in the elevation angle ϵ have a higher effect on the error of the airmass $\sec(90° - \epsilon)$ when the elevation angle is small. WIRA's pointing offsets are checked from time to time by performing scans of the sun of which elevation and azimuth are accurately known by the ephemerides. The attached figures 2 and 3 show the results from such sunscans for the instrument looking westward and eastward. The pointing offset in elevation is not larger than $\pm 0.3°$. This introduces an error in the airmass of not more than 1.3%. Because the error in airmass does not depend on frequency it can safely be neglected for our wind determination.
On the other hand, a pointing error will propagate to the wind speed through the transformation from line of sight wind speed to horizontal wind. The error due to the elevational pointing offset introduced in this way is smaller than 0.2%. The error introduced by the azimuthal pointing offset will in no case be larger than 0.03%.
We will include the accuracy of our pointing and its influence onto the retrieved wind in the final manuscript.

5120 Line 1-2: Can you explain why fitting the Doppler shifts of the correspond-

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ing Voigt profiles are more affected by radiometric noise?

We are sorry, but we do not understand this comment as nowhere in the manuscript we give such a statement.

Are you introducing apriori information by using the mirror and centroid method?

We are not using any a priori information for those methods. Setting a priori constraints on Doppler shift, line shape or other domains without accounting for their influence on the result (e.g. by applying optimal estimation techniques) would indeed be unscientific. As we do not use such constraints we believe our wind retrieval to be applicable to our problem without being obliged to use methods like optimal estimation.

Introducing a Doppler shift as fit parameter (e.g. in the optimal estimation method) seems to be the straightforward approach. I think you get better results with the methods you describe just, because you introduce the WIRA levels, i.e. you assume that the layers are orthogonal (by handling them separately). However in reality this is not the case, at least in realistic spectra containing noise. Therefore it is not really amazing that the methods you use produce less noise in the winds you derive. You would probably get the same if you do 5 separate OEM retrievals for the 5 altitude layers always putting a high constraint (apriori) the other 4 levels. A short discussion why you think mirror and centroid methods are better than OEM would be helpful. As it stands now it looks a bit like trial and error.

We certainly agree that OEM would be a promising approach to get more information out of our measurements. Unfortunately, setting up an OEM retrieval for wind radiometry is not so straightforward. We did not state in any way that our approach is better than OEM. We will be working on an OEM solution in future to refine our retrieval.

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Please also clarify what is the influence of baseline ripples in determining the centre frequency with these methods. Doesn't a baseline ripple create a frequency error? How does this error propagate?

Baseline ripples could considerably influence the wind retrieval if their amplitude was high enough. This has been simulated within our error analysis with different synthetic asymmetries overlaid to a "clean" atmospheric spectrum. With our instrument, however, the baseline amplitude is small enough to have no significative influence the wind retrieval. In the attached figure 4 the averages over all spectra used for the data series presented in the manuscript are plotted. By the naked eye no baseline can be seen. Therefore the center of the spectra was determined by the mirror method (applied to the innermost 700 channels), before the brightness temperatures on the right of this center were subtracted from the brightness temperatures on the left, according to the equation $\delta T_\mathrm{b}(i) = \left(T_\mathrm{b}(\nu_{round(\nu_{center})-i}) - T_\mathrm{b}(\nu_{round(\nu_{center})+i})\right)$, and plotted to the attached figure 5. The same data after a smoothing is shown in figure 6. Therefrom it can be concluded that the baseline amplitude must be very weak. From our error simulations we expect that the wind error induced by such a baseline lies well below 1 m/s.

What kind of temperature profile are you assuming by defining the WIRA levels? Does the temperature profile you use have any influence on the retrieved wind speeds? How large are the error bars of the temperature profile?

The temperature profile does not have any influence on the retrieved wind speed. It was only used for the determination of the pressure altitudes of the WIRA levels. For this calculation, the midlatitude-winter standard atmosphere temperature profile was used, what may introduce an error of up to 340 m to the limits of the WIRA levels for summertime temperatures.

5121 Line 6: why not interpolating between the spectrometer channels?

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We do not see a benefit in interpolating between the spectrometer channels. The calculations with the shifting of ν_{test} by 6.1 kHz increments (bandwidth of one spectrometer channel) deliver enough data points for the subsequent fitting described on page 5121 line 17-21.

5121 Line 16: what means “double sideband calibrated”? (Do you mean “calibrated double sideband spectrum”?)

Yes. The manuscript will be adapted in this sense.

5124 Lines 3-4: which code was applied to what?

The cited procedure is composed by three steps: In the first step the undisturbed absorption coefficients for 82204 frequencies between 142.12489556 and 142.22518444 GHz were calculated on 500 altitude levels logarithmically spaced between 1000 and 0.0006 hPa using ARTS. The absorption coefficients were then shifted by the Doppler shift according to the wind speed on each altitude level and binned to the frequency resolution of our spectrometer within a MATLAB routine. From those shifted absorption coefficients the atmospheric spectra measured at an altitude of 600 ma.s.l. (Bern) were calculated using ARTS. The image sideband in these calculations was assumed to be constant in frequency what is a save assumption because in the 100 MHz range considered here the contribution of the image sideband varies by 0.01 K only.

5124 Line21: “sharpness”: do you mean gradient?

We defined ΔT_b as the brightness temperature difference of a calibrated spectrum between the edge regions and the centrum of our spectrometer bandwidth of

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100 MHz (Eq. (11) in the manuscript). This paragraph will be modified for the sake of clarity.

5125 Lines 13-15: of course according to the definition of the widths of the WIRA levels. But the input winds are layers at least as broad as the WIRA levels. Therefore the conclusion is not obvious and quite likely another reason (e.g. SNR too low) applies here. Please clarify!

The WIRA levels are not boxcar functions. The indicated limits should be understood as delimiters to the range where most of the wind information comes from. They do not delimit the range where all the information comes from. In the case of such an abrupt change of the wind speed as in this generic example where the wind is 50 m/s in one layer and 0 m/s outside this layer, some zero wind speed is averaged into the result. For this reason the retrieved wind speed can be lower than the input peak wind speed. This is most pronounced for the uppermost level which has the largest altitude extension. Please notice that if the input wind is set to 50 m/s over a large range of the atmosphere this underestimation does not occur (page 5125 lines 1-5). Therefore we really think this is an effect of smearing out of the levels. We do not see how such a feature could originate from a too low signal to noise ratio.

5132 Table line 2: “LO of PLL cycle”. The “cycle” seems to be redundant (“Loop” in the PLL).

This will be corrected in the manuscript.

5146 Fig. 11: Please create another plot showing the differences between WIRA and ECMWF.

Such a plot is appended to this document in figure 7. We did not add it to the manuscript because we think the agreement between WIRA and ECMWF is more readily and clearly shown by Figs. 13 and 14 and Table 3 from the manuscript.

Interactive comment on Atmos. Meas. Tech. Discuss., 5, 5107, 2012.

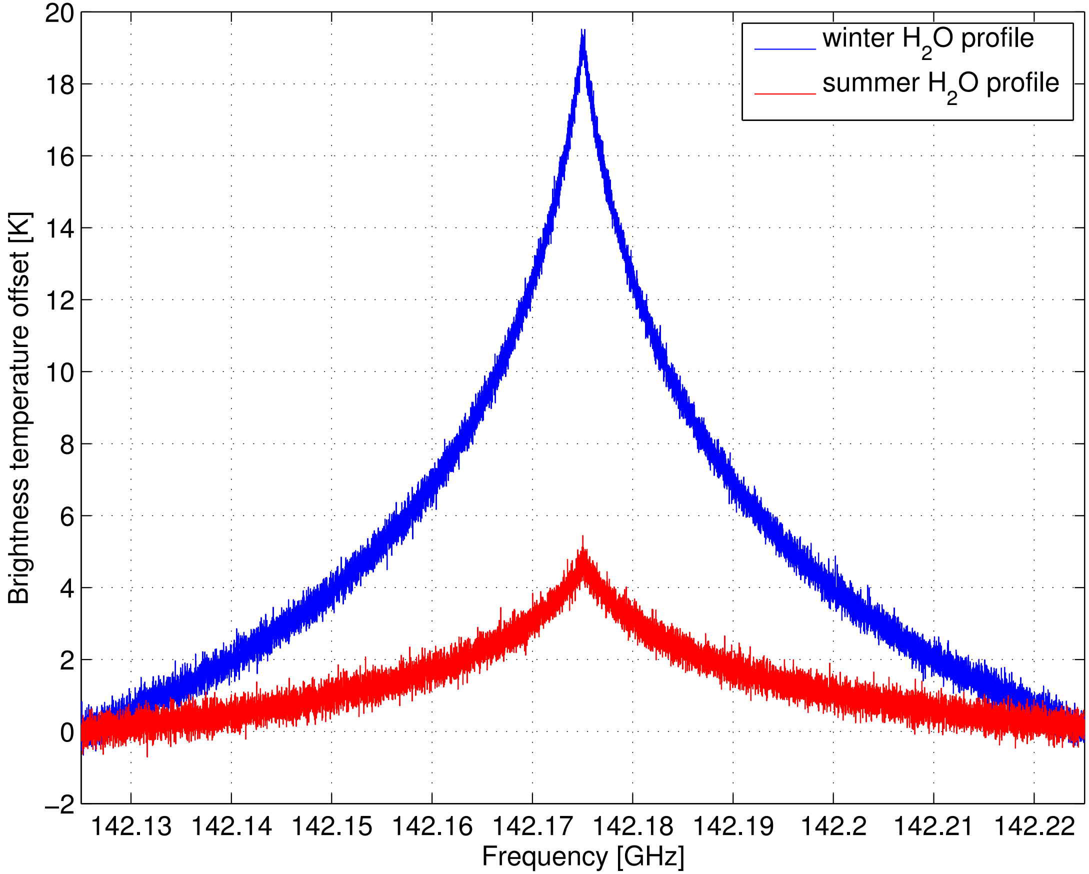

Fig. 1. Ozone emission spectrum for a mid-latitude winter standard atmosphere in blue, and for the same atmosphere where only the water vapour profile were set to the values of a mid-latitude summer standard

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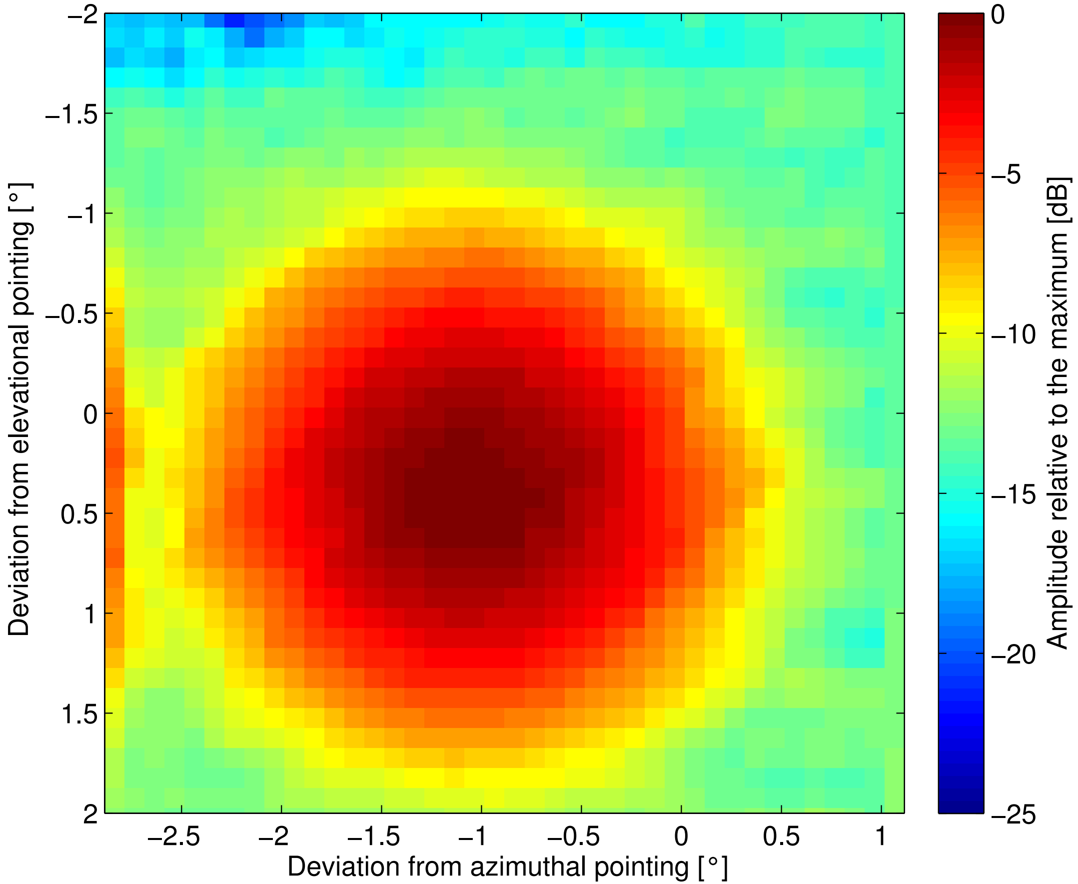

Fig. 2. Sunscan when looking westward. Measurement taken on 3 September 2010.

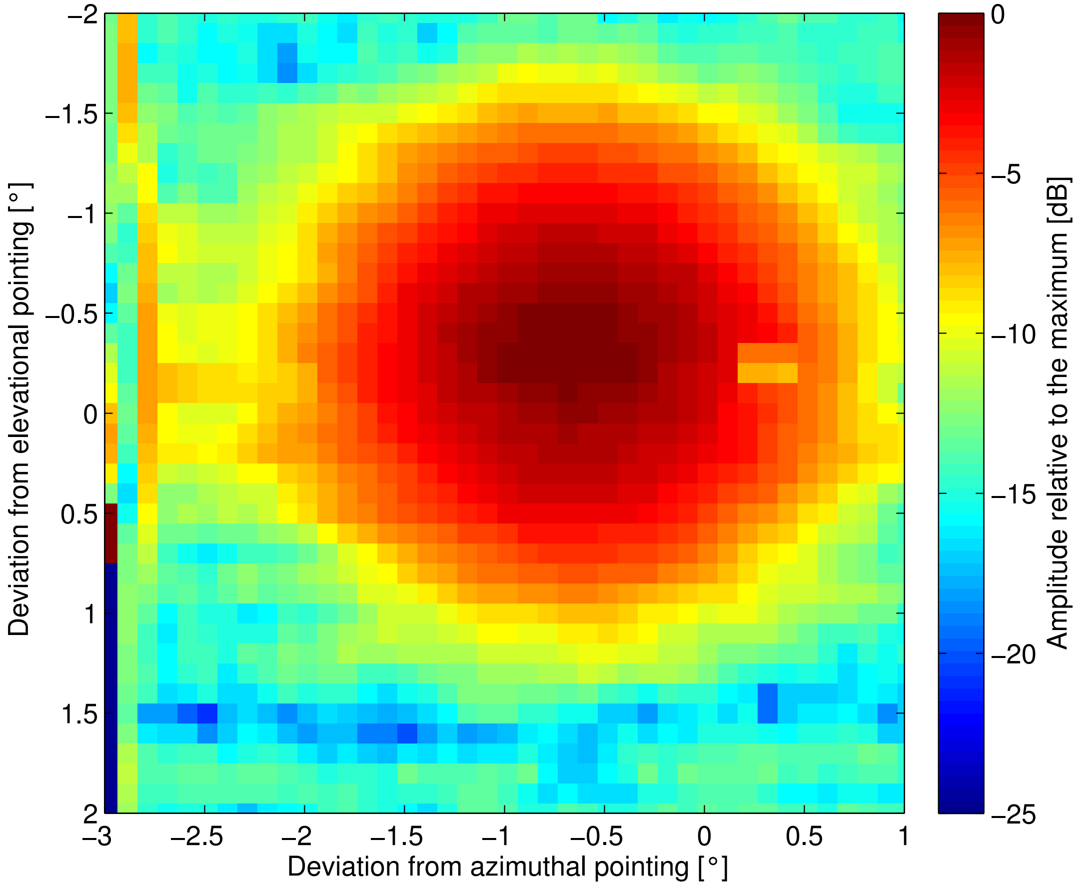

Fig. 3. Sunscan when looking eastward. Measurement taken on 6 September 2010.

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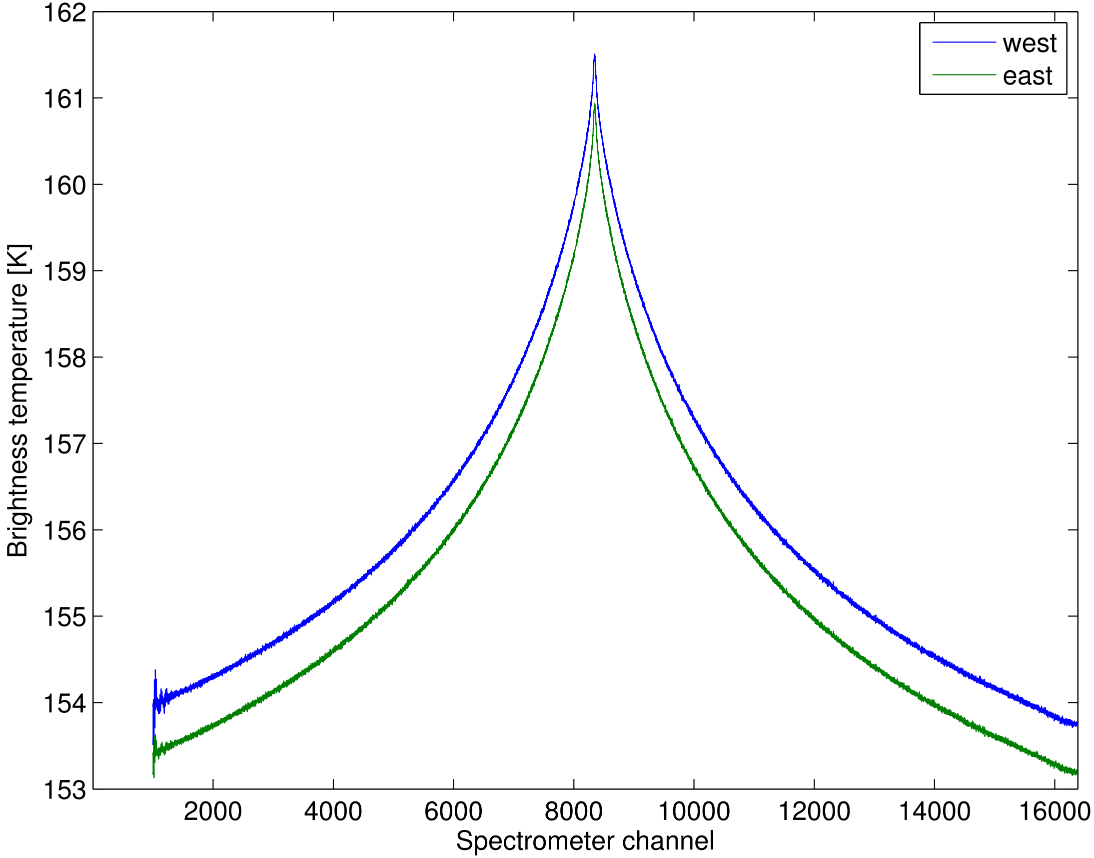

Fig. 4. Average over all calibrated double sideband spectra of the measurement period used in the manuscript for the observing directions west and east.

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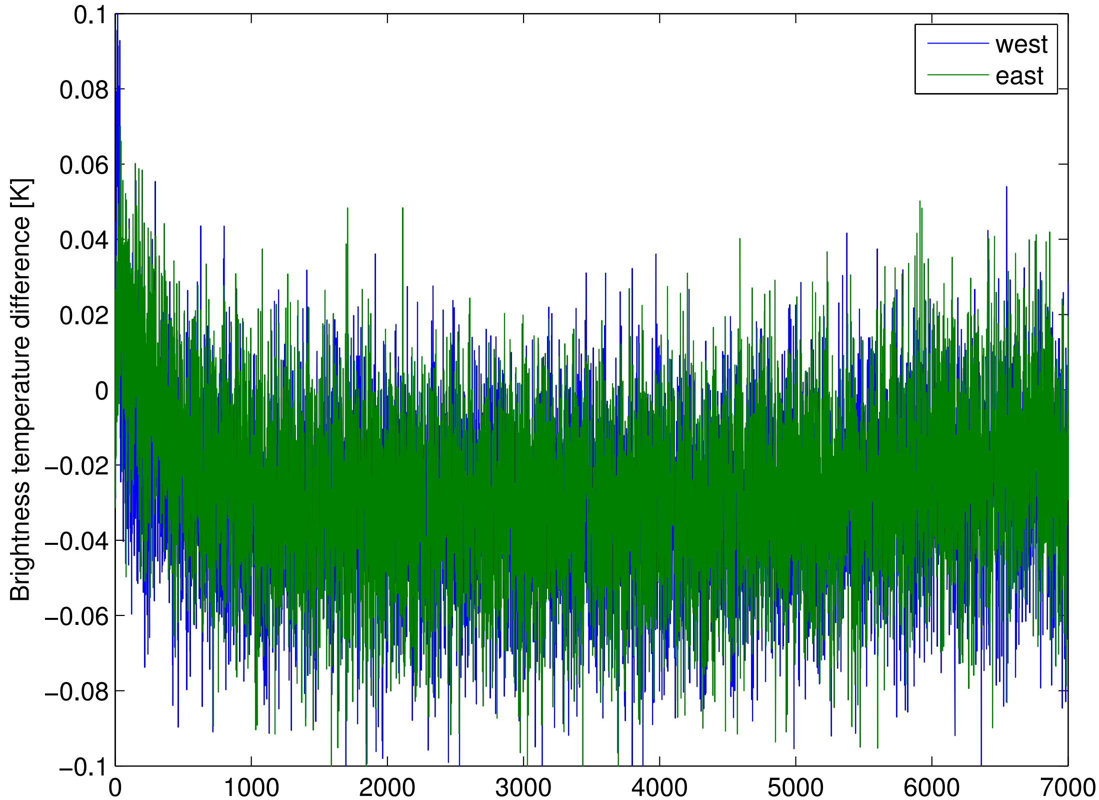

Fig. 5. Difference between the right and the left wing of the average spectra from figure 4. See text for details.

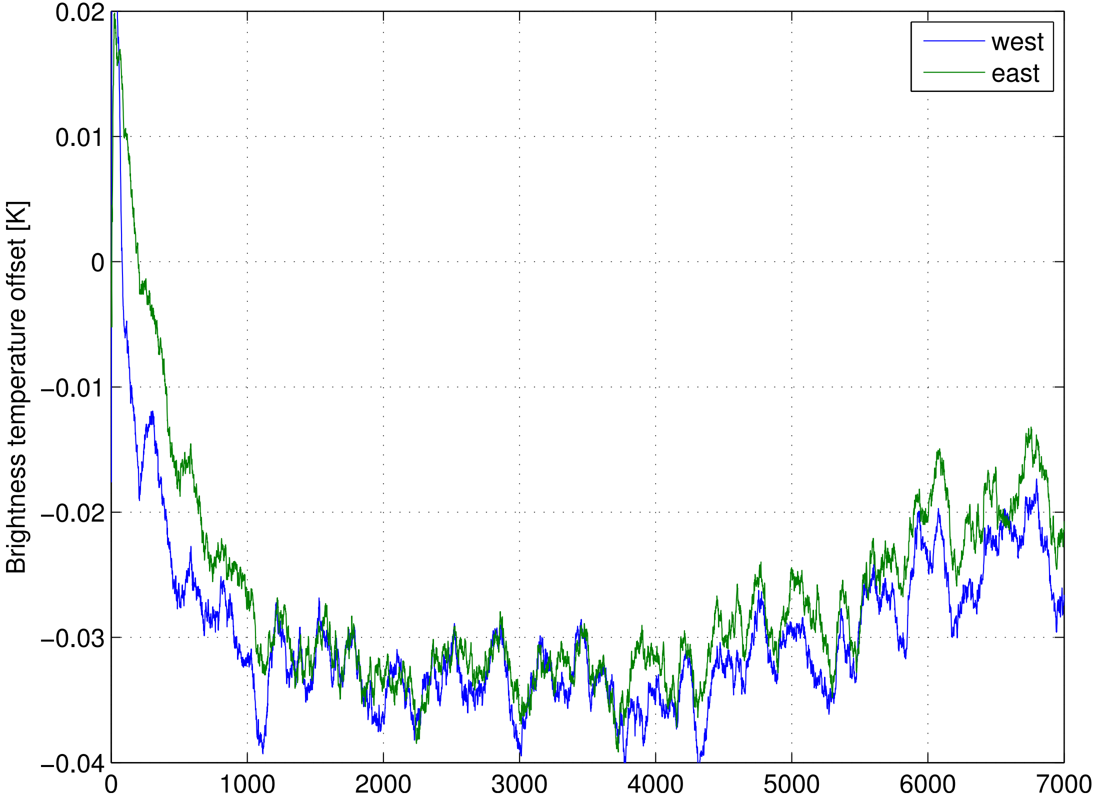

Fig. 6. As figure 5 but with a smoothing filter.

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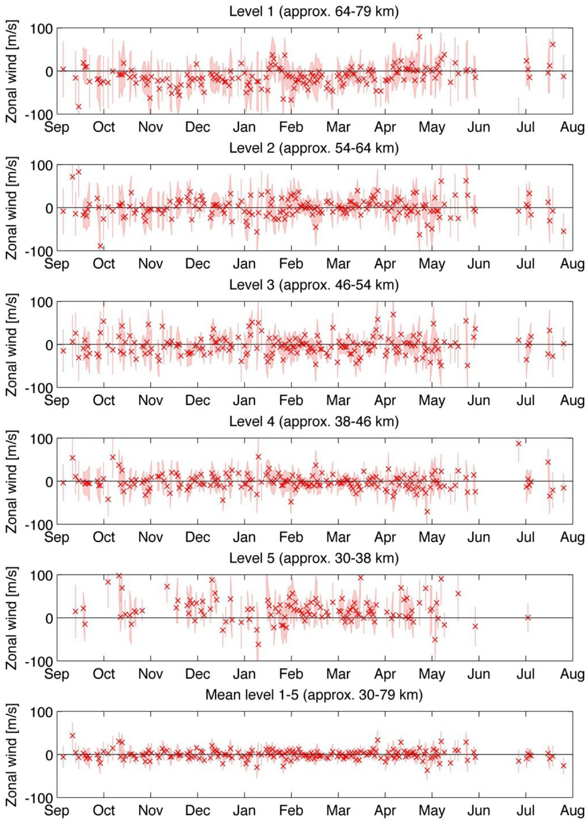

Fig. 7. Time series of the difference in the zonal wind between the measurements from WIRA and the operational analysis data from ECMWF from September 2010 to July 2011. WIRA's error bars are also potted.

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