Interactive discussion of manuscript doi:10.5194/amt-2018-69
concerning comment doi:10.5194/amt-2018-69-RC2.

Reply to comment from Anonymous Referee #2

from Jonas Hagen (jonas.hagen@iap.unibe.ch) on behalf of the authors.

Referee: A table summarizing the instrument and observation characteristics (bandwidth, resolution, integration time, system temperature, line-of-sight elevation range, ...) would help the reader.

Authors: This is a good idea. The characteristics of WIRA-C are:

Optics	Ultra-Gaussian feed horn + elliptical and flat mirrors
Beam width	2.3 ° FWHM
Receiver type	Pre-amplified single-side band heterodyne
Frequency	142.17504 GHz
Bandwidth	2 × 120 MHz
Backend	Ettus Research USRP, FFTS
Spectral resolution	12.2 KHz
System Temperature	550 K
Calibration	Hot load + Tipping curve
Elevation range	All sky

Resulting Changes:

- Include the WIRA-C specs as table.

Equation 3: Is the term $-\sin(\eta)$ missing in the right side of the equation? The way to estimate T_{bg} should be described. I also think that its definition (line 18) is too far from Eq 3.

Indeed. Thanks. The equation (3) should read $\tau = -\sin(\eta)\,\ln\left(\frac{T_m - T_b^{\mathrm{off-resonance}}}{T_m - T^{\mathrm{bg}}}\right)$ where T_m is the mean tropospheric temperature as derived by Ingold et al. (1998) and T^{bg} is the Background temperature which is set to 2.7 K at 142 GHz.

Resulting Changes:

- Fix $-\sin(\eta)$ in Eq. 3 RHS.

Equation 5: Is $M = 2$ or 6 (P 13, Line 13) or other? Is-it the same M for all retrievals? If $M = 2$, the setting looks like a normal retrieval. How the 3-dim retrieval is done? Do the authors quantitatively assess the improvements compared to a normal retrieval?

$M = 6$ for all retrievals. What we call three dimensional retrieval is an OEM retrieval with a 3-dimensional model atmosphere and corresponding covariance matrices and state vectors, that allows to implement spatial variations in some quantities (ozone) and simultaneously combine all available information into one wind profile. Like this we can implement the expectation to observe the same winds when looking east and west, but have different ozone concentrations. Also for $M = 2$ the model atmosphere would need to be 3-dimensional if we would like to retrieve two ozone profiles but only one wind profile.

We performed some comparisons of the two retrievals finding that the 3-dimensional retrieval yields more stable results and – most importantly – rigid quality control parameters such as measurement response, averaging kernels and retrieval errors. In the 1-dimensional setup, these parameters are retrieved for each observation direction separately and need to be combined (averaged) somehow. In our opinion, this is a big advantage of the 3-dimensional retrieval.

Equation 10 corresponds to the linear OEM equation with the forward model $y = Kx$, but it is stated that a non-linear retrieval is used (P 12, Line 15). Some explanations are needed to clarify the apparent contradiction. I also assume that only K and G are updated in the iterative process and not x_a . Am I right?

What we actually do is minimizing χ^2 in (7). The linearised form is applied in an iterative process during which x_a is fixed (for example $x_a = 0$ for wind) but the point of linearisation for K is, of course, updated. In the first round x_a is chosen as point for the linearisation. Indeed, there is some confusion about linear vs. non-linear retrieval, see changes below.

Resulting Changes:

- Link the linear retrieval solution with the iterative process involved as the linear solution is applied iteratively.

Page 10, lines 5-14: The observation strategy is not clear for me. Do the authors compute equation 4 with data obtained over short periods and, then average the calibrated spectra over 12 hours? If yes what is the time period to get a calibrated spectrum?

Yes, that is exactly what we do. We explained the reasoning behind this on page 10, line 10 ff of the manuscript. One calibration cycle takes 2 minutes (see last line of page 7 of the manuscript, in context with receiver stability).

P13, Line 15: More information are needed to understand how the statistics are calculated (which climatology is used, spatial and time ranges to compute statistics, ...) The authors use different a priori errors for the meridional and zonal components of the wind vector according to the wind variability. As stated in the text, such an approach leads to different retrieval performances (retrieval precision and vertical resolution) for both components. This is a choice of the author since the measurement does not de- pend on the LOS orientation. The authors should explain more clearly the motivations for choosing this setting instead of using the same one for both components. The wind variability is multiplied by factor 2 to construct the covariances, which let me think that having covariances representing the variability is not a key issue. Personally I would use a similar a priori error as that used for the zonal wind for both components in order to keep the vertical resolution close to 10 km given that the retrieval precision can be improved by averaging profiles but the vertical resolution cannot. Vertical resolution is an important issue for a site at La Reunion latitude since tides can induce vertical patterns on the meridional winds with vertical scales of 15-20 km and an amplitude that can be larger than 10 m/s.

The a priori statistics for wind are calculated from 6 years of ECMWF data for the specific location of the campaign. Because wind speeds are far from following a Gaussian distribution, we multiply them with a factor of 2. As our wind retrieval should not be influenced by seasonal dependency of the statistics, we use the same (total) variation for all times and thus the a priori statistics only depend on pressure.

Regarding the choice of different a priori co-variances for zonal and meridional wind, there are arguments for both sides. The referee made a very strong point for using the same co-variance for both components. We chose to use the same approach for determination of the statistics (climatology with factor) for both components, which naturally turns out to give different values for zonal and meridional wind. In no way do we state that this approach is in general the right one, but for comparison with other data (lidar and ECMWF) it is favourable in our opinion for the following reasons. As meridional winds are generally weaker than zonal winds, the signal to noise ration is worse, but at the other hand, we can constrain the optimisation a bit more thanks to the lower variability. The MAP regularisation includes a priori statistics to better define the problem. If such information is available it should be used in our opinion.

Resulting Changes:

- Explain how we derive the a priori mean and covariances for wind.

P13, Line 20: As for the wind climatology, we need more information on how the statistics are performed to compute the mean and the covariances of O3. How the six ozone profiles are used?

For ozone, the statistics are derived form a F 2000 WACCAM scenario model run described by Schanz et al. (2014). We determine the mean value and variability of ozone in a window of 11 days around the day-of-year of the measurement while only regarding the very same hours of the day that we integrated over (either day or night) to properly account for mesospheric ozone as proposed by Rüfenacht and Kämpfer (2017). Currently we do not use or discuss the ozone profiles. This might be part of future work.

Resulting Changes:

- Explain how we derive the a priori mean and covariances for ozone.

P13, Line 25: Is-it really indicated in Sect. 4.3 that the O3 covariances are height independent?

Yes, but because as we do a 3D retrieval, we have to deal with vertical and horizontal spatial correlation. The vertical correlation length is set to be 0.3 pressure decades. The horizontal correlation length, which in the end describes the correlation among the 6 ozone profiles is set to be 200 km for all altitudes. Nevertheless, the horizontal correlation between our retrieved grid points is lower in higher altitudes, because the lines-of-sight in opposing directions diverge from each another. This means with increasing altitude, the ozone profiles in opposing directions get more independent.

Resulting Changes:

- Clearly distinguish between horizontal and vertical correlation length for the covariance matrix of ozone.

P14, Line 2, no need of ”hat” in the second $\hat{x}$

Thanks.

P14, Line 33, Should “Sect 4.3” be “Sect 4.4”?

No. Its Sect. 4.3 page 12 line 21 and refers to equation (12), which shows that the observation error is not independent of a priori co-variance.

Resulting Changes:

- Make the reference more clear.

P15, Line 22, correct “to to”

Thanks! (Its P14 L22)

P15, Fig. 9: The ozone line is shifted toward the right side of the band. The first 20 MHz range on the left side of the spectrum should contributes to the wind retrieval at the lowest retrieved altitudes. Combining the two spectra with opposite directions provide antisymmetric wind signature . Is this frequency range a significant contribution to the retrievals? If yes, the wind retrieval might be sensitive to different errors on the amplitudes of the two calibrated and tropo-corrected spectra? If yes, the statement that wind are not sensitive to amplitude calibration errors should be weaken.

We only use the central channel (A) for our wind retrievals. The left wing is only used for tropospheric correction as stated on page 10, line 18 in the manuscript. We agree with the referee that a wider spectrum would give more information on the lowest retrieved altitudes.

P17, Tab 1: How is the perturbed profile computed? Is the same perturbation applied at all altitudes or is it altitude dependent? ($x_p[i] = \epsilon + x[i]$ or $x_p[i] = \epsilon[i] + x[i]$?) If it is the second case what is the vertical resolution of the perturbation and the vertical correlation?

We use different types of perturbation schemes that we call absolute and relative (column 3 in Tab. 1). The temperature and ozone a priori profile are perturbed as $x_p[i] = x[i] + \epsilon$ with a fixed ϵ sampled from the given distribution. For the co-variances we sample a value ϵ_r from a Gaussian distribution with mean $\mu = 1$ and standard deviation $\sigma = 0.25$. The perturbed profile then is $x_p[i] = x[i] + (\epsilon_r - 1)x[i] = \epsilon_r x[i]$. In that case, the total perturbation is altitude dependent due to $x[i]$. It is a common approach to multiply the covariances by a factor in order to estimate their influence.

P19, Sect. 5.3: Does the time series in Figures 11-14 include the day and night data?

Yes, the day and night data are plotted together, so there are two vertical stripes per 24 hours.

Resulting Changes:

- Mention that day and nighttime data are shown together in the timeseries plots.

P21: Does "smoothed in time" mean 12 hours average? The size of the pictures could be increased.

Yes, we average the two ECMWF timesteps that lie within our integration period as explained in Sect. 5.2.1. For daytime, our integratinon period is from 2 to 14 h and contains the 6 h and 12 h ECMWF timestep (all UTC). This is asymmetric by 1 hour, but we prefer the simple scheme over an interpolation as we find the differences in that specific case to be negligable.

P24-P25: The starting time for the observations should be indicated in Fig 15 caption. I think local time is more relevant than UT (Fig. 16 caption). Why some WIRA meridional profiles are cut below 55 km? Fig.16 caption: correct "measuremnts" at the end of the second line.

Thanks.

The WIRA-C meridional wind profiles are cut below 55 km because the quality control parameters are outside of their bounds. While investigating which parameter exactly is out of the valid bounds, we found that the measurement response and offset parameter (as described in Sect. 4.5 of the manuscript) are ok, even below 55 km. To our own surprise we still had another criteria imposed, that we used in an earlier version: the FWHM of the AVK has to be below 15 km. We removed this constraint and replotted the lidar profiles (see figure A of this document) so it is now consistent with the quality control parameters described in Sect. 4.5 of the manuscript and used throughout the paper. Now, the profiles go all the way down to 39 km.

Resulting Changes:

- State starting time of observations in Fig. 15 (they are the same as in Fig. 16).

- Give the corresponding local time for the UTC times mentioned in Fig 15 / 16 caption.
- Fix typo.
- Replot Figure 15 while only using the quality control parameters described in Sect. 4.5.

References

Ingold, T., Peter, R., and Kämpfer, N.: Weighted mean tropospheric temperature and transmittance determination at millimeter-wave frequencies for ground-based applications, Radio Science, 33, 905, https://doi.org/10.1029/98RS01000, 1998.

Rüfenacht, R. and Kämpfer, N.: The importance of signals in the Doppler broadening range for middle-atmospheric microwave wind and ozone radiometry, Journal of Quantitative Spectroscopy and Radiative Transfer, 199, 77–88, https://doi.org/10.1016/j.jqsrt.2017.05.028, 2017.

Schanz, A., Hocke, K., and Kämpfer, N.: Daily ozone cycle in the stratosphere: Global, regional and seasonal behaviour modelled with the Whole Atmosphere Community Climate Model, Atmospheric Chemistry and Physics, 14, 7645–7663, https://doi.org/10.5194/acp-14-7645-2014, 2014.

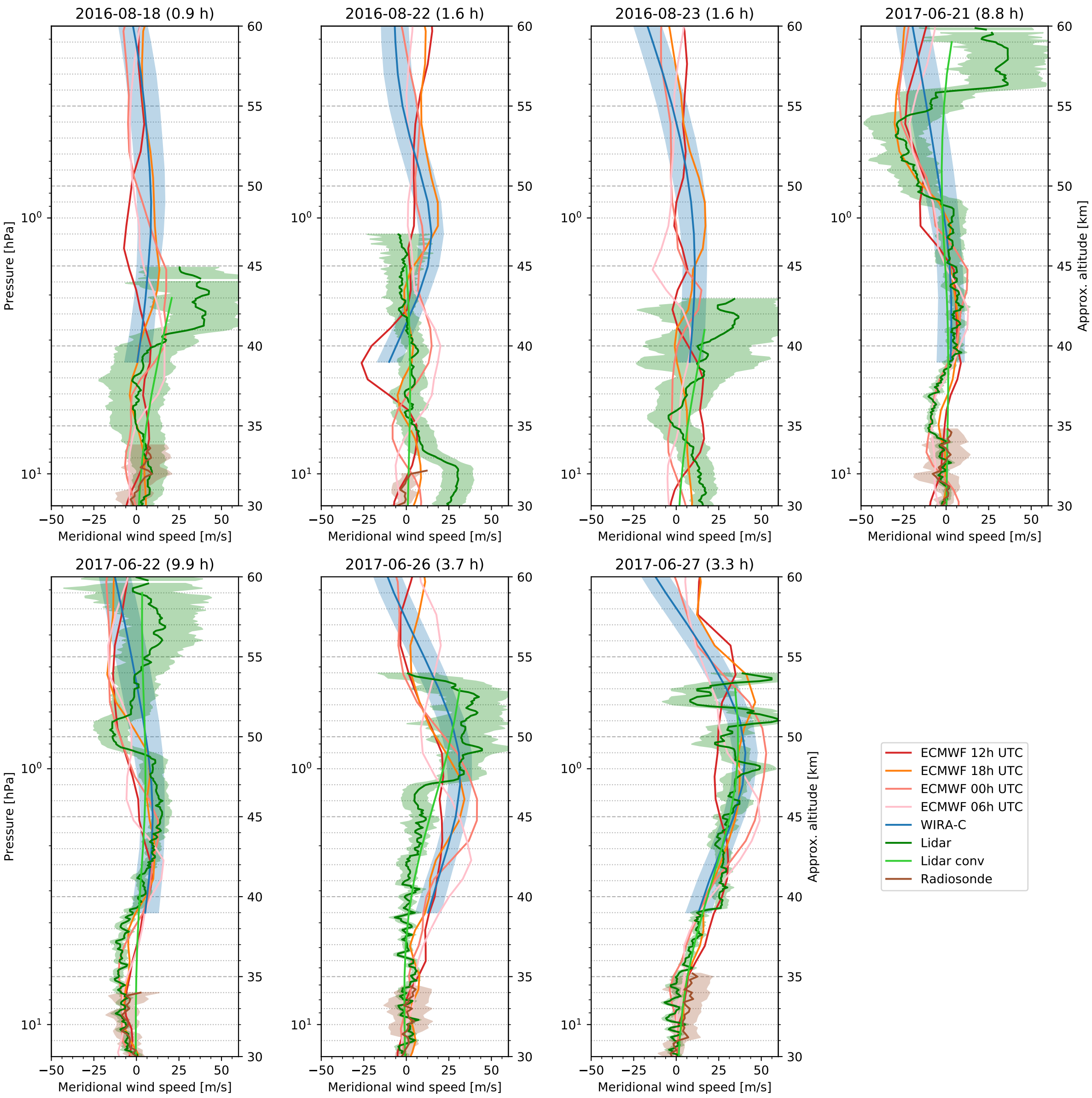

Figure A: Meridional wind measurements of lidar and WIRA-C. Same figure as Fig. 16 in the manuscript, but with the same quality control parameters applied as for all the other plots in the manuscript instead of applying a constraint on FWHM.