Interactive discussion of manuscript doi:10.5194/amt-2018-69
concerning comment doi:10.5194/amt-2018-69-RC3.

Reply to comment from Anonymous Referee #3

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

Referee: Abstract: It could be mentioned that the WIRA-C does not need operator for routine operation. The WIRA-C is presented as an instrument which has never been used in ground- based radiometry before. WIRA-C should be presented as a new generation of WIRA.

Authors: Correct, WIRA and WIRA-C do not need an operator. This is a major advantage over wind lidar systems. Of course, WIRA-C is the follow-up instrument of WIRA.

Resulting Changes:

- Mention autonomy in the abstract.
- Relate WIRA and WIRA-C in the abstract.

Page 3, line 30: As opposed to WIRA which observed at an elevation angle of 22° , WIRA-C can select the angle. It could be here explained why this is important. Page 8, line 3 observations are still done at the four 22° elevation.

22° degrees are an optimal elevation for wind measurements. The angle is sufficiently small to have a high projection of horizontal wind speeds to the line-of-sight, but still big enough to keep the path length through the troposphere reasonably short to get a good signal to noise ratio.

Wind retrievals would not benefit from observing additional elevation angles in terms of uncertainty or resolution. At the moment we use the adjustable elevation angle solely for leveling the instrument and compensate pointing errors.

Resulting Changes:

- Include one sentence about why we choose 22°.

Page 9: Is there a reference for Equation 2?

Yes: (Ingold et al., 1998, Eq. 4). It is derived from the radiative transfer equation for a non-scattering medium and assumes an atmosphere with a mean temperature instead of a temperature profile. This approach is often used for tropospheric correction in microwave radiometry, see Ingold et al. (1998) for details.

Resulting Changes:

- Add the reference for Eq. 2.

Page 10, line 12: An integration time of 12h is chosen. How the wind measurements would be affected (larger error bar, reduced range of altitude?)

If the integration time gets smaller, noise increases. As a result the observation error increases. The altitude range is also affected: If the noise gets bigger, more weight is given to the a priori profile, and thus the measurement response decreases. Starting at the lower domain, this restricts the range of valid points in the profile.

Page 11, line 1: Replace “Wind” by “wind”.

Thanks.

Page 14, line 26: How the errors would vary with the integration time? See comment above.

See response above.

Page 14, line 35: This is not clear why the resolution for meridional wind measurement is larger than for zonal wind?

We determine resolution as Full Width at Half Maximum (FWHM) of the averaging kernels. As observed by the referee, the FWHM for meridional wind is larger than for zonal wind. A compatible definition of resolution would be: Altitude range ($\approx 50\,\mathrm{km}$) divided by degrees of freedom ($\mathrm{dof} = \mathrm{Tr}\,A \approx 5$). The degrees of freedom is smaller for meridional wind because the a priori is more restrictive in our case, resulting in a worse resolution ($\Leftrightarrow$ larger FWHM).

Page 18, line 7: The Integrated Forecast System cycle of the ECMWF product used in this should be mentioned.

We used Cy41r2 (March 2016), Cy43r1 (November 2016) and Cy43r3 (July 2017).

Resulting Changes:

- Mention the IFS cycles in Sect. 5.2.1 (ECMWF model data).

Page 19, line 15: Discrepancies between model and observations are not so clear on the figure. I suggest to add one additional subplot to Figures 11 and 13 showing the difference between WIRA-C and ECMWF convolved.

See figure A and B in this document. The differences between ECMWF and WIRA-C are not significant for the 12 hour retrievals, meaning the difference is about the same magnitude as the retrieval error. To discover significant discrepancies we would need to make aggregations (weekly, monthly, or the like) while respecting the atmospheric processes, like wind reversals or Rossby waves. We think that discrepancies between model and measurements can only be discussed in a meaningful way when taking into account these atmospheric processes using corresponding aggregation schemes. As this is an instrument paper, we would rather not include details about atmospheric physics in this manuscript.

Page 19, line 21: The lower variability in the model is not visible on the figure (see comment above).

At the referenced line (21 on page 19) we refer to the end of April 2017 as a showcase for higher variability but lower absolute wind speed seen by WIRA-C when compared to ECMWF. We provide a zoom in figure C of this document where the higher variability can readily bee seen.

Page 20, line 3: As discussed, lidar data show very large vertical gradients in the wind speed, not only above 40 km but also below 35 km (e.g. Figure 16, 2016-08-22). They do not last more than one day. More descriptions of their characteristics (am- plitude, vertical wavelength. . .) as well as explanations of their origin (internal gravity waves?) are welcome. The vertical gradients in lidar data are not visible in WIRA-C measurements. It can be recalled that WIRA-C, as well as ECMWF (partly) smooth these perturbations because of their vertical resolution.

Perturbations in the wind profile are indeed most likely caused by internal gravity waves, see Khaykin et al. (2015) for characteristics and details of fine structures observed by lidar. For the case mentioned by the referee (2016-08-22), the full altitude range of lidar measurements is shown in figure D. There it is obvious, that also ECMWF captures this layer of strong northward wind, even though at reduced amplitude. This feature is likely due to a gravity wave with vertical wavelength of about 8 km (which is quite typical for upper stratosphere) and an intrinsic period of a few hours (also typical). The RS profile is about 9 hours earlier than lidar measurement, which is why the phase is so different. The wave amplitude is remarkably high, however we trust the lidar readings at this level and the error is relatively small too.

In the manuscript we clearly point out, that these features are smoothed out by the radiometer measurements (page 20, line 5) because the convolved lidar profiles agree well with the lidar measurements.

Resulting Changes:

- Add reference to Khaykin et al. (2015) in relation to small scale structures of lidar measurements.

Page 21, Figure 12: Mention in the legend that zonal winds are displayed. I suggest to enlarge Figures 12 and 14. The smoothed convolved ECMWF curve is not visible (change color?).

The convolved ECMWF curve is mostly hidden by the raw ECMWF curve. This speaks in favour of our measurements as in an ideal retrieval, both curves would co-incide as the averaging kernels would be delta peaks. We will mention that in the figure caption.

Resulting Changes:

- Mention that zonal winds are displayed in the caption of Fig. 12.
- Mention that convolved ECMWF curve is mostly hidden by the raw ECMWF curve.

Page 22, Figure 13: Suggest to adjust the color scale to improve contrast.

Meridional wind speeds observed are mostly very small and the color scale of Fig. 13 is -60 to 60 m/s in order to include the highest observed wind speeds. This is consistent with Fig. 14. We experimented with different color scale limits, but find the chosen solution to be the least misleading option.

Page 23, Figure 14: Why not showing all ranges of altitude as displayed by Figure 12, even measurements are not always available (Figure 13). In the legend, the ranges of altitude should correspond to what is shown.

This is a question of detail versus overview. We focus on the altitude range for which we have actual measurements for comparison and thus tend to show more detail but less overview in these plots. For the full altitude range see Figure E and F in this document.

Page 26, Conclusion: It can be reminded that WIRA-C is an optimized version of WIRA (first sentence). Comparisons between the convolved ECMWF profiles and WIRA-C show an overall good agreement. However, some differences in wind strength at specific time periods are pointed out in the paper (e.g. Figure 11). In the perspective, WIRA-C should be presented more as an independent ground-based sounding technique to provide additional observational constraints in range of altitude where routine measurements are lacking rather than for sake of validation. A limitation of WIRA-C is the altitude resolution. As for the time resolution, are there other technical improvements to be explored in order to improve the vertical resolution? The complementarity of wind lidar (man-power needed for operation) and WIRA-C capable of continuously measurements of the middle atmosphere mean state can be addressed.

Thanks, we will consider the suggestions. Regarding technical improvements for altitude resolution: All passive microwave observations have a rather coarse altitude resolution.

Reducing noise is merely the only solution to improve altitude resolution the authors know about.

Resulting Changes:

- Slightly rephrase certain parts of the conclusions.

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, 905–918, https://doi.org/10.1029/98RS01000, 1998.

Khaykin, S. M., Hauchecorne, A., Marqestaut, N., Posny, F., Payen, G., Porteneuve, J., and Keckhut, P.: Exploring Fine-Scale Variability of Stratospheric Wind Above the Tropical La Reunion Island Using Rayleigh-Mie Doppler Lidar, 03004, 2–5, 2015.

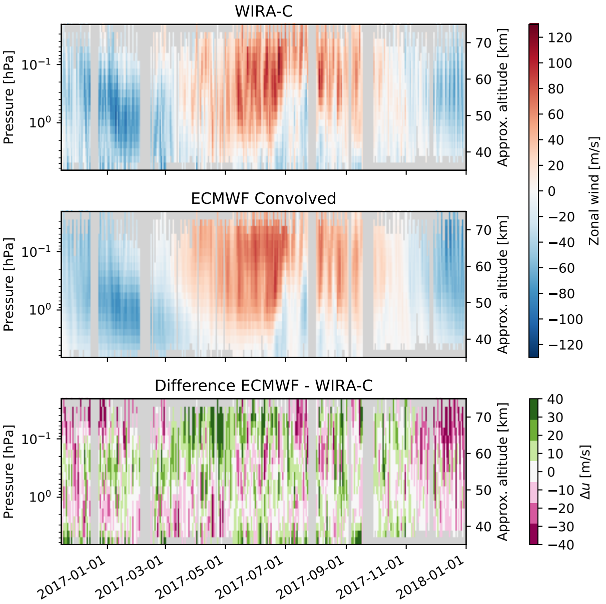

Figure A: Same as Fig. 11 in the manuscript, but with one additional panel showing the absolute differences between WIRA-C and ECMWF.

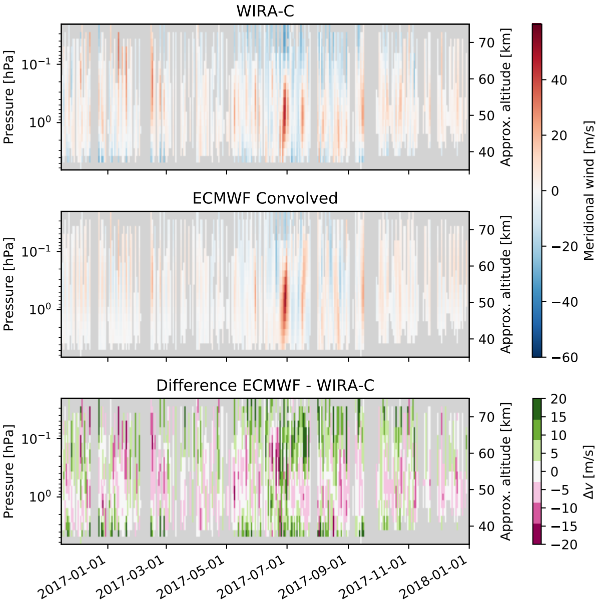

Figure B: Same as Fig. 13 in the manuscript, but with one additional panel showing the absolute differences between WIRA-C and ECMWF.

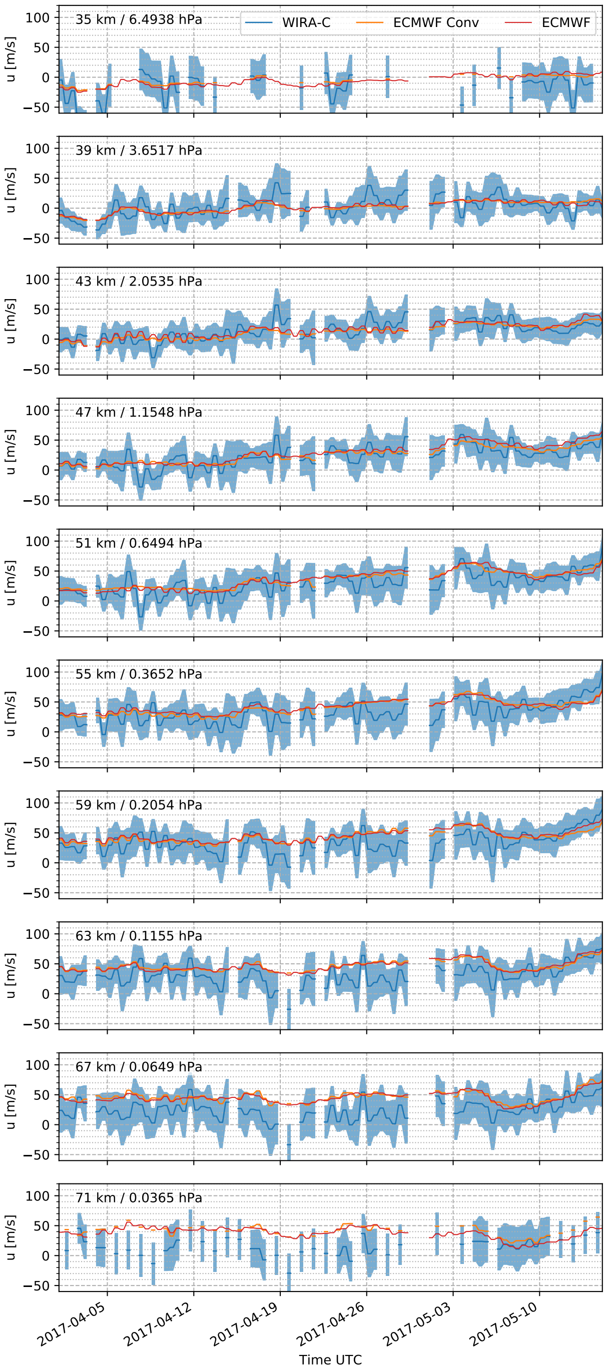

Figure C: Same as figure 12 in the manuscript but zoomed to April and May 2017.

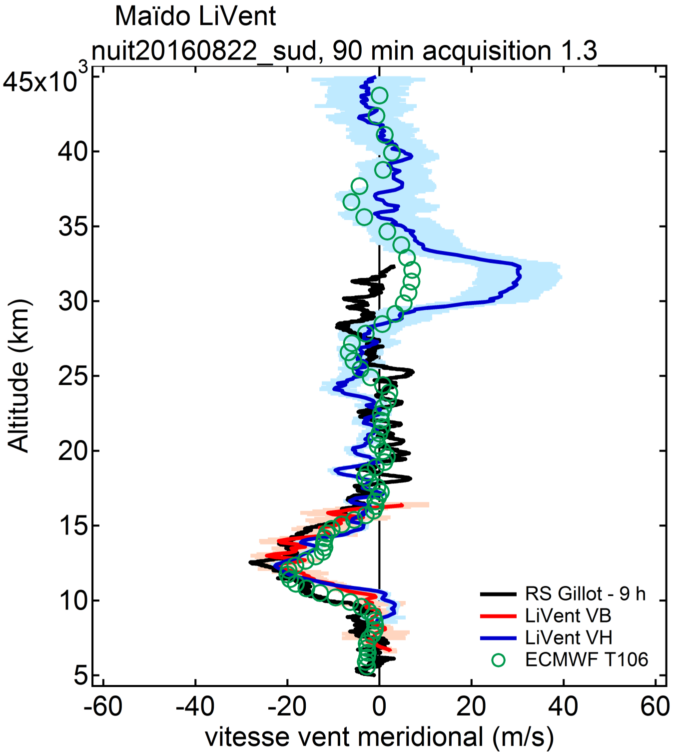

Figure D: Meridional wind profiles from lidar and radiosonde measurements and ECMWF model data for the night of 2016-08-22.

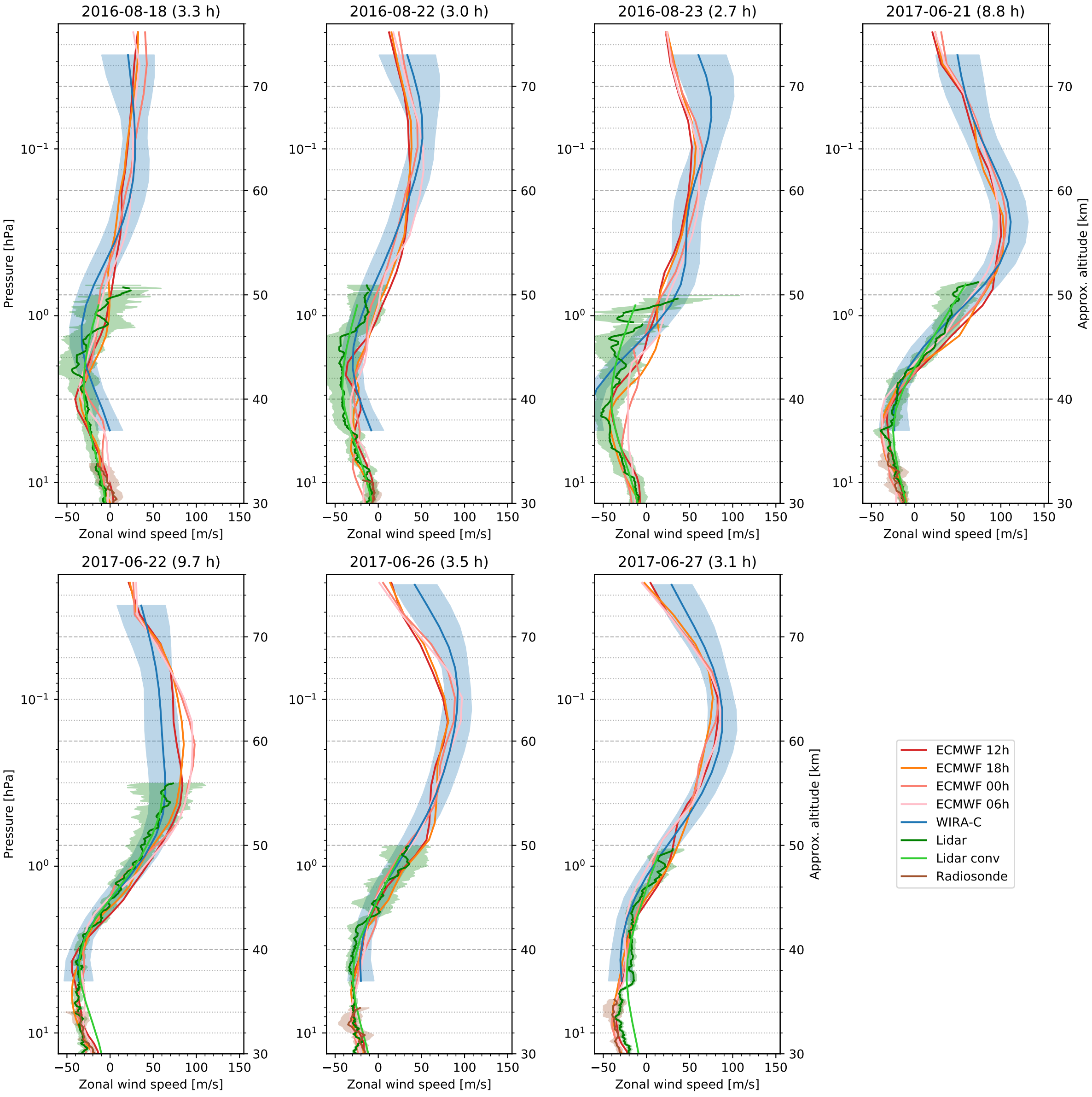

Figure E: Zonal wind measurements of lidar and WIRA-C. Same figure as Fig. 15 in the manuscript, but for full altitude range of WIRA-C.

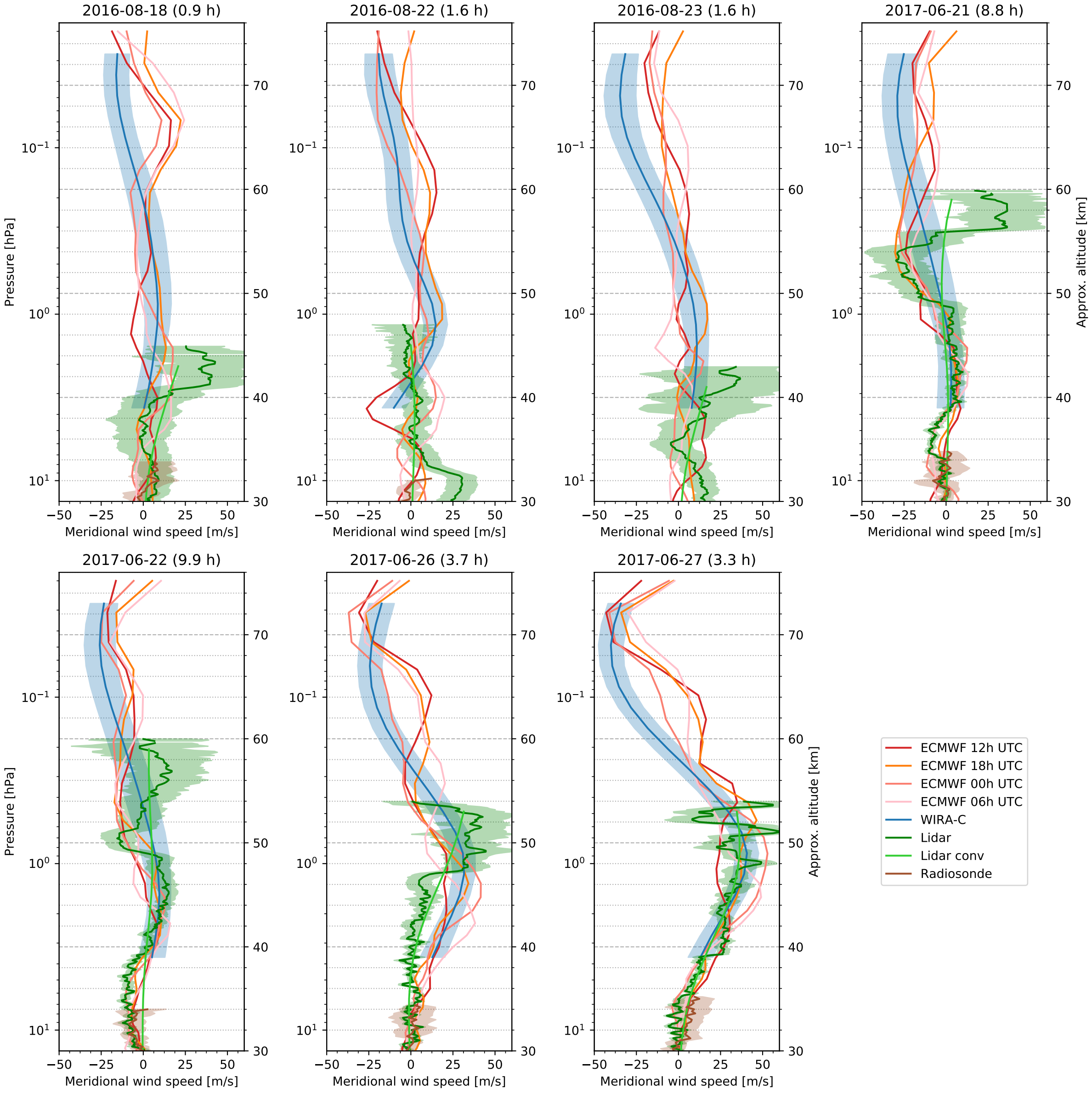

Figure F: Meridional wind measurements of lidar and WIRA-C. Same figure as Fig. 16 in the manuscript, but for full altitude range of WIRA-C.