REPLY TO RC3
MANUSCRIPT ESSD-2021-265

The manuscript introduces the radar data sets collected during the EUREC4A campaign between trade wind region and tropical convergence zone on the research ship Maria S. Merian. The data set is unique and of high interest for the community. Necessary post-processing and some derived products published alongside the manuscript are presented. This manuscript deserves publication after correction of quite a number of small weaknesses and inaccuracies in the presentation.
Questions to the editorial office rather than the authors arise from the use of webpage referencing and a reference to an unpublished manuscript.

We thank the reviewer for recognizing the importance of the dataset collected and we try of best to answer the comments and solve the inaccuracies and weaknesses found in the text.

General points:

The introduction and beginning of the section 2 left me confused about what to expect in this paper. Please be specific about what you will provide in this data set as early as possible. In the manuscript it only becomes clearer step by step. IWV is first mentioned in the beginning of section 2. LWP somewhat later, before IWV is detailed again. I would suggest to mention all these in the introduction and add a product table of all data set, their sampling rate, their expected accuracy, etc.

We included the derivation of the IWV estimations in the introduction. The modification can be found at line 31 in the new version of the manuscript: "The 89 GHz passive channel available in the W-band radar system allowed to characterize the columnar amounts of liquid water and integrated water vapor was retrieved only in clear sky conditions by means of a linear regression with co-located radiosoundings.". We refer to all the data products in section 2.1 and 2.2.

The authors should be clearer and more specific about the limitations of all their steps. Starting from active positioning, but also about the accuracy of all data sets published. … Data without accuracy information is no data.
The accuracies of the roll, pitch and heave measurements from the stabilization platform are reported in section 2.4. Providing accuracies for radar data is actually a research topic itself due to the fact that such variables are non-linear functions of radar raw data. Acquistapace et al. 2017 (https://doi.org/10.5194/amt-10-1783-2017) investigated the sensitivity of the Doppler moments, with a particular focus on the skewness with respect to different spectral resolutions and integration times during identical time intervals to quantify the accuracy of Doppler higher moments. Recently a paper from Myagkov and Ori (https://doi.org/10.5194/amt-2021-225) investigated how to characterize random errors in dual-polarimetric spectral observations using error covariance methods. Radar moments like mean Doppler velocity, spectral width and skewness accuracies might be characterized similarly but as shown, this is a research paper itself and goes beyond the scope of this work.

Our data paper follows the path traced by similar older radar data papers like Neto et al. 2019 (https://doi.org/10.5194/essd-11-845-2019) where no discussion on accuracy or precision of radar reflectivity is mentioned. In our work, we aim at reporting the observations that were collected, discussing all their limitations and uncertainties throughout the text. We welcome the reviewer to suggest any possible approach that they have in mind to tackle the quantification of the accuracy for the derived radar variables.

In section 3.1 and 3.2 the nomenclature should be checked again. I have the impression that not all nomenclature is used correctly and some quantities are labelled in different ways.Please check, if all appendices are mentioned in the text. I only found references to App. A, C, D.

We checked through and we found some little discrepancies in the way the reference systems are called in the text and appendices, that have been fixed. We also noticed that appendices were not referred and we added that. We could not find any additional discrepancy. We thank you for the indication.

Minor and specifics:

Minor language editing will be needed as sentences are ill-constructed from time to time.

l.6: I would prefer not to use manufacturer product names in the abstract. The “PRO” in “MRR-PRO” is not needed and it’s not introduced. Stay more general and leave out the “PRO” until you introduce the product in the “Experimental setup” section.
Thank you for the comment. We removed the PRO until the instrument was introduced and then we left the MRR-PRO.

l.20: “oceanic eddies”. These show up uncommented and seem to be important. Can you add a sentence on what it is and why it is interesting?
We modified the sentence as follows: “The ship sampled some mesoscale oceanic eddies, that are circular fronts of sea surface temperature anomalies caused by oceanic turbulence, locally impacting near-surface wind, cloud properties and rainfall (Frenger et al., 2013).

L22: “OA”. Please introduce.
We added the sentence: “Within EUREC4A, the Ocean-atmosphere component (EUREC4A-OA, https://eurec4a.eu/overview/eurec4a-oa/) was granted two research vessels (RVs) in the Atlantic sea south-east of Barbados to monitor the oceanic processes induced by large-scale oceanic eddies.”

l.28: “MRR-PRO”. As before.
Corrected

L33: “… spatial and time resolution of the entire precipitation life cycle.” Of what? Daily, seasonal, global, local?

Here, we refer to the fact that both radars have high temporal (1-3s) and vertical (<10 m) resolution. Such high resolution allows to characterize and detect the processes occurring in small radar volumes, and therefore gives the ability to detect with a high sampling rate the precipitation cycle from the onset of rain until the moment in which that rain is reaching the sea surface or evaporating. The time scale of such process is hours, so it is not referred to any statistics, but more to the ability of detecting details of processes that were not discernible before.

l.42/43: "9 s". Where does this information come from? Measurement during the campaign? Does the "(Chris Fairall,…)" refer to them? Because the fact that a wavelength of 9 s needs measurements of at least 2 s to represent is mathematically obvious and would not need any support.
The 9s is precisely the information that Chris Fairall gave us from his experience in previous measurement campaigns. It refers to the longest integration time to be set in the radar for being able to correct for ship motions in the data. Although it might seem obvious, experimentally also other values like 2.5 s, or 3 s could seem acceptable. The threshold provided by Fairall was an important reference for setting up the measurement mode and define the chirp table. We reported in the publication because it might be helpful for future deployments as well.

l.47: "additional measurements onboard". Please add a "not presented/published here".
corrected

l.61-63: "Active remote … satellite retrievals." This is a bit repetitive. Please remove.
Removed

l.74-77: "We calibrated … factory calibration." This should be part of the instrument specific 2.1 and 2.2.
moved there, thanks.

l.81: "We launched …". This reads as if you will also present these for a moment. Please be precise what to expect from this manuscript.
We used the verb "we launched" because the radiosondes operation were coordinated and organized on the RV by Acquistapace, i.e. the corresponding author of the paper. Moreover, the radiosonde data are used in the paper for retrieving the IWV as stated in the next sentence and are clearly referenced in the corresponding radiosonde paper, where Acquistapace is co-author. For all these reasons, we do think that the usage that is done in the publication of the radiosonde data is clearly stated and that it would sound weird to describe such data in a different way, given the above-mentioned conditions.

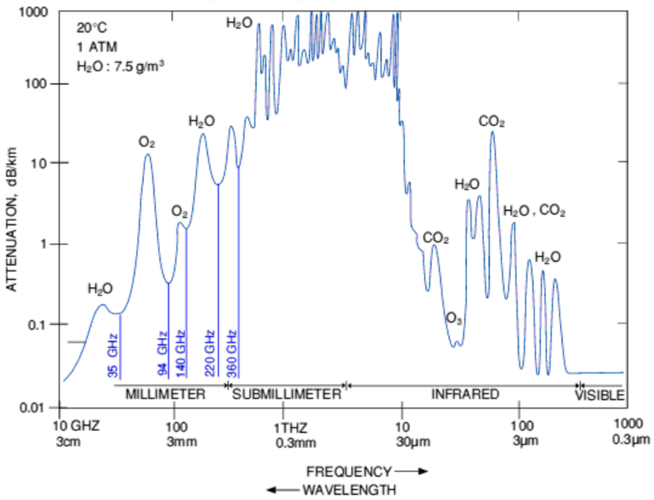
l.81: "descents". What is this?
As explained in Stephan et al, 2021, during EUREC4A not only the ascents of the radiosondes were used to collect observations of P, T, RH but also the descents. By means of a parachute located inside the balloon inflated from the ground, the sonde could fall gently after the breakup of the balloon at the highest point in the atmosphere, usually between 8 and 12 km. For each radiosonde thus, theoretically, we could obtain 2 profiles of the atmosphere.

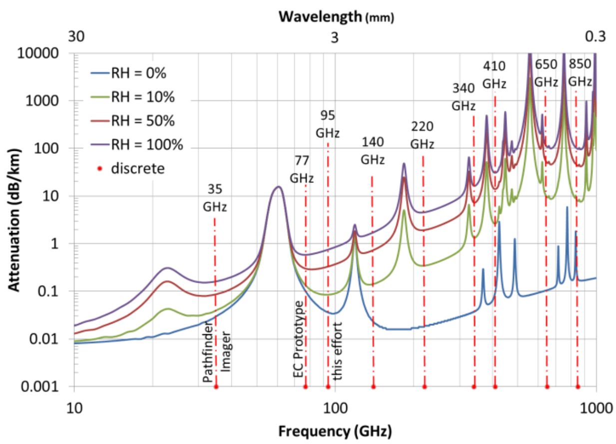
l.83: More pieces pop up. You never said that you will provide an IWV data set, did you?

We corrected that and now it is written in the introduction, together with LWP.

l.107: The ANN retrieval of the manufacturer is not documented anywhere? No reference?
The ANN retrieval is not yet published or documented by RPG.

l.114: Didn't you say that the atmosphere is relatively gas-transparent. How big are your errors? Usually other frequencies are used for IWV! Please comment. This probably only works, because of your dense and closely related radiosonde data? Which different radar "reflectivity values" are you talking about? Why plural?
The atmosphere is relatively transparent in the W-band (94 GHz), as shown in the figures below, but you can see that the response varies depending on the amount of humidity. This is why the passive channel at 89 GHz can somehow detect different IWV values in different conditions. However, much better retrievals can be obtained using a microwave radiometer and exploiting more channels between 22 and 32 and 51 to 58 GHz. Billault-Roux and Berne, 2021 (https://doi.org/10.5194/amt-2020-311) shows a similar approach using neural networks and also documents the lower accuracy of such approach based on a single frequency.
In our case, IWV is retrieved using a linear regression from IWV measurements from radiosoundings, collected during clear sky. To determine whether there are clouds or not, we use the Wband radar reflectivity, that is very sensitive to small cloud droplets. For a given time stamp to be considered clear-sky, all radar reflectivity observations collected in the vertical column of atmosphere should be < -50 dBZ. If such condition is met, then the time is classified as clear sky, and the radiosonde launched at that time is considered in the dataset for retrieving IWV.





sources for the figures: left : https://bit.ly/3qQV6te , right: https://bit.ly/3kTfVQV

l.132: I'm missing the products IWV and LWP.
LWP is mentioned among the integrated variables while the IWV is not stored in the output file because it has been derived just for the paper. The variable stored for future application is the brightness temperature at 89 GHz, as listed among the integrated variables.

l.142: Only this is where you should introduce the "PRO" part in MRR-PRO. "PRO" most likely is the "Professional" one. Only manufacturer terminology, but tell us.
As explained in the manufacturer page relative to the instrument, https://metek.de/product/mrr-pro/ the PRO stands to indicate that the new version of the

MRR is the development of the old MRR with the technique of the MRR-2 that displayed higher performances and significantly improved parameter estimations. After introducing the PRO suffix, we prefer to keep it in the rest of the paper, to highligh that the instrument deployed belonged to the new generation of MRR instruments, with much higher capabilities.

l.146: This sentence seems awkward. Please re-phrase.
At line 146 we found this sentence: "Details on the ship motion correction algorithm and the interference filter are provided in section 3.2 and 3.4, respectively. The data are organized in daily files and the variables provided after the processing chain described in Figure 3 are reflectivity considering only liquid drops, equivalent reflectivity non-attenuated, equivalent reflectivity attenuated, hydrometeor fall speed, spectral width, skewness and kurtosis of the Doppler spectra, liquid water content, rainfall rate, rain drop size distribution, raindrop diameter weighted over mean mass, time, height, latitude and longitude.

We removed Figure 3 and explained the postprocessing more extensively in the text, followed by the list of variables.

Fig. 3: This is "method" not "experimental setup", isn't it? Wouldn't this better fit into 3.2 or 3.4?
We changed the title of the section to "experimental setup and data processing", thank you for your comment.

Tab.1: "spectral bins", "spectral resolution". This refers to the Doppler Fourier spectrum?
The number of spectral bins is the number of points in the fft transform to derive the Doppler spectrum. They correspond to the resolution of the xaxis along which the Doppler spectrum is displayed. The spectral resolution, in ms^{-1}, expresses what is the width in $ms^{-1}$of a single spectral bin. The ensemble of spectral bins composes the x axis along which the Doppler spectrum is displayed.

Please clarify.l.167: At the end of this section. What are the limitations of this positioning correction?
The limitations of the stabilization platform correction are stated in the sentence: "It must be noted that the stabilization platform can compensate for the rotation of the ship but it cannot compensate for the vertical movements along the vertical axis (heave, etc.) and the translations which occur because the ship rotates around its center of mass while the instruments are located elsewhere (see Section 3)"
In the rest of the paper, we discuss extensively the limitations of the table's ability to correct also for the rotation of the ship. The paper is almost entirely about that.

What is the frequency of correction steps? And how does this fit to expected and observed roll and pitch values and radar sampling? Where do the mentioned 35% come from? Please clarify.

Correction is applied to each chirp radar time stamp. This means that is it applied at a time resolution higher than the time resolution of the radar, that is 3s. Specifically, the chirp integration times are given in Table 3. Let's consider a given time stamp of the radar from T1 to T2. The corrections are applied:

- at T1+0.846 for the chirp1 (radar range gates between 100 and 1233 m),
- at T1+0.846+0.786 for the chirp 2 (radar range gates between 1233 and 3000 m)
- at T1+0.846+0.786+1.124 for chirp 3 (radar range gates between 3000 and 10000m).

Note that the sum of the chirp integration times is 2.756 s, less than 3 s. The difference is an additional buffer time internal to the radar.
Roll and pitch values are provided with 1s resolution and the ones assigned for calculating the correction are the closest to the correction time stamp, as defined above, dependent on the chirp. It is clearly evident, thus, that using a higher resolution for the ship data (0.1 s instead of 1s) is crucial for improving the quality of the correction.

The 35% amount comes from the sensors of the table. Table measures roll and pitch as a function of time and whenever the table stops, no data are collected. By looking at the stable table time serie of data, one can easily calculate the amount of time the table stopped and the amount of time it was working.

Top paragraph on page 9 (line numbering mixed up): What is the frequency of MRU position measurements? You have not mentioned it anywhere.
It is 1s, it has been added. Thanks for the comment.

Page 9: There seems to be an 1,70 m offset between W-band and MRR. The image does not show this. Please comment.
Thanks for noticing the mistake. We assigned the same height to the two instruments, that is -17.40. The other measurement was taken when the stable table was off. The hydraulic pump that controls the table pistons, when turned on, pushes up the table and the instruments.

Fig 5: The combination of axes sketch and image in the back is confusing. First it looks as if you show a pitch angle. Then it takes some time to detect that you show an arbitrary combination of all three. Can you improve that? Maybe by changing the ship display and/or moving it away from the center of the figure? And where is the arrowhead of the y-axis?
Thank you for the comment. We tried in the new version of the manuscript to improve the figure. The arrowhead of the y axis, due to the 3d perspective, is not visible because it is in the dark circle. We modified the image.

l.200: "downdraft". The radar rather sees the downward motion of droplets and not the downdraft of the air. Please correct.
Cloud droplets have negligible fall velocities and therefore can be considered as air tracers. It cannot exist a downward motion of cloud droplets without a corresponding downward air flux. This is why generally we can talk about downdrafts also using radar observations. The measured fall speed is always a convolution of the air speed and the droplet fall speed. When drops have a non-negligible fall speed the radar measured velocity is a convolution of their fall speed and of the air velocity. Since rain while falling advects also air, there is also in this case a downdraft associated with the precipitation. This is why we talk of downdraft. We believe that this is the term that better represents the physical processes occurring in the situations observed in this paper.

L.215: Whole paragraph. Above you stated that you use a 20 min time window. Here you state that it is done for every radar chirp. Please explain at what frequency you derived the DeltaT. And please, say a few words about likely reasons of the time offset. I can imagine that a time offset of several seconds between instruments develops over time. An erratic variation over the campaign is something I would not understand.

We thank the reviewer for the comment. The correction is applied to hourly files. For each hour, we estimate what is the time gap that every chirp has (chirp time stamps are clarified above). Such time gaps are different, and this is why we have to do it for each chirp. We estimate one deltaT for each chirp, so in total, 3 DeltaT for every hour. To calculate a DeltaT, we consider a 10 minutes (sorry for the mistake, not 20) time serie of velocity measurements. The 10 minutes duration is necessary to guarantee enough data for the variance calculation, it corresponds to 200 time stamps (at 3 sec resolution). This choice is also due to the nature of these clouds, that often do not last more than 20 minutes in the observations. We average the time series over the chirp range gates, as described in the text, and calculate the variance. The DeltaT minimizing the variance var(DeltaV) is the delay for the chirp. The procedure is repeated for each chirp. Example time series are represented in Figure 6.

Regarding the reasons for the offset: We did all what was feasible to do on the ship to synchronize the instruments. The offset was observed and it is also visible in Figure 6 when comparing <vd> and W_signal. We hypothesize that it might be due to the hardware connections and computer synchronization, but we cannot prove this. Also, as mentioned in the chirp time description, there is an additional 0.3 s time that is necessary for the radar to switch from one chirp to the other and to a new chirp cycle. Some variability can be due also to this internal radar processing time.

l.233/234: Didn't you just explain the same facts using the terms v_d and v_hyd in section 3.1? Please explain the difference once more, if needed. Otherwise please adjust nomenclature and remove repetitions.

We did not really understand to which facts the reviewer is referring to. In line 233-234 there is "The Doppler velocity measured by the radar is the projection of the particle's velocity vector on the radar line of sight. Therefore, the component of the velocity vector of the hydrometeors w signal measured by the radar is positive when hydrometeors move upwards. "We thought that it would have been good to state again this simple convention before entering in a long derivation of vectorial equations where the sign of the vertical axis is actually crucial. Is this the point the reviewer addresses and the sentence to remove?

The reason why the concept is repeated is the following. The complete vectorial equation for the velocity observed by the radar is equation 2. For calculating the time shift, the formula is simplified by neglecting all v_radar components other than v_heave. This approximation is valid since the other terms V_course and V_rot are much smaller than v_heave.
To clarify better this point, we added the following sentence in section 3.1 from line 200 in the new paper version :
"By comparing the heave rate (thin blue line) and< Vd> time series (thick red line in Figure 6) we can derive the time lag ΔT. Cloud droplets have a vertical speed of w_hyd. The ship

is moving vertically due to waves with w_heave. To a first approximation, we can neglect additional contributions to the vertical motion of the ship (for the full vectorial equation see treatment in section 3.2). The radar measures Doppler velocity vd with respect to the instrument on the ship, hence vd = whyd + wheave.

We hope to have clarified the raised point. If not, we welcome suggestions from the reviewer.

l.259: Please comment on the need to label this data as "limited quality" here.
We thank the reviewer for the comment. In this part we just described the approach and we did not enter in the discussion of the quality of the correction. We just present how the correction is performed. Of course, such data have limited quality. However, this point is touched in the discussion on the plot of Figure 7, where the limitations of the approach when the table is not working are clearly displayed. This is why we did not opt for expanding on the data quality at line 259.

Page 13, bottom (line numbering broken again). “intensity” à “magnitude” of a vector?
We substituted intensity with magnitude.

L.268, eq 8: Reads like vectors are subtracted from a scalar?! It should be italic "v"s in the equation 8. On the other hand, it is not intuitive to label the z-component with another letter that "w"? Do you need another definition here? Please clarify and simplify nomenclature.
W is the z component. w_signal is coherently defined along z, while the other two terms are now in italics, representing the z components of the corresponding vectors. We believe the notation in this way is clear. We are sorry for the typo in the equation 8.

L.280: The first part of 3.3 reads slightly repetitive, apart from the horizontal wind influence. I think this part would better fit as last summarizing point in section 3.2.
l.284-292: This is why I'm still missing some information on accuracy of all these corrections in the different situations and some suggestions how to deal with them when using the data! Please add this information.
We decided to include the first part of 3.3 there as a sort of example application of the formulas derived in section 3.2. We believe it is better to separate the parts because section 3.2 is quite long already. We also think that it is important to discuss extensively the cases when the table is working and not working, supporting the discussion with Figure 7.

Regarding the accuracies: it would be fantastic to be able to provide an accuracy, because it would mean that we know the truth, regarding the corrections. Unfortunately, it is not so, and there is no reference to which we can compare to evaluate the correctness of the correction terms. We welcome any suggestion that can come from the reviewer on how to quantify the accuracy of the correction. From our side, we did our best to be rigorous and get the best data in the given conditions.

l.296: “Figure 7d)-h).” No d) and h) only show the platform status. e,f,g show the performance.
Now corrected to Figure 7 e)-g). We thank you for the comment.

l.302: “as described by looking at…” and Fig 8. …. I'm confused. I assume that this is a Fourier spectrum of the time series of vertical motion? Correct? In a certain cloudy range gate you can see the Doppler velocity fluctuation combined from particles’ fall speed and ship motion w_signal. You cannot see the "vertical motion of the radar" v_rad which results from the ship motion, can you? Please mention equations 2, 7 and 8 and explain better.Fig. 8: I guess it should be frequency in "1/s" or better "Hz" on the x-axis? And the top
label "periods" à “period”.

The figure shows the fast Fourier transform of various quantities. In panel a) the black line is precisely the FFT of the nominator of the correction term in equation 6, i.e. (V_wind_s – V_radar) * ep. Generally, V_wind_s has no vertical component (see appendix B), so the scalar product with Ep, when the table works, as it is the case for the figure 8, results in the z component of the vector v_radar, called v_radar_z.
v_radar_z is the resulting velocity “felt” by the radar, and it is given by the composition of the various contributions along z of the terms given in equation 7, namely V_trans = [0,0, w_heave] and V_rot = [v_rot_x, v_rot_y, v_rot_z]. Such contributions are w_heave and v_rot_z.

We compare the FFT of the v_radar_z with the FFT of v_rot_z and w_heave, to demonstrate that the main contribution to the signal comes from w_heave. The FFT of the V_radar_z (black) is basically almost entirely overimposed to the one of the heave (translational velocity, purple line). It means that the heave rate is the main contribution to the vertical motion of the radar, that is on the ship.

In panel b) we compare the signal measured by the radar w_signal (black line here, while in panel a) it was represented by the yellow line) with the FFT of the velocity seen by the radar after applying the correction with the time shift v_hydr, while in panel c) it is the same thing but without the time shift correction. The comparison of panel b) and c) is presented to show the impact of the time shift correction. Basically, the frequencies due to the waves are not removed in panel c, while in panel b they are smoothed in the pink line.

We changed the labels in the figure according to the explanation above and we modified the caption in the new pdf version. We thank the reviewer for the comment that helped us to improve the description of the figure. We hope that now it can be easier to understand the showed results.

l.308: Is this the right range? 0.5 Hz is in the middle of your x axis!? See next point.
0.2 Hz lays on the right edge of the lower axis, in correspondence of 5 s period. The 0.5 Hz is not included in the range of displayed values.

l.310: This smooths the part between above 0.1 = 10 s period, correct? Above you state the range 0.1 to 0.5 Hz which would be period range 10 s - 16 s !?
I am not sure I am getting right the reviewer’s comment here. The range 0.1 to 0.5 Hz corresponds to the range between 10s and 2s. We display the range between 10 and 5 s, which shows the mentioned increase of the spectra towards the Nquist frequency.

l.311: Confusing sentence. And basically, nothing you need to put into an equation. Mean

speed multiplied with time is distance. Remove it.
We thank the reviewer for this comment. We tried our best to discuss the limitations of the presented approach and quantify them. The horizontal resolution for the radar is a distance, and therefore this is why it was expressed as a product of velocity times the integration time.
We reformulated removing the product and the sentence reads now as follows: "However, the 9 s smoothing degrades the average horizontal resolution of the Vhyd, mean by a factor of 9. For an average ship speed of 3 ms^{-1}, the resolution would change from 3 m to 27 m, resulting in a slightly higher resolution than the vertical 30 m one. However, daily maximum speeds for the ship can reach also 9 ms^{-1}, producing thus a coarser resolution."

l.333: "Prominence" is not a mathematical term. Please define.
Prominence is defined exactly after mentioning the word, as the peak's ability to stand out from the surrounding baseline of the signal. This is the most understandable definition, that is also referenced in the description of the python routines to calculate such quantity: https://docs.scipy.org/doc/scipy/reference/generated/scipy.signal.peak_prominences.html

L339: "lowest 600 m". Please give the reason why this assumption/ condition is justified.
The reason for asking for continuity in the lowest 600 m for the mean Doppler velocity of the MRR is that this it approximately the height of the sub-cloud layer, where rain gets out of the cloud and reaches the ground/evaporates. MRR detects only rain, and had strong interference problems above such height. This is the range of heights where we are sure that the MRR can detect rain, so it is worth comparing in this region.

l.342: "abrupt"? Please explain a bit. What reason could there be to accept 2 or 3? The same is true for point 3 in l.343. At least explain why, if they are all found empirically.
All these conditions are posed empirically to remove the signatures due to interference. The way in which the interference pattern affects the mean Doppler velocity of the MRR is displayed in figure figure A1). In figure A1a) the mean Doppler velocity field is continuous where there is signal, and is it a sequence of very high and low values where there is noise. If one calculates the difference of consecutive values along the profile, it is clear that peaks appear whenever nearby values change from extremely high to low or viceversa. When there are just a few peaks (3, or 4) , it might still be the case that there is a real signal in the column. However, when there are more than 8, we experimentally found that those columns correspond to interference (like in Figure A1a) at 1:50.

l.373: I wonder if "flower" has made it to general technical language already. Please explain EUREC4A slang.
We added a peer-reviewed paper published where the flower type of cloud is introduced.

L378: "difficult to quantify". Uuh. Isn't this what a data publication should provide? Best estimates of accuracy of the published data? If you cannot provide any accuracy you should not publish it at all? Please think about a way to provide some estimate on this.
We already answered this comment at the very beginning, stating that providing an accuracy to radar moments is itself a research topic out of the goal of this publication. We also provide information on the correction and its limitation, for what is feasibly possible, as describe in the comments above.

l.385: “Fig 12 b) displays clear areas”. I'm confused. I don't see clear areas in b), I see them in a)? In addition, some explanation would be nice. Why is it clear in a) when I see large negative values in b)?

Thank you for the comment. We realized of an error in the plotting. We added and commented a new figure.

l.399: Please explain. LWP includes the rain. How does it contaminate the measurement?

Rain can make the radome of the 89 GHZ channel wet, degrading the signal. Normally values above 1000 gm-2 are flagged as rain.