Reply to Reviewer 2

We thank the reviewer for his review and his detailed comments.

Below you will find the reviewer's comments in bold and our replies.

This paper examines four methods for diagnosing pointing errors for the proposed WIVERN mission, which would use a Doppler radar performing a conical scan for wind measurements in cloudy areas. I think the title and introduction give the impression that errors are being corrected. However, I found the focus of the paper to be a little different, namely focusing on the errors in estimating the mispointing but not necessarily addressing the problem of correcting the pointing and the associated velocity. I think evaluation of the mispointing is definitely worthwhile, but the authors may want to consider adjusting the title and introduction. My other concern is that the nature of the pointing errors doesn't seem completely general. From Figure 1, it looks like the rotation axis is assumed vertical so that the only errors are a deviation from the elevation angle theta and a deviation of the azimuth angle from that estimated. This means that that the azimuth and elevation angles appear to be considered independently here. Should errors in which azimuth and elevation are coupled also be considered? Could such errors occur, as with a scan-axis mounting offset? Perhaps this is already included but it wasn't clear to me. Lastly, I think adding some additional math to describe each method may make the work considerably clearer.

We agree on the comment, the title is misleading, we will modify it as follow: "Mispointing characterization and Doppler velocity correction for the conically scanning WIVERN Doppler radar". The methods described in the paper do not correct the mispointing itself. In fact, for the mission, it is not paramount to have an accurate and precise pointing, but it is essential to have pointing knowledge within tens of microradians in order to correctly subtract the satellite velocity component along the antenna boresight from the measured Doppler velocity to retrieve the hydrometeor Doppler velocity. The methods quantify the mispointing angles and estimate the error induced by such mispointings on the Doppler velocity. Once the error on the Doppler velocity has been estimated based on Eq. 1, the Doppler velocity is then corrected. Yes, we assume that the azimuthal and elevation mispointing errors are independent one from the other, and further studies must be performed to better evaluate combinations of the two mispointing errors.

A_{roll}, A_{pitch} and A_{yaw} are the roll, pitch and yaw angles, respectively, that characterize a scan-axis mounting offset. If they can be assumed to be constant over time, they will induce the following biases in the azimuthal (e_ϕ) and elevation (e_θ) direction:

$$e_\theta(t) \simeq [-sin(\Omega * t) \quad \cos(\Omega * t)] * \begin{bmatrix} A_{roll} \\ A_{pitch} \end{bmatrix}$$

$$e_\varphi(t) \simeq [-\cos(\Omega * t) \quad -sin(\Omega * t) \quad 1] * \begin{bmatrix} A_{roll}/tan(\theta) \\ A_{pitch}/tan(\theta) \\ A_{yaw} \end{bmatrix}.$$

If A_{roll}, A_{pitch} and A_{yaw} are unknown and are assumed to be constant (e.g. due to the presence of a roll, pitch and/or yaw mispointing error caused by post-launch conditions), they can be retrieved using method #1 (A_x and A_y) and #2 (A_z). In this case, δz, (the difference between the altitude at which the surface reflectivity peak is located and the altitude at which we expect the peak is located) can be averaged over a period enough long (with respect to the azimuthal and elevation mispointing error frequency) so that the effect on δz given by the elevation (δθ) and azimuth (δϕ) mispointing is averaged to zero. Then, A_{pitch} can be retrieved by looking at the δz at the forward and the backward view. A_{roll} can be retrieved by looking at the the δz at right side and at left side view. A_{yaw} can be handled as a δϕ error and retrieved with method #2. If the reviewer thinks this should be added to the manuscript, we will include this in an appendix.

Equation (1): Please include a reference for this equation or a derivation, either in the text here or as an appendix. This would help with the concern about coupling between azimuth and elevation errors.

We will add the derivation in the text. The hydrometeor Doppler velocity, v_D, is obtained by subtracting the component of the spacecraft velocity, v_{SC}, along the antenna boresight from the measured Doppler velocity, v_{mD}. Thus, $v_D = v_{mD} - v_{SC}\sin(\theta)\cos(\varphi)$, where θ and ϕ are the elevation and azimuthal pointing angles, respectively, and with the second term of the equation representing the projection of the spacecraft velocity along the antenna boresight. If the actual pointing of the antenna has a mispointing of δθ and δϕ in the elevation and azimuthal angle respectively, the mispointing error will be:

$$\delta v_{mis} = [v_{mD} - v_{SC}\sin(\theta)\cos(\varphi)] - [v_{mD} - v_{SC}\sin(\theta+\delta\theta)\cos(\varphi+\delta\varphi)]$$

$$\frac{\delta v_{mis}}{v_{SC}} = [\sin(\theta+\delta\theta)\cos(\varphi+\delta\varphi) - \sin(\theta)\cos(\varphi)]$$

$$= [(\sin(\theta)+\cos(\theta)\delta\theta)(\cos(\varphi)-\sin(\varphi)\delta\varphi) - \sin(\theta)\cos(\varphi)]$$

$$\delta v_{mis} = v_{SC}[-\sin(\theta)\sin(\varphi)\,\delta\varphi + \cos(\theta)\cos(\varphi)\,\delta\theta]$$

Line 65: I would expand the phrase in parentheses for better clarity, for example changing i.e., to "is". Even more clear would be "forward direction is phi=0; backward is phi=pi"

We will expand it as you suggested.

Line 91: insert ",it " after "threshold"

We will correct it.

Line 100: For this technique, the delta-z is translated to a delta-theta via (2). The delta-z error comes from mis-estimation of the peak of the surface return, as shown in Figure 2. Are there additional uncertainties in apply (2) that would increase the delta-theta error, e.g., timing jitter?

Any phenomenon that might cause uncertainty in range determination, such as the timing jitter, will cause higher uncertainty in determining the delta-theta. But such uncertainties are assumed negligible in this study.

Line 125: I suggest expanding a bit on the need for flatness. While directly affecting the range to the surface, for method I, its effect on Doppler is not obvious. How would a surface with non-moving topography affect the measured Doppler? How much of the Earth's land would qualify as flat?

Figure 8 shows how much of the Earth's land can be considered flat based on different criteria. We are currently implementing a software to compute the surface reflectivity and Doppler return in presence of mountainous regions. But this is out of the scope of the present study.

Figure 7: what are the dashed curves?

The solid lines are referred to the forward pointing case (azimuthal angle = 0 degrees), while the dashed lines are referred to the side view pointing cases (azimuthal angle = +-90 degrees). We will add this description in the caption of the figure.

Line 167: In receiver mode, I assume that the ARC does not return a signal to the radar. If so, then this analysis uses the data recorded by the ARC. Further, my understanding is that the ARC will get scanned only once, so the example in Fig 9b is the data that would be recorded by the ARC on a single sweep by the

radar antenna. Hence, the ARC essentially records a cut through the 3D pattern. Due to the circular shape, the cut is slightly bent, as noted in the text. Is this a correct description of the ARC measurement? Assuming so, my further understanding is that for an azimuth error, there is a resulting time offset. Are there other, non-pointing, factors that could also cause errors, e.g. timing? What about ARC geolocation accuracy? Are there other error factors in the elevation measurement?

Yes, this is a correct description of the ARC measurement. Depending on different situations, multiple sweeps per overpass can be recorded by the ARC; however, we assumed that only one sweep would be recorded per overpass. Yes, there are some other factors that affect the accuracy of the ARC methodology to detect and correct the mispointing velocity biases. In our analysis, we assume that we perfectly know the geolocation of the ARC, the position of the spacecraft, the propagation time of the signal and the time at which the WIVERN radar send the pulses. Uncertainty in the knowledge of those factors translates in a further uncertainty in the detection and correction of the mispointing Doppler velocity error. We will specify this in the revised version.

Line 249: By "identical", do the authors mean equal magnitudes but opposite signs?

We mean equal in magnitudes and equal in signs. When WIVERN is looking at azimuthal angles differing by 180 degrees, the two ensembles of LOS wind velocities would be equal in magnitude and opposite in sign. From equation (1) we see that also the LOS wind velocity errors are equal in magnitude and opposite in sign. Thus, the errors in the actual wind velocity retrieved (not LOS) will be identical in magnitudes and signs. We will specify that in line 249 we are referring to the error on the actual wind velocity.

Line 259: My understanding is that this paragraph means that the A and D pdfs will converge to one if there is no azimuth error. However, if the two pdfs differ due to the azimuth error, the difference would continue with more data. is this correct - if not, please clarify. I think some minor editing to improve the clarity would be good. Also, I think the frequency of the error needs more explanation. If the frequency is much higher (faster) than the orbital frequency, then presumably both A and D pdfs are smeared; clarification would help. Instead of varying quickly, what if the bias is constant? I think showing equations for the winds and biases would make this much clearer.

The A and D methodology is applicable for azimuthal biases which are constant during very long time scales (e.g. monthly), thus, which remains constant along multiple orbits (i.e. their frequency is lower than the orbital frequency). Instead, if the error frequency is much higher than the orbital frequency, it means that the error would not be constant during several orbits, and this method is not enough fast to tackle it.

The crucial assumption for the methodology to work is that there is no diurnal cycle of in-cloud zonal winds. However, this hypothesis has been rebutted when looking at the ECMWF winds co-located with CloudSat CPR detected clouds. Therefore, this method is not applicable except for detecting large biases after long times. Yes, your statements on the A and D pdfs are correct. We didn't show equations for the winds and biases because this methodology does not work. However, the same kind of methodology has been used in the paper *Battaglia, A., Scarsi, F. E., Mroz, K., and Illingworth, A.: In orbit cross-calibration of millimeter conically scanning spaceborne radars, Atmospheric Measurement Techniques, 16, 3283–3297, https://doi.org/10.5194/amt-16-3283-2023, 2023* and we will add the reference to it.

Line 294: Please better define "all-sky" - is this all directions, instead of just sidelooking?

We meant "all-sky conditions". We will specify it in the text.

Line 305: The results of Figure 15 look promising. However, I'm not clear on how the statistics here translate to an uncertainty in the azimuth offset. An uncertainty of 200 urad is provided in the conclusions, but it's not clear where that came from. Please add a short discussion on how the 200 urad can be derived from Figure 15.

The uncertainty of 200 urad is not derived from Figure 15. Figure 15 and 200 urad uncertainty are related to two different techniques. Section 3 describes two techniques to detect and correct the azimuthal errors. The first technique (which does not work) is based on comparing the horizontal LOS winds at side views retrieved during the ascending orbit with the ones retrieved during the descending orbit. This technique has an uncertainty of 200 urad caused by the fact that there is a diurnal cycle in the in-cloud zonal winds (see Figure 14). So, 200 urad is the uncertainty related to the *ascending and descending orbit* technique.

The second technique consists in comparing the WIVERN H-LOS winds sampled at side views with the ECMWF winds. The pdf of the difference between these two winds is shown in Figure 15.