Author‘s Response Document

The following document contains two long tables with all comments from the two reviewers, along with the author‘s responses and text changes if applicable.

Table 1 contains the comments of Reviewer 1 (John Hubbert).

Table 2 contains the comments of Reviewer 2 (Anonymous).

Line numbers in the column „Where“ relate to the original manuscript. Line numbers in „Text Changes“ relate to the updated manuscript.

Reviewer 1 (John Hubbert)

Where	Comment	Answer	Text Changes
5	so that	fixed	5
10	improved performance. What about average transmitted power? I think the central issue is the SNR provided by the compressed pulse. If both transmitters have the same transmitter energy, the resulting SNRs for a particular target should be about the same.	We clarified the sentence. It now says that the SSPA has a better performance where the Magnetron's SNR is below 20dB. We agree that the SNR should be the same with the same transmitted energy, but only when the receiving chain is also identical. This is not the case. The SSPA uses different matched filters and the pulse compression, which change the received signal, and the noise measurement is different between MAG and SSPA.	10
14f	55 dBZ range-time side lobes.	changed wording.	14
58	dual-transmitter	fixed.	62
80	no comma	fixed.	84
87	define	RFHIC is the name of the company that manufactures the amplifier modules. We clarified the sentence.	93
124	have	fixed	130
129	1) a "high" Nyquist rate? 2) a fine range resolution for velocity? 3) a high granularity of velocity?	We meant a high Nyquist interval. The scans use either a very high PRF or a dual PRF with unfolding. We clarified this.	135
142	2 words	fixed.	148 (also 149)
148	-	fixed.	154
F3	were	fixed.	F3 (and all other

Where	Comment	Answer	Text Changes
			figures where applicable)
151	section?	Wording was changed.	157
153	hypen	fixed.	159
153	if	fixed.	159
156	hypen	fixed.	162
157	have	fixed.	163
159	, e.g.	fixed.	164
159	hypen	fixed.	165
159	and	fixed.	165
164	Normally called the co-polar correlation coefficient	Wording was changed.	170
167	Figs.	fixed	173
176	reflectivity	Wording was changed.	182
176	spatially smoother	Wording was changed.	182
186	spatially smoother?	Wording was changed.	192
190f	estimate	Wording was changed.	196
192	Sensitivity is usually given as the minimum detectable signal at some range.	Wording was changed according to this suggestion.	198: Sensitivity describes the smallest signal that is still detectable by the radar at a given range.
193	smaller rainrates	Wording was changed.	199
193f	dBZ0 sets the absolute calibration, while radar sensitivity is determined by the minimum detectable power. The two combine to determine the minimum detectable reflectivity (in dBZ). This introductory section needs to be "tightened up". Minimum detectable signal is not dBZ0 though closely related.	We rephrased most sentences here to clarify.	199: The sensitivity of a radar is determined by the smallest power still measurable by the receiver, usually given in dBm. Together with the calibration factor dBZ 0 , a range dependent minimum detectable reflectivity can be determined. dBZ 0 is measured during radar calibration for each transmitter and polarization.
203	cross-out; provides	fixed.	211

Where	Comment	Answer	Text Changes
204	cross-out	fixed.	212
208	described in Section 3.1.	Wording was changed.	216
217	the	Word inserted.	225
F5	histogram counts (?)	Wording was changed.	F5
222	Thus	Wording was changed.	230
246	SSPAs don't have a sensitivity. Sensitivity relates to the entires radar system.	We changed the wording to include the whole system.	254f: This relates to the increased sensitivity of the radar system with the SSPA transmitter.
252	indicates	Wording was changed.	261
264	do you mean that the SSPA data shows that more velocities are recoverable in the low SNR areas?	Yes, that was our intention. We changed the sentence to make this more clear.	273: Overall, the SSPA appears to be able to recover more valid measurements, [...]
F8/F9	Figs. 8 and 9 annotation needs to be larger for legibility.	We increased the size of all figures to span the whole page width in this new preprint. We hope that the annotations will be large enough for the final version.	All Figures.
285f	approach what magnitudes?	MAG velocities in the category 0 < TH < 20 dBZ approach those found in the class -20 < TH < 0 dBZ. The latter reflectivities are no longer measurable at a high range, and therefore the range gates contain only noise. The median velocity in noise converges towards 17m/s. We clarified the sentence.	295ff: As was already described above, MAG values in this range approach the magnitudes found in the lowest reflectivity category, which at that range contains only noise. The median velocity in noise converges towards 17 m s $^{-1}$.
286	cross-out	fixed.	297
293	data?	Wording was changed.	304
303	antenna pattern sidelobes or the range-time sidelodes due to pulse compression? Also, these figures should be enlarged to fit the width of the page. Then	Here we mean the range-time sidelobes due to pulse compression. The figures were enlarged and we changed the sentence to specify what place	314

Where	Comment	Answer	Text Changes
	you could insert circles to show the data to which you refer.	we are talking about. We rather would not insert any circles because this might lead the focus too much on the sidelobes, which are not the main focus of the discussion in this part.	
F10	for each transmitter?	Wording was changed.	F10
311	What about noise correction?	Noise correction is possible with our signal processor, but was not applied to the used uncorrected RhoHV. We added this to the sentence to clarify it.	323f: This can be mitigated using the noise correction suggested in Ryzhkov and Zrnic (2019), but was not done for this data.
313	The dependence of rhohv has been shown before (theoretically) and this should have reference.	Reference was added.	326f
315	Is this thermal radiation (blackbody)? If so, then this radiation is emitted by the ground and the antenna pattern will receive this radiation. Please clarify. This is not a function of the nearness if the ground. It's a function of how much of the antenna pattern intersects the ground. Rain also emits noise and can affect the noise floor.	As you suggested, we are talking about the ambient noise from the surroundings that is higher when the antenna is pointing towards the ground instead of vertically upwards. Thank you for your detailed comments on this part of the paper. We have re-written and hopefully improved large parts of it.	328-343
315	Do you mean ground clutter? The ground clutter would be the same both SSPA and magnetron transmitters? Or is this blackbody radiation? (thermal noise)	See above, it's thermal radiation from the surroundings, entering the system through the antenna at low elevation angles due to the intersection of the emitting ground with the antenna's main lobe.	328-343
319	If I am understanding you corectly, this is not true. The thermal noise increase depends on how much of the radar's main beam intersects the ground	Thanks again for pointing this out. We have removed all mentions of the noise being range dependent. As you explained, the range has nothing to do with it, but the elevation angle (and azimuth if the surroundings are heterogeneous) does. This part has been re-written. Please see the track-changes document.	328-343

Where	Comment	Answer	Text Changes
320	Be more specific here. If part of your radar beam intersects the ground causing the thermal noise to increase, that noise floor is seen at all ranges for that azimuth and elevation angle. The point you want to make is clear but the idea needs to be expressed more clearly.	The whole paragraph has been re-written and is now hopefully more clear.	328-343
321	specify what "high" here means.	The number is 0.99. We added it to the text.	335 / 349
321	What's the SNR when using pulse compression?	The 4.25 dB is the SNR after pulse compression. Without the compression SNR would be at negative values, mostly due to the high noise value caused by the large bandwidth of the modulated long pulse. The algorithm first adds the compression gain to the measured signal power and calculates SNR afterwards, using the noise measured with the long pulse.	
322	because the pulse compression increases the SNR. This is well known.	Correct, this is what we meant. The paragraph has been renewed, so this sentence does not appear anymore.	328-343
324	What does high mean here. I believe the equation says ~ 0.96.	Again, our threshold is 0.99. We added it to the new paragraphs.	335 / 349
324f	The DWD must measure the transmit phase of the magnetron and then recohere with that phase. What is the phase noise of the magnetron? You then can calculate the effect of that noise on rhohv.	Phase stability of the MAG system was estimated during installation by pointing the antenna at a strong stationary clutter target and converting the measured CCOR value into an equivalent RMS phase error using: shift in deg = 10^(CCOR/-20) * (180/pi) (Source: Stagliano Jr, J. J., Helvin, J., Alford, J. L., & Nelson, D. (2005, January). Phase noise, coherency, and clutter suppression. In 32nd Conference on Radar	

Where	Comment	Answer	Text Changes
		Meteorology, Thursday (Vol. 13)) The values were well below 1° and at 0.14° for the most suitable target, for which we measured a clutter power of -52.5 dB Could you please give us more information on how to get the effect on RhoHV from here? We are interested in trying this. We are also aware that this is not the best method to find the phase noise. We are planning to implement a suitable measurement in the future.	
325ff	This is imprecise. If the all else is equal (both SSPA and the Magnetron transmit the same amount of energy, then the matched filter bandwidths for each system will yield the same SNR. It's true that the SSPAs have very low phase noise and that fact may give you noticeably high rhohvs.	You are correct, the sentence has flaws. It is not any added noise due to the ground or clutter, but the noise in the SSPA short pulse is smaller than in the MAG due to a higher bandwith and a narrower matched filter which is necessary to separate the returns of the simultaneously recieved short and long pulses. This is now noted in the new paragraphs.	328-343
326	one word	This has been fixed in all occurences.	e.g. 336
330	but this is theoretically quantifiable.	It is and we plan to do some measurements for it. Unfortunately, our SSPA system is not running at the moment.	
332	but ultimately it is the gain offered by the pulse compression scheme that controls the SNR (along with other system components)	Correct, and thank you for pointing us towards this. As noted above, the whole paragraph has been re-written.	328-343
340	be more specific. yields a higher SNR	The sentence has been changed.	354f: Overall, this implies that SSPA has better sensitivity in the pulse compressed region, leading to higher RhoHV in weak precipitation, at the edges of precipitation

Where	Comment	Answer	Text Changes
			areas and also at a larger range compared to MAG.
344f	So, you are saying that then SSPA for your parameters yields a higher SNR and because of that, the rhohv values for the SSPA are higher than the magnetron? You stated above that it is difficult to estimate the SNR for the SSPA data. If this is true, then it will be very difficult to correct rhohv for noise as is done for NEXRAD and other radars. Is this the a deficiency for SSPA technology?	No, on the contrary we say that the SNR in SSPA is lower, but despite it being lower, it is still able to measure a RhoHV close to one. From our understanding SNR ist not harder to estimate, but the term is less clearly defined due to pulse compression and the required addition of returns from different frequencies. We do not yet know how this might effect the noise correction, but it might not be required as frequently, since the SSPA can recover a good RhoHV in weak signals.	
357	mostly? define define this more clearly	With increasing distance from the radar, the smallest measurable Z becomes larger and larger. Very small reflecitivities below 0dBZ can only be measured close to the radar. That means that most data points with such a low reflectivity in great range will not contain any meteorological or other signal, but only the reciever noise. We clarified the sentence.	371f: As described above, this reflectivity category contains less and less valid measurements with increasing range due to the decreasing sensitivity and consists therefore of mostly noise, [...]
366	What does convection have to do with the amount of ground clutter?	This sentence was misleading and was clarified. What we meant to say is that during the presented convective event, the rain cells contained a lot of rain, which gives higher reflectivities than 0 and 20 dBZ. Therefore, this class has less valid samples from precipitation than during the stratiform event.	380ff: Data from the convective case looks very similar, with the difference that the median RhoHV in the category between 0 and 20 dBZ is lower. We attribute this to the convective nature of the event: Most cells contain strong precipitation, so that they fall into the higher categories. The category from 0 to 20 dBZ therefore

Where	Comment	Answer	Text Changes
			consists of more range gates with clutter, where RhoHV is lower than in precipitation.
374	In what values? PHIDP? This sentence is not clear.	Yes, the values of PhiDP gradually increase. We clarified this sentence.	390
390	channels	fixed.	407
393	define	The "U" stands for uncorrected. We decided to just go with ZDR, because we use the uncorrected moments for all evaluations, as is specified in the beginning of Section 3.	410
406	How does this matching procedure integrate with the actual calibration of reflectivity?	We added a sentence to the first paragraph in this section that explaines the matching.	426ff: Raw power samples are taken during stratiform rain where the short and long pulse overlap. Long pulse power measurements are then iteratively corrected with an offset, until no discontinuity in the data between long and short pulse is visible. This offset is found to be constant over a long time under the assumption that neither pulse modulation nor radar hardware changes.
409f	Sentence is not clear.	We changed this sentence and the one before.	see above.
436	sometimes called range-time sidelobes	Wording changed.	455
439	15 km?	With our used pulse duration of 97µs, the pulse length is about 30 km. The range sidelobes can be seen over the whole span, with	

Where	Comment	Answer	Text Changes
		the actual strong target in the center.	
472	with shape gradients in range.	thanks for the suggestion. Reads now "strong meteorological targets with shape gradient in range"	491f
488	Not exactly true. What about trees swaying from the wind?	You are absolutely right. We changed the wording from "no velocity" to "low velocity" and limited it to "most of these scatterers".	507f: Due to the fact that most of these scatterers have a Doppler velocity close to zero, [...]
491	Not exactly true. All ground clutter observed with a scanning radar has a spectrum width. All spectra points within that width should be removed.	We changed the sentence to be more precise here.	510f: Spectral parts that are within a definable interval around the 0 m s −1 radial velocity are removed and interpolated, [...]
496	channels	fixed.	515f
499	-53dB <- 47dB. Are the quoted numbers wrong?	In our system's radar data, CCOR is by definition always negative. A CCOR of 0 dB means that there is no clutter power. A value of -30 dB means that the unccorected signal is 30 dB higher than the one correted for clutter. We added a sentence to the previous paragraph to explain this definition.	517f: Since clutter filtering removes power from the uncorrected signal, the correction is defined as a negative value.
499f	I believe the there is another factor causing this. All else being equal, the "coherence" of the SSPA won't cause such a difference.	We agree, that not all of the observed clutter suppression can be soley attributed to the coherency argument. Part of the improved clutter suppression (we expect about 3 dB) can be attributed to the better pulse-to-pulse coherence of an SSPA. The other half is attributed to the implemented pulse compression technique and the associated signal processing.	
508	All else being equal, the power measured by the SSPA and magnetron transmitter for a clutter target should be the same. The SSPA clutter power	The actual power measured from a clutter target is about the same in MAG and SSPA, but SSPA finds 10 dB more that it classifies as clutter. Simplified, that means	

Where	Comment	Answer	Text Changes
	is 10dB less than the power measured by the magnetron? Am I interpreting these number incorrectly?	that after a clutter correction, a 50 dB clutter target will still have 10 dB in MAG, but 0 dB in SSPA.	

Reviewer 2 (Anonymous)

Where	Comment	Answer	Text Changes
14	Is dBZ correct here? i.e. Is this really range dependent or should more accurately be described as a function of received power?	Thank you for this comment. You are right, this not range dependent. We substituted the dBZ with dB.	14
15	compressed / long	Wording changed.	16
16	has to be / needs to be	Here, we don't agree. It's "the effect" and "approaches", so plural seems fine.	
33	in terms of peak power, PRF, pulse width or duty cycle?	Maximum possible duty cycles. We have changed the sentence to make it more clear.	32f: as well as increasing failures when used with modern scanning strategies that require a combination of PRF and pulse width close to or at the maximum duty cycle.
42	To achieve equivalent sensitivity to a typical magnetron based system	Text adapted.	43
137	Phrasing. "the magnetron based volume begins the cycle" ?	Wording changed.	143
142	Is range bin usually one word?	No it isn't. We fixed this typo.	148
146	Sufficient for what / by what criteria? To match the Nsamples from an uncompressed pulse? But this may not account for the required decorrelation time of the precipitation But possibly for clutter filtering..	Here we meant a sufficient amount of samples to perform a meaningful Fourier transform for clutter correction. We added this to the sentence.	151f: Subsequently, the rotational speed of the antenna might have to be decreased to collect an amount of samples that is enough for a meaningful Fourier transform.
164	Co-polar cross-correlation	fixed.	170
179	While useful to separate the precip from the clutter provided by the alps, it would have been of interest to see if there are any impacts on the SSPA data from that clutter near the radar site. i.e.. very high SNR / returned	The Alps and the foothills are still very much in the 1.5° sweeps, as can be seen in the presentation of the range sidelobes. To avoid the summits, the antenna would	

Where	Comment	Answer	Text Changes
	power.	have to be set to about 3.5° EL. SNR for the mountains in the 1.5° EL sweep is between 60 and 80 dB SNR, so it's well within the linear range of the reciever.	
190	Check phrasing.	Wording changed.	196f
198	Valid at low elevations	Information added.	205
199	at a given range? 1km (?).	Yes, dbz0 is defined at 1km. We added this information.	206
221	Presumably the variability is due to noise breakthrough, rather than signal? it may be useful to comment on this.	We are not sure what the reviewer want to say here. Perhaps the discussion on RHOHV in section 3.4. is illustrative .....??	
265	note that this due to the increase sensitivity in the pulse compressed region.?	Information added.	274f: Particularly in the Northwest of the radar, at ranges larger than 150 km, the SSPA shows a better coverage with valid Doppler data, a consequence of the higher sensitivity of the SSPA system in the long pulse range.
290	Does the greater spatial / temporal variability in convective events and 5 minute scanning difference contribute to this?	Presumably not, since we use data from several hours for each transmitter and aggregate it. This should negate the influence of the 5 minute gap between the data sets. In the mentioned convective case, the median velocity was below 2m/s, so the lines for the different reflectivity classes could almost not be separated, and the distinction between weather and clutter was more difficult.	
305	Due to decreasing SNR: noise placing a limit on the maximum possible correlation.	Information added.	316f: MAG RhoHV gradually deteriorates with

Where	Comment	Answer	Text Changes
			increasing range due to decreasing SNR, [...]
318	The noise estimate should be independent of range as it contains no timing information. It will vary with elevation due to the increasing path length of dense atmosphere contributing to the noise power at low elevations.	We agree, we have renewed the whole paragraph about RhoHV and SNR and have removed all mentions of the noise being range-dependent. Please see the track-changes document for the new text.	328-343
319	Range should not matter - if there is a range effect this must be due to a signal that is related to the transmitted pulse, whereas noise represents a "constant" background power.	Agreed - see the previous comment.	328-343
324f	This is surprising given that rhohv is calculated on the basis of H to V correlation, which will be derived from the same split pulse in both cases? Coherency is more likely to have an impact from pulse to pulse measurements but less so here.	In this case we mean the coherency between transmitted and received pulse. The magnetron system uses a stable local oscillator to find the phase of the pulse. This can be imprecise and adds some uncertainty. The SSPA knows the transmitted phase by default. Despite this, we have removed the mention of coherency. Thanks to your and the other revewer's comments we are now able to explain the observations without it.	
326	It might help to explain this more - presumably the argument is that due to the lower sensitivity due to the lower power fill-in pulse some low intensity clutter is below the noise floor.	Correct. We have re-written large parts of this section. It should be more precise and clearer now.	328-343
332f	This is a surprising result - It would be expected that if the noise is a such a significant fraction of the signal, then a high correllation should not be possible. Very roughly, if SNR ~ 10dB correlations above around ~0.9 should not be possible. This being roughly as expected for MAG : ~20dB SNR being needed to archive a 0.99 correlation.	Please see the track-changes document, where we have explained this part hopefully better. The lower required SNR in the SSPA short pulse is because of the much lower noise than for the MAG pulse. The SNR of the modulated long pulse is caluclated by measuring the	328-343

Where	Comment	Answer	Text Changes
	Unless the SNR here is being calculated against the uncompressed pulse power. This would be unhelpful as the “true” ability to discern a signal would come after compression. However, this would still not explain the difference in the uncompressed region where a 14dB SNR should still be insufficient.. With the compression gain of ~16dB , 4dB would align the long pulse range however.	signal power, then adding the determined compression gain and finally removing and dividing by noise. Noise is magnitudes higher for the compressed pulse though, due to the large bandwidth.	
340	i.e. it has better sensitivity in the pulse compressed region.	Information added.	354f: Overall, this implies that SSPA has better sensitivity in the pulse compressed region, [...]
389	Could the slight difference in range sampling have an effect here?	Yes, this is possible. Thank you for this idea. The SSPA works on 30m raw and 240m processed ranges, so it uses the average of 8 gates. MAG uses 10. This might already work as some kind of smoothing process for the data before our calculations on processed range bin basis. We have added this to the manuscript.	405f: Clutter or range sidelobes might be responsible, as well as the larger amount of raw range bins being used for one processed range gate in MAG data, which works as a smoothing mechanism.
394	What was the value from zenith scans?	Thank you for the idea to check the birdbath scans! During the observed stratiform event from Dec. 2024 we find an average ZDR of -0.05 for MAG and 0.37 for SSPA. We are still not sure where this difference comes from and why we can't find it in the data from the 1.5° EL scans. We will keep investigating this issue. It might have to do with a melting layer that is visible with a low elevation angle, but too close to the radar for the 90° Scans so that it lies within the near field of the antenna.	

Where	Comment	Answer	Text Changes
407	Duplication	Fixed.	424
F17	It would be useful to have a better color table to show variations, in PhiDP in particular. Also, are these color blind friendly?	We changed the color table. We hope the differences now become clearer. It's not easy to find colors that at the same time can show the large span of PhiDP, but also the small gradients that are of interest. All figures in the manuscript were checked with the color blindness simulator under https://www.color-blindness.com/coblis-color-blindness-simulator/ to make sure that they provide at least some contrast under all visual limitations.	F17
474	in the radial direction	Fixed.	493
476	the	Fixed.	496
487	Yes, in the case of weather radar, however aviation radars would call weather the clutter. More generally clutter is not the target of interest.	We added that we talk about clutter in the context of weather radars here.	506
500	Is this actually reduced spectral leakage of the zero velocity clutter bin in to adjacent velocity bins due to reduced pulse to pulse phase noise?	Yes, we agree with your assessment and have changed the sentence accordingly.	521: The larger SSPA CCOR is in parts attributed to the improved pulse-to-pulse coherence of the SSPA compared to the MAG, resulting in less leakage of clutter power to adjacent velocities, and to combination of pulse compression and the associated signal processing.
511	were able to	Fixed.	534
544	And yet seemed to achieve 0.99 at lower SNR- which is not explained or backed up here	The section about SNR and RhoHV has been re-written in large parts. We have added the information that the SSPA short pulse has a much lower noise value due to a lower bandwidth and a	

Where	Comment	Answer	Text Changes
		narrower matched filter. Additionally it can be seen in our Figure 13 that the short pulse will not reach a high RhoHV over its whole range, but only close to the radar.	