REPLY to REVIEWER 1

We thank the reviewer for the insightful comments.

Here after you will find the reviewer comments in bold, our replies in italic.

One thing that could aid understanding could be a brief description of different types of radar models. As I understand it, the model described here simulates mean quantities and uncertainties, followed by generation of noisy samples (see my comment below). Perhaps a discussion of why this is used versus simulation of, for example, received amplitudes from collections of point scatterers. Another possible discussion would be validation of the model. Besides the one example in Section 3, were there other tests, either similar to Section 3 or perhaps idealized cases?

Yes indeed the model simulates mean quantities and errors as computed from theory for polarization diversity pulse pair. These errors proposed by Pazmany et al, 1999 have been confirmed by an airborne field campaign (Wolde et al, 2019). There are other simulators that compute I and Q time series like in Battaglia et al., 2013. This solution is quite demanding in terms of computational costs. There are no other simulators for conically scanning polarization diversity W-band spaceborne radars to our knowledge. We have tested our model with simple 1D scenes but a thorough validation is not that straightforward.

Are there plans to go beyond Mie theory?

Indeed the code accept look-up-tables (LUTs). Some of our LUTs are already computed with Rayleigh-Gans approximation, so there is no hurdles to include e.g. DDA computations. For preferentially oriented hydrometeors and dichroic media things are more complicated and they require a polarization-dependent treatment of backscattering and extinction. Some text to clarify this has been introduced in Sect.2.2.2. This is planned as future development (see new Table 2).

Antenna pattern – for example, a sinc function would be approximated as a Gaussian main beam plus sidelobes?

Yes, we have now implemented an antenna pattern with sidelobes. An example of such antenna has been included in the revised version. No appreciable differences have been noticed with such low level of sidelobes.

On page 12, line 20 "convoluted" is maybe better "convolved".

Corrected

My understanding from pp. 15-16 is that the theoretical uncertainties are used to generate properly distributed noise that is combined with the calculated means. Is this correct? Does the code also output the underlying means and uncertainties?

Yes exact, we have rewritten part of the text to make this more clear. In Fig. 15 right panel you can actually see the standard deviation errors associated to the Doppler velocities.

Maybe more details could be provided on the simulated brightness temperature, such as bandwidth, integration time, and resulting uncertainty. Are the brightness temperature samples computed the same way as radar observations, namely, by generating means and then adding noise?

Yes correct. Bandwidth and integration time are relevant for the computation of uncertainty. Uncertainties of the order of 3 K are expected for 5km integration and the current of bandwidth. .

I initially got confused by the text at the bottom of page 18, which mentions "Panel B" and Figures 11A and 11B. As stated it's all correct, but, for clarity, perhaps the discussion of Figure 8 could be its own sentence. This could be followed by new sentence, such as "For this full scan circle, Figure 11 shows the antenna weighted hydrometeor water content, as computed using the following".

Amended.

In Figure 12, why is the surface Doppler (height 0) in the lower right panel so weakly modulated by azimuth angle?

There is no azimuthal dependence expected for the Doppler velocity of the surface, which is assumed to have zero velocity. Note that the satellite velocity along the boresight direction is always subtracted out.

P. 21, around line 12 – not sure I understand the comment that "the ghosts are significantly smaller over land than over ocean". The effects in Figure 14 seem larger over land.

Thanks for pointing it out. Of course the sentence should read: that "the ghosts are significantly smaller over ocean than over land".

p. 25, line 10 – "20 full revolutions" – is this the same mean reflectivity and velocity but different noise or this is 20 different scenes from the full track?

20 different turns. We have clarified this in the text.

REPLY to REVIEWER 2

We thank the reviewer for the insightful and detailed comments.

Here after you will find the reviewer comments in bold and our replies in italic.

According to title and abstract, the paper aims to present an end-to-end simulator for the scanning Doppler radar WIVERN proposed to the ESA Earth Explorer program. Particularly with this aim, I find the paper too unspecific and lacking details, ie failing the traceability criteria. Also, the differences and novelty compared to Battaglia et al. (2018) do not become sufficiently clear to me.

We have tried to be more specific and detailed in the revised version. The main difference from the Battaglia et al paper is that in that case the simulation used a very simple 1D scene (reconstructed from CloudSat). In the current implementation the full 3D scanning geometry of the WIVERN satellite is implemented. This allows to account and assess how the quality of the Doppler signal will depend on the azimuth viewing angle. Also the simulator is now coupled with a full 3D cloud output which allows to evaluate the importance of non uniform beam filling errors. Finally, there is an orbit model coupled to the radar instrument model. This for instance allow to link the instrument model to errors like the mispointing errors which are orbit related. All these are completely novel aspects. See new text at bottom of page 3 and top of page 4.

On the other hand, I find the paper to focus a lot on the WIVERN instrument and its observation error analysis. While this is very valueable and fits the scope of AMT (while a simulator-focused paper would better fit into GMD according to my understanding), it should be reflected more clearly in title and abstract.

Comment received. It is true that we are focusing more at the observation error analysis. We have changed the title to "Observation error analysis for the WIVERN W-band Doppler conically scanning spaceborne radar via end to end simulations") and the abstract accordingly.

Major comments:

The introduction elaborates on aims and novelties of the WIVERN mission (far too much in my opinion, since this is supposed to be a simulator-paper, not a WIVERN mission paper), however I miss putting it in context with the past and current sat-borne radar missions CloudSat and, due to its Doppler capabilities in particular, EarthCare. Also, it lacks a definition of what is meant by "end-to-end simulator", incl. what it distinguishes from satellite, observation, or forward simulators or operators (at least in the understanding and usage of the authors) and a review of the state of the art in such simulators or operators. In that context, a definition or explanation what the authors mean by "polarization diversity" could be helpful, too.

We have introduced a paragraph where we explain the key differences with other simulators currently available (end of page 3 beginning of page 4). The Earth CARE simulator in particular is for a pulse-pair (not for a polarization diversity pulse pair system) Doppler radar, and it is not for a conically scanning. In its current version it has no mispointing error characterization, and a very crude surface modelling.

From the intro of Sec2, it is unclear to me whether the referenced literature describes approaches in general, or a specific algorithm or implementation of a module, and the following subsections do not make it clearer. Also, please distinguish between options available in the E2E simulator and specific setups used here.

These are the different modules implemented in the E2E simulator. Some of them are based on previous work and described in the literature. We have rewritten some of the introductory part of section 2.

It remains unclear, what the exact requirements are on the model input incl. which parameters are needed (which hydrometeor parameters specifically? temperature? etc.). Are the SAM data described in subsec 2.1 the only data the E2E simulator is/can be used as model input, or is this "just" what is used in the application examples later on?

SAM is what is used at the moment. We are currently working at interfacing the code with WRF. In principle any geolocated model output can be ingested. The model output needed are temperature, pressure and relative humidity plus the different hydrometeor contents (and particle size distribution assumption). This has been now specified in

Subsec 2.2.1 details the planned WIVERN orbit and observation geometry. However, how is this implemented in the E2E simulator? Are, e.g., the orbits hardcoded or can orbit parameters be changed, ie different orbital setups be explored? If so, what can the user specify?

Yes the orbit parameters can be changed. The simulator implements an orbital model deriving from the two-body problem theory, with the addition of orbital perturbations due to the J_2 *effect to simulate Sun-Synchronous orbits. The user can indeed modify the initial date and duration of orbital propagation and the orbital parameters. Knowing the satellite position vector over time and the scanning method, a vector-based approach is followed to localize the antenna boresight direction and the illuminated region of the atmosphere and the surface.*

Subsec 2.2.2 lacks almost all useful details about the scattering lookup tables like: which parameters are tabulated, bulk or single scattering properties? Over which tabulation parameters? where does the size distribution information come from and how is it taken into account? what dielectric property assumptions are made? how can lookup tables be generated, e.g. to switch to other scattering approximations like the mentioned Rayleigh-Gans?

We have bulk extinction, backscattering and scattering coefficients tabulated per unit mass as a function of characteristic size (mean mass-weighted diameter) and mu (Gamma functions are used). The model also use exponential functions for PSDs with specific assumptions on N_0. We have included all the requested details.

How are the empirically derived LDR linked to Mie reflectivities, is there anything to ensure a certain level of consistency? As LDR are derived based on ground-based observations - are they comparable to sat-borne measured ones?

AT the moment the LDR is not consistent with reflectivities but it is simply based on climatological observations. The LDRs are relevant when considering the cross-talk effects; at this stage we only want to see what is the climatological impact of the ghosts, thus we believe this is enough at this stage. We do not have any polarimetric observation from space-borne radars (even at lower frequencies) but there is no reason (apart from the increased footprint size and increased levels of multiple scattering) why sat-borne measurements should be different from ground-based ones. A new sentence has been introduced at the end of Sect.2.2.2.

Table 4 is never discussed nor mentioned in text. It's completely unclear what it is presenting and why it is there.

Yes Table 4 has been deleted. Thanks for spotting it.

Figure 6 seem to indicate that a plane parallel atmosphere model is used - is that so? Also, is the beam lobe modelled with a constant solid angle or a geometric distance opening (given values in meters, the figure seems to indicate the latter).

No, the model is full 3D, so the antenna pattern is currently modelled as a Gaussian main lobe. The simple plane parallel atmosphere was implemented in the 2018 version. The caption of figure 6 has been modified

For subsec 2.4, please give a short explanation what pulse pair processing is (or, what you mean by that).

The Doppler velocity in radar systems is derived by measuring phase shifts between successive pulses (pairs). We have introduced some explanation and references. See new text in Sect.2.3

Does the E2E simulator for the radiometric mode shortly mentioned as subsec 2.6 consider gas absorption/emission, too, or just hydrometeors scattering and emission/absorption contributions? If the first, what absorption model is used?

Yes gas absorption is included. The Rosenkraz model is used. We have included appropriate references to it.

For the case study (subsec 3.1), please be more specific: what date and time is that? what is the general weather situation? Where is the reader supposed to see "some strong wind shear" in the modelled scene?

You can see the strong wind shear in Fig.12 top right panel in the bottom right section of the scene.

For the figures in general, please consider the use of color schemes that are suitable for people with color vision deficiencies, preferably such that provide perceptual uniformity.

All figures with colorbar (12,13,14,15,17) have been changed. We have used colorbars recommended by https://ntrs.nasa.gov/api/citations/20180004634/downloads/20180004634.pdf.

For the case study figures, to allow easier comparison, please be so kind to use the same x-axis (incl. same axis parameters and units) for all of them (if using azimuth, axis ticks & labels at 90° spacing would be nicer and support interpretation better). Moreover, when discussing specific patterns in a figure, refer to the axis parameter used in that figure (in text, surface reflectivity is referred to in along track coordinates, while the plot is in azimuth coordinates).

Ok we have amended the figures accordingly (see new Fig.12)

For the list of problems to investigate in the future in Sec4, that by the way is quite specific compared to the rather indistinct description of the current state of the E2E in Sec2, it would be interesting to know, which problems require additional simulator development/implementations and which are rather setup changes.

We have added some text to explain this in Sect. 4.

Thanks for the list of specific comments that have been implemented in the revised version.