**Title:** Overview: Fusion of Radar Polarimetry and Numerical Atmospheric Modelling Towards an Improved Understanding of Cloud and Precipitation Processes.

**Reviewer#1**

**General Comments:** As the overview article for the PROM special issue, this manuscript provides a well-rounded description of the constituent PROM projects. Preliminary results and updates for each of the projects are included along with some context for where they fit into the current state-of-the-art understanding of combining radar polarimetry with models. Overall, the writing is clear and well-organized, with concise summaries of what has been found so far and what is planned for phase 2 of the project, although there are at times awkward phrasings and sentences that should be re-organized (some of which are addressed in the technical corrections). In general, given the scope of how many topics, projects, and data sources are covered in the paper, the large majority of comments are merely clarifying in nature, although some work is needed to make some of the formatting of the manuscript consistent throughout (e.g., abbreviations, date formatting, references, etc). Otherwise pending some of the requested clarifications I believe the manuscript can be published in the special issue.

We like to thank the reviewer for his/her time and valuable input which helps to improve our manuscript. Please see our replies highlighted in blue along with your suggestions. The revised manuscript is also provided with tracked-changes for clarity.

**Specific Comments:**

Line 24 (and 40): Is there evidence that can be provided that cloud and precipitation processes are "the" main source of uncertainty in NWP, or one among many? Consider changing "the" to "a".

The reviewer is right in pointing to a sloppy formulation here. In the entire process, it is only one of several important aspects (e.g. initial conditions in NWP and boundary conditions in climate projects are also very uncertain). We chose to switch to "a" main source of uncertainty in the Abstract, and are now precise in what we mean in the opening sentence of the Introduction by clarifying we mean it is "the" main source within the models themselves (and also provide a reference for this assessment).

Line 53: I understand what the authors mean by "the triangle" of polarimetry, models, and DA, but this phrasing is a bit awkward. Perhaps "tripartite" might work better here, or "the triangle between radar polarimetry…"

Yes, we followed your second suggestion and changed to "..the triangle between radar polarimetry, atmospheric models, and data assimilation and called for a coordinated interdisciplinary effort."

Line 62: Can the authors expand a bit on what is meant by "quantitative process detection"? Is this referring to things like Hydrometeor Classification Algorithms or more like a quantitative analysis of polarimetric fingerprints?

The focus is not on standard Hydrometeor Classification Algorithms (e.g. Dolan and Rutledge, 2009) providing the dominant hydrometeor type (ice, snow, rain, hail, or graupel) within a volume, but includes retrievals of more advanced hydrometeor partitioning ratios from radar observations, defined as the relative mass contribution of a specific hydrometeor type, or further development of polarimetric retrievals of hydrometeor mixing ratios, like liquid water content and ice water content including their accuracies. We also focus on a quantitative analysis of polarimetric fingerprints, e.g. aggregation and riming processes generate similar tendencies in ZH and ZDR. A more detailed quantitative analysis and/or the inclusion of additional (e.g. spectral) information may allow distinguishing between those processes exclusively based on weather radar observations. Another emerging field of research within the scope of SPP-PROM are thermodynamics, i.e. latent heat profile retrievals. We included for clarification in the manuscript: „…including a quantitative analysis of polarimetric fingerprints and microphysical retrievals,"

Line 76 and elsewhere: Inconsistent abbreviation for Section (e.g., Sec. vs. Sect.). I would tend toward not abbreviating it at all, but it should be consistent.

We cross-checked the guidelines of the journal: "The abbreviation "Sect." should be used when it appears in running text and should be followed by a number unless it comes at the beginning of a sentence." We changed it accordingly throughout the text.

Line 99: Do the authors mean fronts themselves or frontal precipitation being composed of these filaments? Please clarify. It is also not immediately clear to the reviewer how this portion relates to the rest of the paragraph/work.

We agree with the reviewer that this statement is not very clear, and since indeed it is not essential for the understanding of what we want to convey, we delete it in the revised manuscript.

Line 104: Please define the acronym ECHAM.

ECHAM is a general circulation model developed by the Max Planck Institute for Meteorology in Hamburg by modifying global forecast models developed by ECMWF (European Centre for Medium-Range Weather Forecasts). The model was given its name as a combination of its origin (the 'EC' being short for 'ECMWF') and the place of development of its parameterisation package, Hamburg. In the manuscript, we included a short note, that the acronym is a combination of ECMWF and Hamburg.

Line 113: I find the reference to the "ICON variants" confusing. Do the authors mean the NWP-scale ICON versions (i.e., those that inherited the COSMO microphysics)? Or do they mean the ICON model in general vs. either ECHAM or COSMO? Please clarify.

This was indeed an overly short and thus unclear formulation. We now write in a more precise formulation: "In PROM, primarily the ICON model is used, in its three different variants (ICON-LEM, ICON-NWP, and ICON-A/GCM)"

Line 118: Can the authors expand just a bit on what is meant by "intricate" here? Is it that the actual distributions are more intricate as is inherent to all spectral bin approaches or are there additional numbers of ice categories, etc?

We explain this now in a bracket, namely that ice - different from liquid-water droplets that are spherical and of constant density - may take different shapes and densities.

Line 132: This may be a bit pedantic, but I don't think it should be said that weather radars sample precipitation processes -- rather, they sample precipitation-sized particles from which ongoing microphysical processes can be inferred. Consider revising.

The text was revised accordingly: "… weather radars which provide a 3-D sampling of precipitation particles in the lower atmosphere above Germany every five minutes."

Line 144: While I understood the point, the phrasing "allow even more to zoom in" is a bit awkward. Consider "allow for a more granular look at"

The text was modified following the reviewer's suggestion.

Line 158 and elsewhere: There are various inconsistent date formats throughout the manuscript (e.g., line 917). Please make these consistent in "DD Month YYYY" format throughout.

The correct date format is used now.

Line 159 and elsewhere: There are repeated definitions of certain acronyms like JOYCE-cf, which has already been defined. Please revise so that each acronym is only defined once.

Thanks, we deleted the repeated definition.

Line 166: By "above -15C" I assume the authors mean (physically) above the -15C level rather than at temperatures above -15C, correct? Please clarify.

Correct, above -15°C refers to temperatures colder than -15°C (so at heights above the -15°C isotherm). This has been changed in the document.

Line 176: Please define acronyms "POLDIRAD", "DLR", "miraMACS", and "LMU".

POLDIRAD is the acronym for the C-band Polarization Diversity Doppler Radar at DLR, where DLR stands for Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center). The acronym miraMACS refers to the MIllimeter-wave cloud RAdar of the Munich Aerosol Cloud Scanner at LMU, where LMU stands for the Ludwig-Maximilians-University. We added this information where applicable.

Line 185: While it is still being developed, can a bit more be said about this retrieval algorithm -- what is it retrieving? IWC? Dm? Etc. What type of algorithm is it?

We added the missing details to the sentence describing the retrieval in development which now reads: "The measurements of Z, DWR and ZDR enter a retrieval algorithm currently in development where they are compared to T-matrix scattering simulations of horizontally oriented soft spheroids using a cost function minimization."

Line 191: What is meant here by "sound" statistical basis? Can more detail be provided?

Thank you for pointing out this inaccuracy! We replaced this adjective with a more explanatory sentence: "IcePolCKa compiled over 30 convective days of polarimetric measurements and simulations with 5 different schemes over a 2-year period, which is currently used to analyze how well these different microphysical schemes reproduce the polarimetric observations."

Section 3.1: Overall, it is not entirely clear to me the differences between IMPRINT and IcePolCKa, as they both utilize DWR and multi-frequency measurements (while IMPRINT admittedly also uses spectral polarimetry) and focus on ice microphysical processes. Is the primary difference the wavelengths used (e.g., Ka-W vs. Ka-C), or the fact that models are only a component in IcePolCKa? I believe there is easily room for both projects to exist given outstanding uncertainties in ice microphysics, but it might be helpful if they were explicitly contrasted so readers can understand where each of them fits in. (This is done well in the HydroColumn section on lines 199-203, which specifically notes the use of spectral analysis at C band which makes that project unique).

We thank the reviewer for this important comment. One new component of the IMPRINT project is indeed the combination of triple-frequency zenith pointing observations with spectral cloud radar polarimetry (as opposed to the C-band polarimetric radar of IcePolCKa). The use of W-band polarimetry allows as to be much more sensitive to smaller ice particles and lower particle concentrations as for example KDP scales with 1/wavelength. Furthermore, we are also using three vertically pointing radars at X, Ka and W-band frequencies, which provide us with additional spectral information, and a wider range of particle sizes can be characterized (DWR-KaW is sensitive to the early growth of aggregates, whereas DWR-XKa for the later growth). The IMPRINT project focuses on the understanding of ice microphysical processes, mainly secondary ice production and aggregation by combining the radar observations with a 1D Monte-Carlo Lagragian super-particle model, with which the processes of ice formation and growth can be studied in detail. The lagrangian nature of the model used allows us to track the particles formation and growth history, and with the newly implemented habit prediction scheme and fragmentation scheme we are able to test hypotheses which were made from studying the observations.

In contrast to IMPRINT, the IcePolCKa project explores the feasibility to narrow down ice crystal properties from spatially separated weather and cloud radars. Coordinated Range-Height-Indicator (RHI, varying elevation at constant azimuth) scans along the 23 km long cross-section between the two radar instruments allow to track and observe DWR and $Z_{DR}$ fingerprints of individual cells. *In IcePolCKa we furthermore study the ice particle growth and its role in precipitation formation within convective cells, while the IMPRINT project focuses on typical mid-latitude frontal clouds which occur most frequently during winter time. Convection would simply limit the use of Doppler spectral information (due to dynamical broadening, smoothing effects) which is one of the key approaches in IMPRINT. In IcePolCKa we currently develop an algorithm which combines Z,* $Z_{DR}$ *and DWR measurements from the spatially separated radars to retrieve IWC,* $D_m$ *and the aspect ratio of ice crystals. These parameters are retrieved iteratively using a least-squares fit between our measurements and T-matrix scattering simulations. Since we tried to find the simplest ice particle model, which is still able to explain our measurements, we used the model of horizontally aligned spheroids in combination with an effective medium approximation following Hogan et al (2012). In contrast to other studies our approach allows us to study the covariance of DWR and* $Z_{DR}$ *while seamlessly varying the particle density,* $D_m$ *and the aspect ratio. For this task, more* *sophisticated models, like DDA simulations of specific ice crystals, would introduce additional challenges to define the aspect ratio in the first place and make it hard to sort a collection of ice shapes along these free variables.*

We introduced the above mentioned explanations in the manuscript and tried to clarify the different focus areas of the two projects and hope it is now more clear to the readers.

Line 263: Is this cross-section reconstructed from a PPI or a true RHI? It appears to be the former but this should be added.

Yes, the cross-section is reconstructed from a measured volume scan. Following text has been added in the revised manuscript:

“Fig. 5 shows vertical cross-sections reconstructed from volume scans measured with BoXPol …”

Line 266: I am a bit confused by the sudden introduction of B-PRO, especially given the subsequent space dedicated to the polarimetric EMVORADO in 4.1. What are their differences and why would one be used over the other (e.g., in section 4.2.1)? A bit more info might be helpful here and explain why they are switched between.

Selection of B-PRO for this study was driven by availability: B-PRO was already available at the start of the PROM project, while Pol-EMVORADO has been developed within the project. Hence, the FO processing in the ILACPR sub-project was carried out using B-PRO (with some refinements done during PROM and benefitting from experiences and findings of the parallel Pol-EMVORADO development). Differences within the actual polarimetric FO parts of B-PRO and (Pol-)EMVORADO are rather minor. Preliminary comparisons exhibit only small differences that do not affect the conclusions of the ILACPR study.

However, EMVORADO itself has evolved significantly between the version B-PRO is based on and the current one, Pol-EMVORADO has been developed for and is integrated into. This includes all sensor characteristics: B-PRO is only capable of calculating radar parameters at (NWP) model grid points, and any sensor characteristics (other than radar frequency) have to be implemented by the users themselves. EMVORADO on the other hand considers the actual observation setup incl. tracing of the bending ray(s) through the 3D model fields, the beam pattern and beam broadening, allowing to consider the effects of attenuation. Furthermore, the current EMVORADO is much more computationally efficient by applying lookup tables that get calculated once if necessary (all described in detail in Zeng et al., 2016). Pol-EMVORADO makes all these new(er) EMVORADO features available also for polarimetric calculations.

Particularly at this place in the manuscript, we consider these details in history as of minor interest for the reader, hence prefer(red) to leave them out here. The features of (current) EMVORADO are listed in Sect 4.1 that covers the (primary) forward operator development within the PROM project. Following text has been added in the revised manuscript to clarify the reviewer’s concern:

“To generate the synthetic radar observations the Bonn Polarimetric Radar observation Operator, B-PRO, (Xie et al., 2021; Xie et al., 2016; Heinze et al., 2017; Shrestha et al., 2021b) has been applied. B-PRO is based on the non-polarimetric version of EMVORADO (Zeng et al. 2016); its code part for computing unattenuated radar reflectivity on the original model grid (Blahak, 2016) has been expanded to unattenuated polarimetric variables based on spheroidal shape assumptions (T-matrix). Because the full polarimetric version of EMVORADO (Pol-EMVORADO) as described below in Section 4.1 was only released very recently, the model data in this sub-project was processed using B-PRO. Preliminary comparisons between B-PRO and Pol-EMVORADO (not shown here) exhibit negligible differences in their results on the model grid, but Pol-EMVORADO would have been much more computationally efficient and would have allowed to take effects of beam broadening and attenuation along the actual radar ray paths into account."

Lines 275-277: Please move this information up to line 265 where the perturbed CN and INP are first mentioned.

Thanks, we followed your suggestion.

Lines 273-275, 277-279: These are interesting results -- can the authors add a bit about what they might imply, as is done for the subsequent ZDR column discussion? I would have expected higher CN to result in higher Z due to suppressed warm rain processes and enhanced growth of hail due to the availability of SLW which would cause higher Z as earlier studies have implied, but it seems this is not the case here. Also, the finding that IN doesn't seem to change the simulated polarimetric variables while Continental vs. maritime does (lines 277-279) is interesting and deserves further exploration, even if brief.

Based on the 2-moment cloud microphysics scheme with fixed shape parameters for the hydrometeor size distribution, we find that "high CN resulting in high Z", does not seem to apply for this case. The simulations with maritime CN produce low cloud droplet concentrations with relatively larger mean diameter compared to the continental CN. Accompanied by strong updraft, this also leads to high concentrations of supercooled raindrops above the melting layer with broader spatial extent (due to broader updraft region) compared to continental simulations. In terms of ice processes, the maritime simulation with low IN has a higher mean ice particle diameter, and also produces large size hail particles compared to the continental runs, resulting in higher Z.

Also, as shown in the time-series of the CAF, simulations with continental aerosol and default/high IN tend to exhibit similar behaviour in radar space, with the latter exhibiting higher CAF only at latter stages of the storm. The continental CN simulations with default and high IN differ in terms of simulated updraft speed and total hydrometeor content, being higher for the latter one. However, Cont-highIN produces relatively smaller size graupel and hail particles compared to Cont-defIN, resulting in similar Z.

The following text has been added in the revised manuscript:

"The simulations with maritime CN produce low cloud droplet concentrations with larger mean diameter compared to the simulations with continental CN. Accompanied by a very strong updraft, this also leads to high concentrations of supercooled raindrops above the melting layer with broader spatial extent (due to a broader updraft region) compared to continental simulations. This contributes to enhanced growth of hail, producing larger size hail particles compared to the the simulations with continental CN and contributes to an enhanced growth of hail resulting in higher Z. Also, as shown in the time-series of the CAF, simulations with continental aerosol and default/high IN tend to exhibit similar behaviour in radar space, with the latter exhibiting higher CAF only at latter stages of the storm. The continental CN simulations with default and high IN differ in terms of simulated updraft speed and total hydrometeor content, being higher for the latter one. However, Cont-highIN produces smaller graupel and hail particles compared to Cont-defIN, resulting in similar $Z_H$."

Line 305-306: This sentence ("An example…") seems out of place with the surrounding discussion since an example is already referenced in an earlier sentence.

We agree, these lines were disordered and related to 2 aspects: 1) uncertainties in bulk models in general and 2) determination of parameters that are not constrained by the model but are relevant to the forward operator. We revised as follows:

"However, bulk cloud microphysical parameterizations required for NWP models include assumptions on several critical parameters and processes which are not explicitly prognosed respectively resolved by the governing numerical model. An example are the inherently assumed particle size distributions and their relations to the prognostic moments (hydrometeor mass and number densities). Another challenge is the handling of hydrometeor parameters that are insufficiently or not at all unconstrained by the model's microphysics but are highly relevant for the calculation of virtual observations in the (radar) observation operator. For example, the melting state as well as shape, microstructure, and spatial orientation of the different hydrometeors are not prognostic (or not even implicitly assumed) in most operational bulk schemes. Therefore, suitable assumptions need to be made in observation operators in order to compute meaningful virtual observations."

Line 330: What is meant by "reflectivity weighting" here?

The beam pattern (or antenna pattern or instrumental function), ie. the different weight of the measured parameter depending on where within the sensor's (non-infinitesimal) field of view the signal is arriving. Reformulated as follows:

"The effects of neglecting radar beam pattern and broadening..."

Line 354: "Typical features" is a bit vague. Can the authors describe the features in Fig. 7 a bit more specifically?

We extended the sentence with the information "i.e. bands of enhanced $Z_{DR}$ and $K_{DP}$ in the DGL and decreasing but mostly positive values downwards to the melting layer."

Line 380: Isn't the DGL typically defined with its center around -15C (as stated on line 210)?

Yes, you are right. It is corrected in the revised manuscript.

Line 382: The polarimetric variables (e.g., ZDR and KDP) were defined early on but then occasionally re-defined throughout the manuscript (E.g., lines 382, 948, 959). These should be made consistent to (generally) always use the abbreviation once introduced.

Thanks, we clarified the distinction between the differential reflectivity in logarithmic scale $Z_{DR}$ and the differential reflectivity in linear scale $Z_{dr}$. However, to our knowledge it is fine, and sometimes also wanted, to repeat the definitions in figure captions, to enable the understanding of figures without the text.

Lines 391-393: Am I understanding correctly that this then implies a deficiency in the radar operator? That is, if the model is actually simulating significant graupel (even if erroneously) but the HMC applied to the simulated polarimetric observations does not identify graupel, that implies that there is an incongruence between the operator and the model physics, correct? This is an interesting finding but a bit more detail might be helpful.

There are deficiencies in the operator, but mostly regarding the representation of snow and more pristine ice particles (as outlined in the manuscript). Regarding the point the reviewer is addressing, we reformulated the sentence in the manuscript for clarification: "Applying the HMC, which is based on clustering, to the virtual observations, however, it does not reproduce a graupel layer of similar intensity (Fig. 8c), probably caused by a too strong ZH and temperature influence (compare with Fig. 7) relative to the polarimetric variables in the classification scheme which needs further investigation. A persistent challenge in according routines is, that clusters are always separated by the 0°C-level (e.g. Ribaud et al., 2019), i.e. hail or graupel are identified as clusters only below or above the melting layer."

Reference:

*Ribaud, J.-F., L. A. T. Machado, and T. Biscaro: X-band dual-polarization radar-based hydrometeor classification for Brazilian tropical precipitation systems. Atmos. Meas. Tech. 12, 811–837, 2019.*

Lines 406-407: The relevant letters in the full name of the project should be capitalized with the acronym wrapped in parentheses to match the other projects.

Yes, we changed it accordingly.

Line 477: Can the issues encountered with KDP data be briefly explained?

The authors studied a supercell case observed in Oklahoma and KDP values showed high observation errors as a result of contamination from wet hail, dust and debris and nonuniform beam filling. We added this information in the manuscript.

Line 488-489: This again may be pedantic, but I would rephrase this slightly. We have had 3- and 4-D mosaics of Z for a while now which do contain microphysical information about hydrometeors' size, concentration, and phase -- these are just severely underconstrained and underdetermined. Perhaps instead of "for the first time" the authors can say something like, "modellers now hold an unprecedented amount of microphysics-related…"

We like to make the comment that the microphysical information content of mosaics of Z regarding ongoing precipitation generating processes is very limited compared to polarimetric mosaics and also reflectivity-based microphysical retrievals like LWC and IWC show higher uncertainties compared to their polarimetric counterparts. However, we are also fine with your formulation and revised the sentence accordingly.

References: There are some inconsistencies regarding the formatting of the references (e.g. journal abbreviations (Monthly Weather Review vs. Mon. Wea. Rev, lines 836 vs. 840.), occasionally “pp.” before the page ranges, missing trailing periods, missing commas (E.g., line 740), etc).

Thanks, we went again through the references and we hope all inconsistencies are corrected now.

Figure 2: I believe the caption here is wrong, with b) and c) switched compared to the figure labeling.

Yes, we corrected it.

Figure 5: It was hard for me to see the grey lines in panel (a). Can these be made much bolder/wider?

Done.

**Technical Corrections:**

Line 26: Remove comma after “hypothesis” ->Ok

Line 28-29: “C band” → “C-band”-> OK

Line 32: “still considerable knowledge gaps exist” → “considerable knowledge gaps still exist”-> OK

Line 37: “it” → “this manuscript” or “this article”-> OK

Line 42: Remove “Since several years”-> OK

Line 46: “parallel to” → “parallel with”-> OK

Line 53: “called” → “call”-> OK

Line 56: “started” → “began in”-> OK

Line 83, 117: “cloud-” → “cloud”-> OK

Line 93: “still rudimentary” → “still-rudimentary”-> OK

Line 105 and elsewhere (e.g., line 423): “of the order” → “on the order”-> OK

Line 107 and elsewhere (e.g., line 418, 457): “currently replaced” → “currently being replaced”-> OK

Line 108: Add “the” before Max-Planck.-> OK

Line 118: “Hebrew University cloud model” → “Hebrew University Cloud Model”-> OK

Line 120: “by” → “to”-> OK

Line 136: Think an “and” is needed before “their observations”.-> We suggest to include “but”

Line 142: Consider changing “strength” to “magnitude”.-> We followed your suggestion.

Line 143: “differential change” → “differential phase” or “differential phase shift”-> Corrected.

Line 149: “at improving” → “to improve”-> OK

Line 153: “polarimetric” → “polarimetry”-> OK

Line 155: Should “Ze” be “Ze” here (as on line 232)?-> Yes, we adapted the formatting.

Line 160: “in about” → “at about”-> OK

Line 161: “in case” → “in the case”-> OK

Line 179: “23 km long” → “23-km-long”-> We think this is not correct?!

Line 182: “wavelength” → “wavelengths”-> The text is revised.

Line 191: Remove “E.g.”-> OK

Line 191: “Predicted Particle Properties” should be capitalized.-> OK

Line 210: No hyphen needed between Z and increase. -> Hyphen deleted.

Line 221: “thrives” → “seeks”-> OK

Line 237, 240, 255: “allow(s)” → “allow(s) us”-> OK

Line 238: Should “slanding” be “slanting” or “shifting”?-> Yes, slanting.

Line 268: Should 3.1 refer to section 4.1 instead? -> Removed.

Line 280, 282, 283, etc: No hyphen needed in ZDR column. Also remove “those”. -> Done.

Line 307: “interaction” → “interactions” -> Done.

Line 311: “Central” → “The central” -> Done.

Line 315: “up to now” → “up-to-now” -> Done.

Line 320: Should “access” be “accesses”? -> Done.

Line 331: “fall speed” → “hydrometeor fall speeds” -> Done.

Line 349: “as” → “are” -> “Assuming hydrometeors as” changed to “Modeling hydrometeors as”

Line 356: “in large” → “into large” -> Done.

Line 373: “grid-point” → “gridpoint” -> Changed to “grid point”.

Line 375: “within and below the melting layer (ML)” to the end of sentence -> Done.

Line 377: “leading in” → “leading too” -> Reformulated.

Line 380: “centred” → “centered” -> We are using British English.

Line 383: hyphenate “COSMO-simulated” -> Reformulated.

Line 387: “NWC” → “NWP” -> Done.

Line 401: Change hyphen to comma. -> Done.

Line 466: Remove comma after “Both”-> OK

Line 485: Hyphenate “as-complete-as-possible”-> OK

Line 486: Missing “-art”-> Included

Line 494: “microphysic” → “microphysics”-> OK

Line 496: Add “The” before “Developed”-> Included

Line 505: “made progress” → “progress made”-> OK

Line 958: “imulated” → “simulated”-> Corrected

Line 960: “together” → “together with”-> Corrected

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**Reviewer #2**

**General Comments:** This paper provides an overview of the German DFG Priority Program "Polarimetric Radar Observations meet Atmospheric Modeling (PROM). This was a program that has undergone its first 3 years of research and this article serves as an overview article that apparently will follow this article in the journal. The paper provides a short background to the program and then goes through each project one by one and gives an overview and short overview of each project within the priority program. The paper reads very much like a summary report intended for funding program managers rather than a scientific article dissemenating scientific results, in which very little background, prior research, and interpretation is given to each result shown. There also aren't any links to findings of the present project, which will apparently follow in the special issue (surely these papers must be submitted or close to submitted if the reviewer understands correctly?), but there aren't any pointers to those papers or other articles that came out of the first 3 years of funding. In addition, future directions of the project are not given. Since I do not have the full information about what the role of this article is, I will let the editors decide what to do with this paper. However, I do believe that the scientific community would benefit from a review article that pointed better to the published literature, current, and future work of the project. Thus I recommend returning the paper with major revisions.

We like to thank the reviewer for taking the time and the valuable inputs which helped to improve our manuscript. Please see our replies highlighted in blue along with your suggestions. The revised manuscript is also provided with tracked-changes for clarity.

**Major comments**

1. The paper has an inconsistent and overall light level of citing relevant prior literature when new concepts are introduced. A review/overview article should do a careful job in doing this. In looking at the citations, most are before 2015 and there are only a few since then. It seems like these citations are mostly from prior proposals/working documents? I suggest updating the article to have a more comprehensive/up to date bibliography. Also in the text, highlight and differentiate what has been found that is **new** rather than just a repeat/extension of what has been done already in the literature.

Thank you very much for pointing this out. The revised manuscript provides an up to date bibliography and more clearly differentiates between new findings and what has been done already in the literature. In the following the authors of all contributing projects comment on the changes made if any.

**Operation Hydrometeors:** We have revised Sec. 4 & 4.1 to more explicitly cover the state-of-the-art / recent developments in polarimetric forward operators and how the developments presented here relate to them. In particular, we have added a paragraph on forward operator (FO) efficiency both in the text parts reviewing the state-of-the-art and challenges (Sec. 4) and describing Pol-EMVORADO development (Sec. 4.1). We have also added a concluding statement summarizing what is new (or rather unique) about the (Pol-)EMVORADO operator.

Furthermore, the paper by Besic et al. (2018) is the most recent and first paper dealing with the derivation of hydrometeor mixing ratios. Thus, in contrast to previous studies, the authors do not restrict to the determination of the dominant hydrometeor type. Within this project, we have modified the approach by Besic et al. (2018) as documented in the conference paper by Pejcic et al. (2021); an according publication in a peer-reviewed journal is also planned. Other more recent publications since 2015 dealing with hydrometeor classification, e.g. using a Bayesian approach (Yang et al. 2019) or Neural Networks (Lu and Kumar 2019), again restrict to the identification of the dominant hydrometeor class. Referencing these would go beyond the scope of this publication.

**IcePolCKa:** We have added references to more recent literature. This refers to the following sentences: It is well known that cloud microphysics introduce substantial uncertainty to NWP simulations (e.g. Morrison et al., 2020, Xue et al., 2017). Rigorous uncertainty quantification on a statistical basis could help to pinpoint the underlying microphysical processes (Morrison et al., 2020).

**IMPRINT:** We have extended the number of references to previous literature regarding spectral polarimetry and combined multi-frequency observations of the dendritic growth layer as suggested by the reviewer. We further rephrased large parts of the IMPRINT paragraph to better differentiate between results and signatures known from previous literature and the new findings coming out of the analysis of our novel observational dataset (please see also major comment 2).

**ILACPR:** We have added up to date bibliography where applicable. Particularly, citations to the findings of the present project have been added (Shrestha 2021; Shrestha et al. 2021a, b) which includes published and submitted manuscripts:

"TSMP was found to generally underestimate the convective area fraction, high reflectivities, and the width/magnitude of so-called differential reflectivity (ZDR) columns indicative of updrafts, all leading to an underestimation of the frequency distribution for high precipitation values (Shrestha et al. 2021a). A decadal scale simulation over the region using the hydrological component of TMSP also showed that much of the variability in the simulated seasonal cycle of shallow groundwater could be linked to distribution of clouds and vegetation (Shrestha 2021). This additionally emphasizes the importance of model evaluation to represent clouds and precipitation processes."
The new findings including results which confirm previous findings have also been highlighted in the revised manuscript.
**POLICE:** To our knowledge, Ryzhkov et al. (1998), Nguyen et al. (2019), and Murphy et al. (2020) are the only articles where polarimetric microphysical retrievals are evaluated using aircraft microphysical probes. While the first two listed were cited already in the first version of the manuscript, we now also included Murphy et al. (2020). Colleagues from Oklahoma University are currently finishing an evaluation paper exploiting the IMPACTS campaign, but it is too early to reference it. Within the POLICE project, an evaluation paper exploiting the OLYMPEX campaign is in preparation (see your major point 2).
We now also referencing Carlin et al. (2021) in the revised manuscript with respect to their published polarimetric microphysical retrievals.
**PARA:** We also updated our references (in fact, one - new IPCC AR6 instead of AR5, but we had many references newer than 2015 anyway).
**HydroColumn:** Further relevant references were added. The novelty of using Doppler measurements from vertically pointing (longer-wavelength) weather radars within an operational scan strategy is stressed in the revised manuscript, based on one case study where airborne in situ measurements were available for a comparison with the recorded radar signatures.
**REDPOL:** This project cited already very recent literature, thus no updates have been performed with respect to this point.
**PICNICC:** We added new references into the description of the PICNICC project presented in section 3.2. The newly added references Matrosov et al. (2001), Radenz et al. (2021), and Vogl et al. (2021) provide more details on the applicability of the SLDR for shape observations, the suitability of the used measurement sites for inter-hemispheric aerosol contrast studies, and the detectability of riming, respectively.
2. Are the figures in this paper from publications or are any publications that have arisen from or will be part of this collection or are anticipated to be submitted? Overall, I felt that the text read in the future tense quite often (written like a proposal, identifying goals) rather than summarizing exactly what has been accomplished in the first 3 years of the project. With the renewal of the funding for the program presumably coming up - I would think that it would be in the interest of the program participants to put their best foot forward and highlight their results rather than reiterate their proposal from several years ago. Even if this will be done in subsequent publications - I believe that this article should point to those results.
**Operation Hydrometeors:** We have revised the wording to more clearly separate problem description, starting point and achievement of the project as well as remaining challenges and options/plans to tackle those. Here, we only give a rough overview of what has been performed and summarize achievements. Details are subject to separate publications within this special issue (Shrestha et al., 2021b; Mendrok et al., 2021). And as outlined under major point 1, as follow-up of the conference paper by Pejcic et al. (2021), a publication in a peer-reviewed journal (most likely within the special issue) is also planned concerning the advanced hydrometeor classification and quantification algorithm.

Overall, the illustrations presented in this chapter have been prepared specifically for this paper and not yet been made public otherwise. However, they are at least partly related to subjects studied in detail in the separate publications.

**IcePolCKa:** As requested by reviewer #1, we introduced a whole paragraph to clarify the different focus areas of IMPRINT and IcePolCKa from an observational standpoint. Here, we explain in detail the novelty of our approach and our progress (we proved the feasibility to narrow down ice crystal properties from spatially separated weather and cloud radars). In the observational part of IcePolCKa we finished to develop an algorithm which combines the Z, ZDR and DWR measurements from the setup of spatially separated radars to retrieve IWC, the mean particle diameter Dm and the aspect ratio of ice crystals. Details are described in our study Tetoni et al (2021) which we recently submitted to AMT. Furthermore, preliminary results from the ongoing NWP studies were added (Köcher et al, to be submitted). To that end, we supplemented the following paragraph: Within our study, a setup for systematic characterization of simulated microphysical processes in NWP models in comparison to fingerprints in radar observations has been implemented: [...] To that end, a cell-tracking algorithm (TINT; Fridlind et al, 2019) facilitates comparison on a cell object basis [...] Comparison of macrophysical cloud characteristics, such as echo top height or maximum cell reflectivity, in general show that the model simulates too few weak and small scale convective cells, independent of the microphysics scheme. Contoured frequency by altitude distributions (CFADs) of simulated and observed radar signatures are used to reveal deviations in ice and liquid phase. Preliminary results indicate that the P3 scheme is best representing radar signatures within the ice phase, while a spectral bin scheme tends to better simulate radar signatures within rain, where all other schemes have issues in correctly reproducing observed ZDR features.

**IMPRINT:** Similar to IcePolCKa, we have clarified the different focus of IMPRINT compared to IcePolCKa, as requested by reviewer 1. Figure 1 has not been used in any other publication. Only a small number of previous studies have combined multi-frequency radar observations with radar polarimetry. To the authors knowledge, our observational setup is the first which analyzes the Doppler spectral information of both the multi-frequency and the polarimetric observations. We have changed our paragraph to highlight our new approach and demonstrate the added value in our case study.

**ILACPR:** The tense has been modified to summarize the accomplishment in the first 3 years of the project. The results and figures presented in the section have not been previously published and are part of forthcoming manuscripts for the special issue.

**POLICE:** No figures of our upcoming publication regarding the evaluation of microphysical retrievals with in-situ measurements are included in the manuscript. Instead, panels g) and h) in Figure 7 compare simulated and polarimetry-derived ice water content to illustrate the application of such new microphysical retrievals for model evaluation.

**PARA:** No future tense in our bit, and we did present results.

**HydroColumn:** The results and the novelty of using Doppler measurements from vertically pointing (longer-wavelength) weather radars within an operational scan strategy are stressed more in the revised manuscript (as opposed to prior work that has mostly focused on analyzing Doppler spectra from higher-frequency cloud research radars for the interpretation of clouds and precipitation).

**REDPOL:** Figure 6 is not published previously. It uses the newly developed polarimetric operator Pol-EMVORADO on the results of data assimilation of radar reflectivity and radial velocity. Data assimilation experiments were performed using uncertainty quantification methods investigated during the first phase. Further investigation of these results for a longer time frame will most likely be a part of a manuscript submitted in the future.

**PICNICC:** We specifically prepared figures for this manuscript and do not refer to future plans.

3. The grammar in the article is quite variable from section to section. I suggest individual editors pass through the document to harmonize the voices, tenses, word usage, and punctuation throughout the document.

The authors now went again carefully through the text to improve and harmonize our manuscript. Please see also the version provided with tracked changes visible.

4. Many of the papers figures show illustrative points rather than any scientific hypothesis test or addressing any particular science question quantitatively. I will just point this out to the authors and the editor. It may be appropriate for this "prospectus" of the program, but as being tasked as a reviewer of this paper without any special instructions I just want to point this out.

**Specific comments:**

1. L24: "the main" may be overstating the importance - it is really one of many according to the IPCC, etc.

Agreed, we soften this to "A main source…".

2. L28: the usage of "e.g." is not standard in the document. Suggest finding/replacing with, "for example" or "such as".

To our knowledge the use of "e.g." is fine. Copernicus' "English guidelines and house standards" (https://publications.copernicus.org/for_authors/manuscript_preparation.html#english) as well as other recent articles published in ACP (see for example Kutzner et al. and Das et al. listed on https://www.atmospheric-chemistry-and-physics.net/) make use of it as well. Hence, we prefer to keep it as is.

3: L29: national weather service is a proper noun?

No, it is used as common noun here.

4. L32: suggest changing "higher moment" to "complex" as more species are also being introduced in addition to more moments.

Thanks, done.

5. L32: suggest moving 'still' to after 'gaps'.

Done.

6. L40: this sentence is redundant with what has already been said.

Yes, but it was just the abstract. We would prefer to keep this sentence.

7. L42: "Since" -> "For"

We changed it as follows: "A wealth of new information on precipitation microphysics and generating processes can be gained from observations…"

8. L46: "parallel to" -> "parallel with"

Corrected.

9. L47: what is "their"?

We rephrased the sentence: The synergetic exploitation of polarimetric precipitation radars together with measurements from cloud radars and other instrumentation available at supersites and research institutions enables for the first time a thorough evaluation and potential improvement of current microphysical parameterizations based on detailed multi-frequency remote-sensing observations.

10. L53: suggest inserting "consisting of" after "triangle".

We inserted "between" after "triangle".

11. L53: "and" -> "which"

We prefer "and", otherwise it will be the second "which" in this sentence.

12: L53: change subscript quotation to superscript for English"?

Done.

13. L59: just speak of the "triangle" rather than listing all 3 again?
Please, let us repeat them once more.
14. L88: "hardly" -> "poorly"
Done.
15. L88: what are "these"? Processes?
Reformulated to make the sentence more clear.
16. L90: suggest removing "will".
Yes, thanks.
17. L91: suggest adding "and including" before "the scale".
Agreed and included.
18. L94: who is "they"?
The models. We clarified it in the manuscript.
19. L94: induce*d*
Why past tense? We would prefer to keep 'induce'.
20. L98-99: needs a citation
The sentence is no longer included in the revised manuscript.
21. L116: needs citations.
Reference added.
22. L127-130: This sentence could use some more context.
The explanation is now expanded.
23. L135: improve*s*
Done.
24. L137: needs citations
As examples we included Gao et al., 2011; Jung et al., 2012, You et al., 2020, and Wang et al., 2020.
25. L144: please reword "even more to zoom"
We wrote now "allow for a more granular look at…"
26. L172: references to spectral polarimetry literature could help in this paragraph
We added more literature regarding spectral polarimetry to the IMPRINT paragraph.
27. L184: "ambiguities in ice crystal size and ice water content" - this is not a complete idea - ambiguities in retrieving these geophysical variables?
Exactly, we clarified it in the revised manuscript.
28. L193: remove "a"
Done.
29. L199, add comma after "date"
Comma added.
30. L201: e.g. -> such as
'such as' is already used in the same sentence; 'e.g.' makes sense here and is non-repetitive in contrast to the reviewer's suggestion, so 'e.g.' is again used in the revised manuscript.
31. L218: again, missing references to prior work
Following the reviewer's suggestion, references to related (recent) work were added.
32. L240: "allow to retrive" -> permit the retrieval of
We rephrased to "allow us to retrieve the vertical profile of the hydrometeors"
33. L253: noticing tense is future. see major comment above. This reads like a proposal rather than results and findings.
We have rephrased the section to address the reviewer's concern - summarizing the accomplishments of the first 3 years, pointing to the results and findings and fixing the tense accordingly.
34. L334: use of e.g.
We prefer to keep it. Please consider our feedback to comment #2 above.