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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Microphysical Properties of Three Types of Snow Clouds: Implication to Satellite Snowfall Retrievals" *by* Hwayoung Jeoung et al.

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Line 23: Specify the region of the study. Different regions may show different snow characteristics.

Indeed, the characteristics are region-dependent. We added the phrase "over Pyeongchang area in the east coast of the Korean Peninsula".

Line107-110: What does it exactly mean by this? Still explaining the Bayesian algorithms? Please clarify.

Yes, here we are still explaining Bayesian algorithms. To clarify, this sentence is rewrit-

ten as: "The snowfall rates in a Bayesian algorithm database are often retrievals from radars and the brightness temperatures are either those collocated measurements of passive microwave radiometers or simulated by radiative transfer models."

Line 135: It would be helpful for readers to specify the greatest DTB, and the thresholds for each very shallow or very deep.

This sentence is revised as: "The results show that the discrepancy between simulated and observed brightness temperatures is the greatest for very shallow (cloud top around 2 km) or very deep (cloud top around 8 km) snowing clouds with discrepancy value being over 10 K in the former and over 30 K in the latter case, although it is generally less than 3 K when averaged over all selected pixels under snowfall conditions."

Line 139: Please clarify the sentence. Add more explanation if needed.

This sentence is revised as: "For very shallow snowing clouds, cloud liquid water may be rich and contributes substantially to the observed brightness temperatures. However, the radiative transfer model, which uses CloudSat radar and GMI retrievals as input, failed to account for this liquid water abundance, resulting in a large discrepancy between simulated and observed brightness temperatures."

Line 145 One additional sentence would be desirable to explain an object of the field study. & Line 146: Any reference for ICE-POP?

A sentence and a reference are added. "The experiment focuses on the measurement, physics, and improved prediction of heavy orographic snow in the PyeongChang region of South Korea (Gehring et al., 2020)."

Line 152-153: This study also includes a Bayesian retrieval for GPM GMI, not just to analyze the observational measurements. Any additional goal to emphasize the value of this study?

A new sentence is added. "Furthermore, we examine how a Bayesian snowfall retrieval algorithm with GPM/GMI observations would perform for the snowing clouds observed during this field experiment."

Eq.(1): No need to adjust for snow events over Korea, and specifically for 94 GHz cloud radar?

This equation was originally derived for CloudSat radar which has the same frequency (94 GHz) as this surface radar. So, adjustment for frequency is not needed. However, adjustment for snow events over Korea is an open question. The particle shapes and size distributions used for deriving Eq.(1) will differ from those in snow events over Korea. But it is difficult to know how they differ. So, uncertainties will be associated with using this equation. We added one sentence to mention this issue. "It should be mentioned that although Eq.(1) is developed for CloudSat radar which has the same frequency as the RPG-FMCW radar, uncertainties in particle shapes and size distributions will certainly cause errors in snow water content derived in this study."

Line 205-206: How to derive Tc. How is it considering the cloud base?

We derived Tc by the air temperature at the height of the geometric middle of radar reflectivity profiles. In other word, cloud base is assumed to be the lowest level with valid radar echo. In case of snowfall, it is assumed to be the ground. A sentence is added to describe this derivation. "which [Tc] is determined in this study by the air temperature at the height of the geometric middle of valid radar reflectivity profiles."

Line 238: 0.1 m/s is only in this case or averaged from multiple cases?

It is an average for multiple cases. We examined this and some other cases, and found 0.1 m/s is a reasonable threshold to determine cloud top. This exemplar case is given here to show how this threshold worked.

Line 244: "While quantitative analysis was not ..." -> How do you expect this could impact on the results and future improvement (in conclusions)?

Particle shapes definitely are useful information in understanding microphysics and improving retrieval algorithms. These data are treasures to be explored in the future. We

added some discussions in the last (conclusions) section. "Lastly, it is worth mentioning that there are still many valuable datasets, such as particle shape and size distribution information from PARSIVEL, 2DVD and MASC, which we didn't analyzed quantitatively in this study. A thorough analysis of those datasets in conjunction with the remote sensing data will undoubtably improve future snowfall retrieval algorithm development."

Line 266: "A common radar..." -> Any previous studies? & Line 268: Any references to determine snow event types over this region?

This paragraph is completely rewritten. We added a summary of synoptic patterns for snowfall in the Pyeongchang area and their associated snow clouds types. A number of references are also provided. The deep clouds are commonly associated with low pressure systems, and the shallower clouds are associated with convective cells. The revised paragraph is as follows. "There are several synoptic weather patterns that cause snowfall over the Pyeongchang area. The first pattern is a synoptic low pressure system, so-called "cold low", developed over the Yellow sea (west of Korea) or cold continent and causes the snowfall over the northern or middle part of Korea when moving to east (Chung et al. 2006; Ko et al. 2016; Park et al. 2019). As this system crosses the Korean peninsula, the system become weaker and shallower once moving over the Pyeongchang area. The precipitation intensity and depth of system depend on the strength of low pressure. The second synoptic pattern, "warm low," develops over the warm ocean near East China sea or South sea and moves to north-east or east (Nam et al. 2014; Gehring et al 2020). This synoptic pattern brings abundant moisture to Korean Peninsula and is typically favored for vertically well-developed precipitation system. As the warm low pressure passes the Korean Peninsula and East sea, the winds over the Pyeongchang area and East sea turns to easterly or north-easterly, bringing in cold air to the east coastal area. Thus, we expect that the depth of precipitation system is likely first deep with large moisture and later becomes shallower as influenced by north-easterly cold air. The third interesting pattern, so-called "air-sea interaction", is developed by the easterly or north-easterly flow due to the Kaema high over the northern mountain complex or high pressure over Manchuria by the eastward expansion of the Siberian high (Kim and Jin 2016; Kim el at 2019). Thus, the cold north-easterly or easterly flow enhances the interaction with warm moisture ocean, resulting in the development of shallow convection and thermal inversion in the lower troposphere. The shallow convective clouds moved to the coastal and mountain area in which lifted by the orography. An example of radar reflectivity cross section is shown in Fig.1 where deeper clouds lead to shallower convective cells. This is the case of the second synoptic type, warm low. During the passage of the warm low, the system reached to 9 km. However, the precipitation system is shallower than 1 km during easterly or north-easterly flow when the warm low pressure passed the East sea."

Line 291: -20 dBZ -> with that, light snow events can be yet counted sufficiently?

Based on studies we know so far, -20 dBZ is a quite a low threshold. We added 2 sentences and a reference here to justify this threshold. "In a study by Wang et al. (2017) based on CloudSat radar reflectivity profiles, they found that precipitation onset often occurs when radar reflectivity is about -18 to -13 dBZ. We use the value of -20 dBZ as criterion in this study to make sure that all possible snowfall cases are included in the precipitation samples."

Line 294-295: Need more details about samples collected during the field experiment (such as the numbers basically as written in the conclusion part).

This paragraph is rewritten to give info of the samples and the ways how the fractions are calculated. The revised text is as follows. "Surveying all observed data for the entire winter, approximately 374 hours of observations are deemed as snowfall events after we apply the -20 dBZ threshold at the lowest bin and the Sims and Liu (2015) algorithm to exclude rain events. These observations are then averaged over each 5-minute interval to form 4491 samples. The relative frequencies of occurrence (area fraction, calculated by the number of samples of a given snow type divided by the total number of snowfall samples) and snowfall amount (volume fraction, calculated by the

snowfall amount produced by a given snow type divided by the total snowfall amount by all types) for the three types of snowing clouds are shown in Fig.3. The snowfall volume is the accumulated snowfall with the rate estimated by eq.(2) from radar reflectivity at the lowest bin. Over half (67.4%) of the observed samples are near-surface snowfall, followed by shallow (21.2%) and then deep (11.4%) snowing clouds. However, deep snowing clouds contribute the most to the total snowfall volume (45.3%), followed by shallow (28.5%) and then near-surface (26.2%) snowing clouds."

Line 427-428: Are those averaged profiles from observed samples?

Yes. We revised this sentence to clarify. "Note that in these radiative transfer calculations, mean snowfall rate profiles derived from observations are used. The mean profiles are derived as follows. We first group all the observed snowfall rate profiles according to their cloud type, and then for each cloud type we average those profiles that fall into a given snowfall rate bin."

Line 429: The heights to place the liquid layer are right above the snow cloud layer?

Actually, the liquid layer is within the snow cloud layer, but closer to the top part of the snow cloud layer. We assume the clouds are mixed phase clouds with the liquid embedded in the upper portion of the cloud layers.

Line 433-434: Add the decreased TB values.

This sentence is revised. " . . ., only about 1.5 K for 89 GHz and 2.5 K for 166 GHz occurring when liquid water path is very low."

Line 544-545: Please make it clear that this is for the cases studied here or particularly over the target region in this study.

We added "In this region during the observation period," to clarify.

Line 571: What it means exactly? The half of a priori database was from model simulations?

This part is rewritten to make the meaning clear. Now it reads: "Moreover, we examined the ability of a Bayesian type algorithm to retrieve surface snowfall rate for snow events similar to those observed in this study when using GPM/GMI observations. First, using the approximately 19,000 observed snow cloud profiles, brightness temperatures at GPM/GMI channels are computed. Then, these snowfall rate and associated brightness temperature pairs are randomly divided into two equal-number groups. One group is used as "observations" and the other is used as the a priori database of the Bayesian algorithm."

3. Technical corrections. Line 288: Add year. Line 556: with vast majority of "them" Line 570: half "of"

All are corrected as suggested. Thank you.

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