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Geoscientific
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Interactive comment on "Evaluation of ice and snow content in the global numerical weather prediction model GME with CloudSat" *by* S. Eikenberg et al.

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We thank the reviewer for the useful comments. It seems that the majority of the comments are due to unclarities concerning the data processing and the criteria, as was also the case with Anonymous Referee # 1. We have therefore made an effort to improve the formulations in the respective paragraphs, as described in detail below.

Major comments:

1. **Reviewer comment (RC)**: The CloudSat IWC retrieval frequently fails to con-

verge. In these situation a “fill value” is used. How do these fill values effect your results, especially with regard to Figure 4a?

Author Reply (AR): The fill value in case of divergence is -444.4 and, being an ”out of range” value (see Section 4.1), it is filtered out within our data pre-processing. Because we only consider ”matching pairs in time and space” of Cloudsat and model data, this fill value has no effect whatsoever on our results — except for slightly reducing the data set.

For Figure 4a, though the criteria are all switched off, our whole chain of data pre-processing is still performed. Since Anonymous Referee #1 also had some comments on Section 4.1, we modified it to: ”*...with the nearest neighbour technique. Due to the coarser resolution of the model, this means that one model profile is assigned to several adjacent CloudSat profiles. ... Additionally, an along-track 37-profile moving average is applied to all CloudSat data to take the coarser horizontal model resolution into consideration. The original horizontal resolution of the CloudSat data is maintained, but by applying the running mean clouds in the observations become broader and in-cloud reflectivity maxima are extenuated. After this pre-processing, in order to account for instrument and retrieval algorithm sensitivities, only data (from model and observation) which are firstly within the CloudSat CPR sensitivity range and secondly deemed trustworthy are included in the investigations, i.e.,...*”.

2. **RC**: I am confused by several aspects of the matching/filtering.

   (a) **RC**: In section 4.1 you write ”*To account for instrument and retrieval algorithm sensitivities, only data which are firstly within the CloudSat CPR sensitivity range and secondly deemed trustworthy are included in the investigations, i.e., -26 dBz* $< Z <$ *+29 dBz (no reflectivity factors below -26 dBz due to increased influence of noise) and 0.001* $gm^{-3} <$ *IWC* < 1 gm^{-3}.” By ”*data*” do you mean both observational data and model output?

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How are these limits applied with respect to Figure 4? Or do these limits only apply to Figures 2 and 3? Please clarify.

AR: The limits are applied to both model and observational data and all presented results include these limits. In Fig. 4 it is merely the criteria (see Section 4.3) which are switched on/off differently. We agree that this section of the manuscript might not be formulated clear enough and have therefore modified it to "*...After this pre-processing, in order to account for instrument and retrieval algorithm sensitivities, only data (from model and observation) which are firstly within the CloudSat CPR sensitivity range and secondly deemed trustworthy are included in the investigations, i.e.,* -26*dBz* $< Z <$ *+29 dBz (no reflectivity factors below* -26 *dBz due to increased influence of noise) for CloudSat observations and QuickBeam simulations and 0.001* gm-$3 <$ *IWC* $<$*1* gm-3 *(cf. Sect. 3) for CloudSat retrieval and model output.*".

(b) **RC**: I am confused by the criteria discussed in Section 4.3. Please expand further this material.

AR: As explained above we only consider matching pairs of model and observation. In order to improve the comparability between both we defined the criteria in Section 4.3 in order to focus on relatively simple conditions, namely the "pure" ice phase (criterium 1) and homogeneous, stratiform conditions (criterium 2-4). We did not set too stringent thresholds for these criteria because the sample size shouldn't be reduced too strongly. Criteria (2) and (3) are applied to the model data as some of the information is only available there, e.g., convection.

- **RC**: How is criteria (2) applied to the observational data?

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AR: Critera (2) and (3) only applied to the model data. If they are not met, both model and observation at this pixel are excluded from investigation, although the criterion comes from the model alone. We are aware that in this way a forecast error/displacement can lead to deviations, however, due to the large number of pairs ($>$ 20 million) this should only lead to some noise.

RC: You write "*Criteria (2) and (3), though diagnosed from model output, are assumed to be true for CloudSat.*" What does "*assumed to be true*" mean? There is no filtering of the observational data? If so, that would seem to invalidate any comparison. Also, if that is true how can the red-line in Fig. 4a be different then the red line in 4d?

AR: To help clarify this in the manuscript, the respective sentence has been modified to: "*To improve the comparability of model and observations four criteria are applied to the data. If a threshold is not met, both model and observations of a matching pixel are discarded...*".

- **RC**: How is criteria (3) applied to the observational data? Do you calculated cloud fraction over some distance or a given latitude range? It doesn't make any sense to me to remove IWC in the model with a cloud-fraction limit and yet take all observed IWC values (if that is what you did).

  AR: The criteria is not applied to observational data — see above.

- **RC**: Is criteria (4) only applied when comparing reflectivities?

  AR: Yes.

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RC: It clearly the values you produces in Fig. 4b and thereafter are going to be a strong function of these criteria and you need to provide more details and explain why you implemented these specific values much more thoroughly. E.g., why a cloud-fraction of 50%? Why not 33% or 66%? It feels like you have somehow "picked" values that give you the result you wanted for Figure 4b.

AR: The cloud cover threshold was chosen as a compromise, to eliminate as much inhomogeneous cases as possible, but at the same time to maintain a reasonable amount of data and not be too strict.

3. **RC**: In the introduction you write "*Ice clouds have a large impact on the Earth's climate system due to their effects on the global radiation budget.*" I couldn't agree more. Can you say anything of top-of-atmosphere and surface radiative fluxes from the model? In particular, when you increase the falls speeds (i.e., material associated with Figure 8) what happens? Increasing fall speeds improved agreement with CloudSat but does this cause problems or improve the radiative fields?

   AR: At the moment SWC is not radiatively active in the GME (though there are plans for the future) and only IWC is an input parameter for the radiation module. Because IWC does not significantly change with the enhanced snow fall speed (see Fig. 8) the radiative fields do not significantly change with the enhanced snow fall speed.

Minor comments:

1. **RC**: In the introduction you write, "*The CloudSat Cloud Profiling Radar (CPR) (Stephens et al., 2002) offers the so far unique opportunity to vertically resolve ice clouds from space — in contrast to the numerous passive satellite-based*

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sensors." A somewhat similar comment is contained in the abstract. This is not strictly true in that there have been several lidar system that provide vertically resolved information on many ice clouds (including those "too thin" for CloudSat) and the PR on TRMM is able to see a lot of ice material – that someone looking up from the ground would likely call a cloud. Rather I would say CloudSat is the first millimeter-wavelength radar in space and provides sufficient sensitivity that it is able to vertically resolve most frozen hydrometeors.

AR: Since the lidar system is limited to optically thin ice clouds, we did not regard it as a system capable of vertically resolving ice clouds, in general. However, as suggested, we modified the sentence accordingly to "*The CloudSat Cloud Profiling Radar (CPR) (Stephens et al., 2002) offers the opportunity to vertically resolve most frozen hydrometeors from space — in contrast to the numerous passive satellite-based sensors.*. The limitation of CloudSat and the advantage of a lidar concerning the smaller particle regime is already mentioned in the following sentences of the manuscript.

2. **RC**: In Section 4.2 you write "*The fuzziness of the Z-IWC relationships resulting from the two approaches becomes clear in Fig. 2.*" I'm not sure I understand "*fuzziness*". Do you mean the width of the distribution? Please rephrase.

   AR: The sentence has been modified to: "*The difference in the Z-IWC relationships resulting from the two approaches becomes clear in Fig. 2.*".

3. **RC**: In Section 4.2 you write "*Note firstly that the mean bin-temperature of the two Z-IWC relationships differs in the region of largest IWC and reflectivity factor values...*". I do not follow. Please rephrase and explain why it is an important observation.

   AR: The sentence is important to illustrate that there is no unique Z-IWC-T relationship. For clarification the sentence has been modified to: "*Note that while the Z-IWC relationships from both approaches aggree in their general behaviour, dif-*

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ferences exist in particular concerning large IWCs and cold temperatures. Note also that the Z-IWC relationship from Hogan et al. (2006) is based on measurements in the mid-latitudes, whereas the Z-IWC relationships from CloudSat and GME1007 in Fig. 2 are based on near-global data.

4. **RC**: In Section 4.3 you write "*... only temperatures lower than –10°C to avoid liquid and mixed phase...*". Since there is liquid water below -10°C, you probably mean "most" mixed phase?

   AR: The sentence has been modified accordingly.

Interactive comment on Geosci. Model Dev. Discuss., 4, 419, 2011.