

Replies to reviewer 1.

We thank reviewer 1 for comments on our paper which have improved the manuscript. We answered to all the questions, except for a few questions for which we did not think it was the best way for improving the manuscript. The way comments were accounted for is described below.

Corrections :

Specific Comments 1. Title The paper doesn't actually answer the question in the title. The authors tell us the estimate in the CloudSat domain (i.e., north of 82S). This is indeed the scientifically careful thing to do, but I think that the authors have enough information that they could make a reasonable estimate over all of Antarctica, which is what the non-specialist community really needs to know (and what the title promises).

The aim of this study is to document Antarctic precipitation from observations to benchmark climate models. Thus, we do not want to use climate models for assessing Antarctic precipitation until the south pole. We think we answer to the title in term of spatial variability of Antarctic precipitation even if the method does not provide information between 82°S and 90°S.

2. What does CloudSat miss? The authors point out that diamond dust is the dominant precipitation type on the high plateau. I'm not sure that they are as clear as necessary about how much diamond dust CloudSat actually sees, although P.1287,L.15-16 and P.1288,L.25-26 raise the issue after the fact.

We want to point out that CloudSat miss all the precipitation below 1300m over the surface (not only diamond dust, but all the precipitation which occurs below 1300m). This kind of precipitation is called shallow precipitation in our paper. The diamond dust is only mentioned in the introduction.

Therefore, "the weak reflectivity of small hydrometeors" refers to the size of the hydrometeors detected by CloudSat (altitude > 1300m) on the Antarctic plateau. On the Antarctic plateau, the size of the hydrometeors is small, thus the radar reflectivity of these particle should be small.

Page 7, lines 234-236. The sentence : "*Moreover shallow precipitation missed by CloudSat, and CloudSat sensitivity to very light snowfalls that occur in the interior could induce this difference.*" has been changed for "*Moreover shallow precipitation missed by CloudSat, and the weak reflectivity of small hydrometeors in the interior could contribute to this difference.*"

One result is that the analysis potentially conflates the notion of deposition (P.1289,L.3-6) with very light precipitation. I can believe that deposition occurs, but the calculated value, although reasonable, could well be missed diamond dust, right?

It is likely that shallow precipitation missed by CloudSat is the main issue. However, the contribution of deposition (hoarfrost formation) is unknown over the Antarctic plateau. Thus, we mention both causes as possible issues.

3. "flags" The terminology of "flags" usually seems to be what we would call "overpasses" or "samples".

Flag is the terminology used in the CloudSat 2C-PRECIP-COLUMN product and its description. Page 4, lines 109-110. The following sentence has been added : "*Thus, we redefined new flags from the original 2C-PRECIP-COLUMN flags.*"

4. P.1282,L.12 Presumably “sixth bin” is following a DEM? Readers aren’t experts on this.

Page 3, line 73. The following sentence has been added : *"The radar bin containing the surface is determined with a digital elevation model."*

5. P.1283,L.20-25 I’d say authors should point out that this approach, while reasonable, invariably inflates the fractional coverage by precipitation occurrence. The same is true in P.1284,L.1-3 for the “mixed” class.

Page 4, line 115. The following sentence has been added : *"It is relevant to note that this method tends to inflate the precipitation occurrence"*.

Page 4, line 121. The following sentence has been added : *"For the precipitation phase, this method tends to inflate the mixed precipitation class"*.

6. P.1284,L.10 Please state what the remapping scheme is to take the ERA-I grid to the 1x2 analysis grid.

We did not interpolate the ERA Interim dataset on the 1°x 2° analysis grid for the comparison of table 1, but the nearest grid cell of the ERA Interim reanalysis has been taken into account for comparing the datasets.

Page 6, line 198. The following sentence has been added : *"The nearest grid cell of the ERA Interim reanalysis has been taken into account for comparing the datasets"*.

But the ERA Interim dataset has been interpolated on the 1°x 2° analysis grid for creating the new figure 4. Page 7, line 219. The following sentence has been added : *"For comparing the datasets, ERA Interim reanalysis have been interpolated on the same 1° x 2° grid as CloudSat."*

7. P.1284,L.15 I’d like to see the authors go on to be clear about what this means in terms of the parameterized microphysics, parameterized sub-grid-scale creation of precipitation mass, and explicit grid-scale creation of precipitation mass.

Page 4, line 128. The following sentence : *"The 6 h forecasts of precipitation are used here"* has been changed by *"The 6 h and 12 h forecasts of precipitation are used here"*.

Page 5, lines 130-133. *"No precipitation observation is inserted in the numerical model, but precipitation is predicted by the model using other observations such as temperature and humidity."* has been changed by : *"Direct precipitation observations are not assimilated into the model, but precipitation is modified in the analysis through the four-dimensional variational assimilation of other variables such as temperature and humidity (www.ecmwf.int) ."*

Page 5, lines 134-136. The following paragraph has been added : *"ERA Interim has been chosen in this study because it likely offers the most realistic depiction of Antarctic precipitation (Bromwich et al., 2011). However, it has been shown that ERA Interim could have a dry bias over the East Antarctic plateau (Bromwich et al., 2011; Favier et al., 2013)."*

8. P.1284,L.22-24 I realize that the study is being done at the 1x2 scale, but I think it’s highly relevant at this point to also report the fractional coverage on the original CloudSat footprint scale. In part, this is important information related to the typical sizes of precipitation systems over Antarctica.

We agree with the reviewer, a supplementary material file has been added with a map of the fractional coverage inside.

Page 4, lines 103-107. The following sentence has been added : *"Moreover, the ratio of the surface directly observed by CloudSat over the surface of the ice sheet is shown in figure S1. Even for latitudes less than 82°S, the surface directly covered by CloudSat is only a fraction of the total surface of the ice sheet. However, the spatial scale of precipitation events and the overpass frequency ensure adequate statistical sampling over the duration of the study (supplementary material S1)."*

9. P.1285,L.9 I think you need to add “in the area observed by CloudSat”.

Page 5, line 155. In Fig.3, the part of the continent with surface elevation over 2250m represents 50% of the surface of the entire ice sheet (including the part of the continent between 82°S and 90°S).

We added *"(including the part of the continent between 82°S and 90°S)"*.

10. P.1286,L.8 I think you need to be explicit about the limitations, something like “for 4.5 years of curtain data accumulated on 1x2 grid boxes”. Also, in the following sentence you should probably say “relative uncertainty”.

Page 6, line 188 : We added *"for 4.7 years of curtain data accumulated on the 1° x 2° grid boxes"*, and we added *"relative uncertainty"* instead of *"uncertainty"* in the following sentence.

11. P.1286,L.14 I do not understand “the part of”.

Page 6, line 194. *"the part of"* has been changed for *"the relative contribution of"*.

12. P.1286,L.27 You have not motivated why a threshold is necessary. I suspect it’s because ERA-I drizzles most of the time.

Page 7, line 209. The following sentence has been added *"This threshold is necessary because the ERA Interim precipitation rates were strictly positive 60 % of the time between 2006 and 2011 at Dumont D’Urville station"*.

13. P.1287,L.11 I don’t understand the “likely lower” statement.

Page 7, line 222. *"likely lower"* has been changed for *"probably lower"*.

14.P.1289,L.14-15 New information shouldn’t be introduced in the conclusions – it belongs back in the main body of results.

This information has been moved from the section "4. Discussion and conclusion" to the new section "3.3 Comparison of the snowfall rate from CloudSat to surface mass balance observations".

Page 8, lines 277-279. The following sentence has been added : *"Assuming that accumulation has not significantly changed during the last 50 years (Monaghan et al., 2006a; Frezzotti et al., 2013), the accumulation from Arthern et al. (2006) represents 95 % of the snowfall over the Antarctic ice sheet north of 82 °S."*

Page 10, lines 315-318. The following paragraph has been added : *"Expectedly, the surface accumulation of snow is on average less than snowfall. However, it appears to exceed snowfall in areas of lesser precipitation where uncertainties on both precipitation and accumulation reports are largest. A significant contribution of hoarfrost to the surface mass balance of these areas may not be excluded."*

15. P.1289,L.27 This statement is so general, I'm not sure it's useful.

"Near surface reflectivity is sensitive to the size of hydrometeors, and on the plateau, particles are probably too small to increase the near surface reflectivity above the threshold precipitation certain".

We think it is an interesting explanation of the new figure 2 c). But this statement has been moved from the conclusion to the section 3.1 Precipitation characteristics from CloudSat (P5, lines 160-162).

16. Fig.3 is pretty low in information content; could it be integrated with Fig.1?

We agree with the reviewer. Fig.3 has been integrated with Fig. 1. And the transects have been removed from this figure.

Technical Corrections :

17. P.1281,L.17 “did not give quantities” is “was not quantitative”, I think.

Page 2, line 51. *"did not give quantities"* has been changed for *"was not quantitative"*.

18. P.1281,L.20 “measure” is “estimate” – this is remote sensing.

Page 2, line 54. *"measure"* has been changed for *"estimate"*.

19. P.1282,L.3 “cloud particles and hydrometeors” – cloud was the point of CloudSat.

We do not understand the comment and in L.3 it is not written *"cloud particles and hydrometeors"* but : *"the power backscattered by hydrometeors according to the distance from the sensor"*.

20 P1285, L.3 : “if” should be “on whether”.

Page 5, line 150 *"if"* has been changed for *"on whether"*.

21. P.1285,L.16 “A lot of” should be “Relatively more”.

Page 6, line 169. *"A lot of"* has been changed for *"Relatively more"*.

22. P.1287,L.20 “due to” should be “as good as” – it's not the forecasts that are chance, it's their skill.

Page 7, line 239. *"only due to chance"* has been changed for *"as good as random draw"*.

23. P.1289,L.9 “was still lacking so far” isn't correct English; maybe “has yet to be established”.

Page 9, line 311. *"was still lacking so far"* has been changed for *"has yet to be established"*.

24. Fig.2 caption “flags sorted as” isn't correct English; maybe “cases of”.

Fig.2 caption : *"flags sorted as"* has been changed for *"flags indicating"*.

25. Fig.5 The vertical axis requires a label.

Figure 5 has been replaced by the new figure 4. The transects have been replaced by four maps.

Replies to reviewer 2.

We thank reviewer 2 for comments on our paper which have improved the manuscript. We answered to all the questions, except for a few questions for which we did not think it was the best way for improving the manuscript. The way comments were accounted for is described below.

Major comments :

1) The short abstract gives the false impression that the study provides a definite answer to the question asked in the title. Nothing is said about the uncertainties of the results, which are substantial. Can this new "model-independent" climatology be actually used to assess the output from atmospheric models? Do it allow a quantitative or only a qualitative assessment of Antarctic precipitation? For example, in the abstract, a distinction between the two CloudSat precipitation products (frequency versus rate) and their reliability would be in order.

The abstract has been changed to better reflect the reviewer concerns, the new abstract :

“Climate models predict Antarctic precipitation to increase during the 21st century, but their present day Antarctic precipitation differs. A model-independent climatology of the Antarctic precipitation characteristics, such as snowfall rates and frequency, is needed to assess the models, but was not available so far. Satellite observation of precipitation by active spaceborne sensors has been possible in the polar regions since the launch of CloudSat in 2006. Here we use two CloudSat products to build the first multi-year model-independent climatology of Antarctic precipitation. The first product is used to determine the frequency and the phase of precipitation, while the second product is used to assess the snowfall rate. The mean snowfall rate from August 2006 to April 2011 is 171 mm/year over the Antarctic ice sheet north of 82°S. While uncertainties on individual precipitation retrievals from CloudSat data are potentially large, the mean uncertainty should be much smaller but cannot be easily estimated. There are no in situ measurements of Antarctic precipitation to directly assess the new climatology. However distributions of both precipitation occurrences and rates generally agree with the ECMWF ERA-Interim dataset, the production of which is constrained by various in situ and satellite observations but did not use any data from CloudSat. The new dataset thus offers unprecedented capability to quantitatively assess Antarctic precipitation statistics and rates in climate models.”

2) The study is presented as "a fully model-independent climatology of Antarctic precipitation". Given the important role of ERA-Interim in the definition and validation of the CloudSat products, one can obviously question this independence. Some nuance should be added to the statement.

“Fully” has been removed. The following sentence is in the new abstract : *“However distributions of both precipitation occurrences and rates generally agree with the ECMWF ERA-Interim dataset, the production of which is constrained by various in situ and satellite observations but did not use any data from CloudSat.”*

3) The determination of a precipitation threshold for one single, coastal site (DDU) and the use of the same threshold over all Antarctica is clearly not optimal. First, the availability of radiosonde data at DDU and their assimilation into ERA-Interim does not necessarily imply greater reliability of ERA-Interim precipitation in the area. Indeed, the amount of precipitation in the reanalysis are primarily influenced by the model physics, the model configuration (horizontal resolution), and the ability of the reanalysis to reproduce the characteristics of the synoptic disturbances around Antarctica. Therefore, I assume that DDU is probably no better than another location along the coast of Antarctica.

We fully agree with the reviewer that model physics, model configuration including resolution and general ability to reproduce synoptic disturbances are critical aspects of the quality of (re)analyses. Yet, precipitation is a threshold process, and occurrence and quantity of precipitation at a given time are critically dependent on accurate reproduction of temperature and humidity profiles in the model. Considering that there is no other radiosounding available within less than 1100 km, and that there are still limits with the assimilation of satellite data (e.g. infrared sounders like AIRS and IAISI can't see through clouds), the daily assimilation of the DDU radiosounding is bound to contribute the quality of the analysis there.

Second, the authors should explain how they determine the precipitation threshold of 0.07mm/6h. Is it by maximizing the success rate for "no precipitation", or the one for "precipitation certain", or both?. Third, I assume that the procedure can be reproduced at other locations in Antarctica (ideally at every other grid point covered by the CloudSat products). This would certainly improve the agreement between CloudSat and ERA-Interim (for ex. in Fig. 5).

First, we replaced the three transects by 4 maps in the new figure 4 representing the same variables at the continent scale.

P7, line 212. The following sentence has been added : *“(0.07 mm/6h corresponds to the threshold for which the highest Heidke Skill Score has been obtained (Barnston, 1992))*.

Yes, the procedure for determining the threshold can be reproduced at other locations in Antarctica. We made the same figure than the figure 5 (transects), but with taking a threshold which maximizes the Heidke Skill Score at every locations (see figure 1 of this document). The Heidke skill score depends of the number of samples for each class. If there is a class with a lot of samples compared to the other class, the Heidke skill score will maximize more the success rate for this class than for the other class. Thus, because the Heidke skill score has been calculated using the flags indicating no precipitation and precipitation certain, it will maximize the class “no precipitation”. And it is particularly true in the interior of the ice sheet where there are less flags indicating “precipitation certain” compared to the periphery. Because the Heidke skill score maximizes the success rate in the class “no precipitation”, the threshold increases where there are less flags indicating precipitation certain. Thus, the threshold determined with this method is higher in the interior of the ice sheet (where the snowfall rate is smaller) than on the periphery.

Therefore, we think that this method is not very appropriate for determining a threshold at every locations in Antarctica. That is why, we chose to keep the same threshold at every locations.

Page 7, lines 224-231. The following paragraph has been added :

“The method used for determining the threshold at Dumont d’Urville (highest Heidke skill score obtained for this threshold) has been tested in the interior of the ice sheet. This method tends to maximize the success rate of the different classes according to the number of samples in each class. Because there are less flags indicating precipitation certain in the interior of the ice sheet

compared to the total number of flags (Fig. 2 c)), it tends to maximize the class "periods without precipitation". Thus, the threshold in the interior of the ice sheet tends to be higher than 0.07mm/6h, while the precipitation rate is smaller in this region. That is why, we chose to keep the same threshold for the whole continent than the threshold determined at Dumont d'Urville."

4) The assessment of uncertainties does not include the error related to the low temporal sampling of the CloudSat products. This issue should be briefly commented upon in section 2. The statement "...which represents one orbit every 5 days" leaves the reader wondering about the impact the 80% of the days that are left out. The authors only briefly refer to this issue in the second-to-last paragraph of the manuscript (page 1290) and only in qualitative terms. One way to assess quantitatively the sampling error would be, for example, to use ERA-Interim data to determine the sensitivity of the multi-year average precipitation rates to the temporal sampling.

We fully agree with the reviewer that testing the temporal sampling of CloudSat is essential. A new figure (figure 5 c) has been created in order to test the temporal sampling of CloudSat. This is a map of the snowfall rate from ERA Interim with the same temporal sampling as CloudSat. Every time a grid cell has been overflowed by CloudSat, the corresponding time step in ERA Interim has been retained. The map of the ratio of the snowfall rate from CloudSat over the snowfall rate from ERA Interim has been replaced by this new map in figure 5.

Page 8, lines 252-262. The two following paragraphs have been added :

"A comparison between the snowfall rate observed by CloudSat and simulated by ERA Interim is shown in Fig. 5 and in Table 2. For this comparison, a map with the same temporal sampling as CloudSat has been created. Every time a grid cell has been overflowed by CloudSat, the corresponding time step in ERA Interim has been retained. This dataset has been created in order to test if the temporal sampling of CloudSat may result in a bias for the period August 2006-April 2011.

The snowfall rates from ERA Interim with the same temporal sampling as CloudSat and from the full ERA Interim dataset are similar (163 mm w.e. per year for both datasets over the Antarctic continent north of 82°S). The snowfall rate from ERA Interim with the same temporal sampling as CloudSat is slightly stronger over the interior of the ice sheet (53 compared to 49 mm w.e. per year), and slightly lower over the periphery (271 compared to 273 mm w.e. per year). These are considered as marginal differences, and temporal sampling of CloudSat does not seem to be an issue."

5) The comparison between CloudSat products and the accumulation map from Arthern et al. (2006) is not only complicated by the fact that one is measuring falling precipitation while the other is measuring net snow accumulation at the surface. It is also complicated by the numerous issues affecting the Arthern et al. data set, in particular the unreliability of a number of observations used in their spatial interpolation (see Genthon and Krinner 2001; Van de Berg et al. 2006; Magand et al. 2007; Magand et al. 2008; Bromwich et al. 2011; Favier et al. 2013). Some of these papers refer to the Vaughan et al. (1999) accumulation data set rather than the one from Arthern et al., but the two data sets used the same observations to carry out their interpolation. In short, it is not clear what can be concluded from the comparison CloudSat vs Arthern et al. For a comparison with in situ accumulation measurements, I suggest using the more reliable (yet more spatially limited) SMB data set described by Favier et al. (2013) and available at <http://www-igge.ujf-grenoble.fr/ServiceObs/SiteWebAntarc/database.php>.

We agree with the reviewer that there are concerns with Arthern et al., 2006 accumulation map. A comparison between the accumulation from Favier et al., 2013 and the snowfall rate from CloudSat

has been added in the new figure 6.

However, the dataset from Favier et al., 2013 has not been interpolated over the whole continent. Furthermore, we think that it remains interesting to compare the snowfall rate from CloudSat with the accumulation over the whole continent. Thus, both datasets (Arthern et al, 2006 and Favier et al., 2013) have been compared to the snowfall rate obtained with CloudSat in the new figure 6.

The section 3.3 has been changed for :

3.3 Comparison of the snowfall rate from CloudSat to surface mass balance observations

Table 2 and Fig 6 show a comparison between the snowfall rate obtained by CloudSat for the period August 2006–April 2011, and the accumulation rate assessed by Arthern et al. (2006) for the period 1950–2000. Arthern et al. (2006) used in-situ glaciological measurements to assess the accumulation, and passive radiometer data (AMSR-E) sensitive to snowpack characteristics for interpolating their results.

Assuming that accumulation has not significantly changed during the last 50 years (Monaghan et al., 2006a; Frezzotti et al., 2013), the accumulation from Arthern et al. (2006) represents 95 % of the snowfall over the Antarctic ice sheet north of 82 °S. The snowfall rate observed by CloudSat is higher than the accumulation over the periphery of the ice sheet, which is expected due to the negative contribution to accumulation of evaporation, melt, run-off, and blowing snow.

However, the snowfall rate observed by CloudSat is lower than the accumulation in the interior. Snowfall rate assessed by CloudSat over the interior of the ice sheet may be underestimated due to shallow precipitation missed by CloudSat and the weak reflectivity of small hydrometeors.

Additionally, modelling studies have suggested that deposition (inverse sublimation) could be stronger than evaporation at some locations in the interior of the ice sheet (Genthon and Krinner, 2001). Thus, hoarfrost formation could contribute significantly to the accumulation, and precipitation could be lower than accumulation in these regions.

Ground-based measurements used to produce the accumulation map from Arthern et al. (2006) were not filtered according to their accuracy, and some measurements have been found to be unreliable (Magand et al., 2007). Genthon et al. (2009b) have shown that the unreliability of some in situ observations used by Arthern et al. (2006) would lead to an overestimated accumulation in the interior of the ice sheet. Thus the accumulation from Arthern et al. (2006) could be overestimated in this region. Moreover, Magand et al. (2008) have shown that the interpolation based on microwave surface emission used by Arthern et al. (2006) can be inaccurate in coastal areas affected by melt during the summer.

Favier et al. (2013) assembled a surface mass balance database in which ground-based measurements have been sorted into three classes according to their accuracy. Observations sorted in the most reliable class for the 20th century by Favier et al. (2013) have been used in this study. The ratio of the snowfall rate observed by CloudSat over the accumulation from Favier et al. (2013) is reported on the map of Fig. 6. When several values of accumulation are given in the database of Favier et al. (2013) for the same grid cell of 1° x 2°, the mean value for the grid cell is shown in Fig. 6. Overall the comparison between the snowfall rate from CloudSat and the accumulation from Favier et al. (2013) confirms the results from the comparison with the accumulation map of Arthern et al. (2006). However, in some grid cells, accumulation is not spatially homogeneous, and a few in situ measurements can be sometimes not representative of the mean accumulation in the grid cell. For instance, there is only one value of accumulation for the three red dots of Fig. 6 showing the largest ratio between the snowfall rate from CloudSat and the accumulation from Favier et al. (2013).

Minor comments and corrections :

Page 1280 line 11. Suggestion: "Antarctic snow accumulation". Also, change "melt, run-off" to "melt/run-off" or "meltwater run-off" as the two processes represent one single term in the surface mass budget.

Page 1, line 18. "*Antarctic accumulation*" has been changed for "*Antarctic snow accumulation*", and "*melt, run-off*" has been changed for "*meltwater run-off*".

Page 1280 line 14. The absence of significant change is for the *total* Antarctic snow accumulation.

Page 1, line 20. "*in Antarctic accumulation*" has been changed for "*in the total Antarctic snow accumulation*".

Page 1280 line 16. Suggestion: "are likely to occur, with global consequences".

Page 2, lines 21-22. "*future changes are likely which will have global consequences*" has been changed for "*future changes are likely to occur, with global consequences*".

Page 1280 line 17. Suggestion: "the projected 25% increase".

We mean that in case of 25% increase in accumulation, there will be a drop of approximately 1.6 mm per year in global sea level.

Page 2, line 22. "*over the 21st century, a 25% increase in accumulation*" has been changed for "*a projected 25% increase in accumulation over the 21st century*".

Page 1280 line 24. The scatter in Antarctic precipitation estimates is not restricted to climate models. It is also seen in results based on global reanalyses and regional models. In addition, what is needed is not so much "to understand the processes controlling Antarctic precipitation rates", but rather to obtain observation-based, model-independent, and Antarctic-wide estimates of precipitation.

Page 2, line 36 "*There is therefore a need to understand the processing controlling Antarctic precipitation rates*" has been changed for "*There is therefore a need to document Antarctic precipitation from observation to benchmark climate models*".

A paragraph has been added about Antarctic precipitation in the regional models and the reanalysis (see the following comment).

Page 1281 line 1. Atmospheric modeling (with global reanalyses and regional models) has also been paramount in the assessment of Antarctic precipitation/surface mass balance (Van de Berg et al. 2005, Monaghan et al. 2006, Bromwich et al. 2011, Lenaerts et al. 2012) and should be mentioned here. Arthern et al. (2006) used satellite microwave observations as the background field for their interpolation, not directly for their assessment of Antarctic snow accumulation.

Page 2, line 38. "*While accumulation rates have been assessed using satellite and in situ measurements (Arthern et al., 2006 ; Eisen et al., 2008)*" has been changed for "*While accumulation rates have been assessed using in situ observations (Arthern et al., 2006 ; Eisen et al., 2008).*"

The following sentences have been added in order to mention studies about Antarctic precipitation in the reanalysis and the regional atmospheric models :

Page 2, lines 27-36. *The Antarctic precipitation rates have also been evaluated from regional atmospheric models (Bromwich et al., 2004; Van de Berg et al., 2005; Monaghan et al., 2006b; Lenaerts et al., 2012). The mean solid precipitation rate over the grounded ice sheet reported by Van de Berg et al. (2005) is 164 mm/year using the model RACMO2/ANT. Moreover, Monaghan et al. (2006b) found a precipitation rate of 178mm/year and 200 mm/year with Polar MM5 using the reanalysis NCEP-II and ERA40 respectively for the initial and boundary conditions. Reanalysis have also been used for assessing Antarctic precipitation (Monaghan et al., 2006a; Bromwich et al., 2011). Bromwich et al. (2011) have compared 6 reanalysis datasets and found that the mean precipitation rate on the grounded ice sheet varies from 145 to 203 mm/year depending on the reanalysis.*

Page 1281 line 11. Bromwich (1988) could also be cited with regard to diamond dust.

Page 2, line 49. Bromwich (1988) has been added with regard to diamond dust.

Page 1281 line 17. Suggestion: "provide/allow quantitative estimates" instead of "give quantities".

Page 2, line 51. “*did not give quantities*” has been changed for “*was not quantitative*”.

Page 1281 line 24. The last two paragraphs of the Introduction give the false impression that the paper presents the first investigation of Antarctic precipitation based on CloudSat precipitation products. The study by Boening et al. (2012) has obviously laid some important groundwork but is only cited at the very end of the manuscript. The authors should mention this paper at least once in their Introduction and say, for example, how they intend to build upon this earlier work.

Page 2, lines 56-62. The paragraph : “*While several algorithms have been tested for precipitation over polar regions using CloudSat (Kulie and Bennartz, 2009; Hiley et al., 2010), no precipitation climatology have been done over Antarctica. In this study, we used two CloudSat products to make the first multi-year climatology of Antarctic precipitation from spaceborne observations.*” has been changed for “*Several algorithms have been tested for precipitation over polar regions using CloudSat (Kulie and Bennartz, 2009; Hiley et al., 2010). Moreover, Boening et al. (2012) have already shown that there is a good agreement between CloudSat, GRACE, and ERA Interim for Antarctic precipitation measurements over Dronning Maud Land (30°W-60°E, and 65°S-80°S). However, no precipitation climatology has been done over Antarctica at the continent scale. In this study, we used two CloudSat products to make the first multi-year climatology of Antarctic precipitation north of 82°S from spaceborne observations.*”

Page 1281 line 26. Correction: "has been done"

Page 3, line 60. “*have been done*” has been changed for “*has been done*”.

Page 1282 line 7. Suggestion: "the characteristics"

Page 3, line 68. “*to determine characteristics*” has been changed for “*to determine the characteristics*”.

Page 1282 line 13. Suggestion: "using the temperature"

Page 3, line 74. “*The phase is obtained by the temperature*” has been changed for “*The phase is*

obtained using the temperature”.

Page 1284 line 8. The proper reference for ERA-Interim is Dee et al. (2011).

Page 4, line 126. The reference Dee et al., 2011 has been added, but the reference Simmons, 2006 has not been removed because it also describes the ERA Interim product.

Page 1284 line 9. Suggestion: "ERA-Interim provides data from 1979..."

Page 4, line 126. “*ERA Interim provides reanalysis from 1979*” has been changed for “*ERA Interim provides data from 1979*”.

Page 1284 line 14. Suggestion: Replace "inserted" with "ingested".

Page 4, lines 130-133. The sentence “*No precipitation observation is inserted in the numerical model, but precipitation is predicted by the model using other observations such as temperature and humidity.*” has been changed for “*Direct precipitation observations are not assimilated into the model, but precipitation is modified in the analysis through the four-dimensional variational assimilation of other variables such as temperature and humidity (www.ecmwf.int).*”

Page 1284 line 14-15. Strictly speaking, ERA-Interim forecast model does not "use other observations such as temperature and humidity" to predict precipitation. Precipitation is a product of the model physics and is only to some extent influenced by the assimilation of observations (using the terminology of Kalnay et al. (1996), precipitation is a "class C" variable). Furthermore, the authors should at least briefly mention potential issues with ERA-Interim precipitation in Antarctica. For example, at least two studies of Antarctic surface mass balance (Bromwich et al. 2011; Favier et al. 2013) have shown that this reanalysis has a dry bias in the interior of East Antarctica.

Page 4, lines 130-133. The sentence “*No precipitation observation is inserted in the numerical model, but precipitation is predicted by the model using other observations such as temperature and humidity.*” has been changed for “*Direct precipitation observations are not assimilated into the model, but precipitation is modified in the analysis through the four-dimensional variational assimilation of other variables such as temperature and humidity (www.ecmwf.int).*”

Page 5, lines 134-136. “*ERA Interim has been chosen in this study because it likely offers the most realistic depiction of Antarctic precipitation (Bromwich et al., 2011). However, it has been shown that ERA Interim could have a dry bias over the East Antarctic plateau (Bromwich et al., 2011; Favier et al., 2013).*”

Page 1284 line 22. Suggestion: "over the Antarctic continent"

Page 5, line 144. “*on the Antarctic continent*” has been changed for “*over the Antarctic continent*”.

Page 1284 line 26. Neither of the acronyms, WAIS and EAIS, are used in the rest of the manuscript. Consider deleting them.

Page 5, line 147. The acronyms WAIS and EAIS have been deleted.

Page 1285 line 16. Correction: "occurs"

Page 6, line 169. “*A lot of liquid and mixed precipitation occur over the Peninsula*” has been changed for “*Relatively more liquid and mixed precipitation occurs over the Peninsula*”.

Page 1285 line 25. The authors should discuss how the 171 mm/yr estimate from CloudSat compares with the values reported by other studies (e.g., Bromwich et al. 2011, Lenaerts et al. 2012)?

Page 6, line 178. We can not directly compare the 171 mm/yr found with CloudSat with values reported by other studies, because the value found with CloudSat is an average north of 82°S and not until the pole.

Page 1286 line 1. Is the fact that the precipitation rates for West Antarctica and peripheral Antarctica are identical just a coincidence?

Page 6, line 182. Yes, it is a coincidence that the rates for West Antarctica and peripheral Antarctica are identical.

Page 1286 line 3/7. I encourage the authors to use a), b) c), etc. in figures with multiple panels so that they can refer more precisely in text to the panel they are discussing.

The labels a), b),c) have been added in the figures with multiple panels.

Page 1286 lines 22/25. Correction: "at Dumont d'Urville"

Page 6, line 203. “*in Dumont D'Urville*” has been changed for “*at Dumont d'Urville*”.

Page 1287 line 8. Consider carrying out the comparison over three larger longitudinal sectors, instead of three lines. This would likely reduce the "noise" in the curves shown in Fig. 5 (in particular the blue curves).

Page 7, line 219. We agree with the reviewer, the new figure 4 shows four maps instead of the transects from the discussion paper.

Page 1287 line 9. Correction: "same as for Dumont d'Urville"

Page 7, line 220. “*The threshold used in ERA Interim was the same than in Dumont d'Urville*” has been changed for “*The threshold used in ERA Interim was the same as for Dumont d'Urville*”.

Page 1287 line 10. Correction: "depend on the location"

Page 7, line 221. “*The value of the appropriate threshold seems to depend of the location in Antarctica*” has been changed for “*The value of the appropriate threshold seems to depend on the location in Antarctica*”.

Page 1287 lines 25-29. The better agreement between CloudSat and ERA-Interim near the coast is more likely due to the fact that the threshold was derived for a coastal location (DDU).

We recognize that a threshold derived for a coastal location is bound to generally optimize the agreement near the coasts. We do report this conclusion lines 13-14 page 1287 of the original manuscript (Page 7, line 233) .

However we are not convinced that this is necessarily the more likely reason. The coastal regions are swept by passing synoptic perturbations that release precipitation. The synoptic perturbations and thus the precipitation events are well captured in the reanalyzes because there are comparatively more observations to force both the timing and the intensity of the perturbations. When perturbations reach the interior, they are fainter and there are less observation to help the model “decide” whether, when and where to dump moisture.

In the figure 2 of this document, we made the same maps as in the new figure 4, but with a threshold of 0,01 mm/6h in ERA Interim. Of course with a lower threshold, the success rate decreases for the map “Periods without precipitation”, and increases for the maps “Precipitation certain” and “Precipitation possible”. Overall, the Heidke skill score is lower with a lower threshold. But the spatial pattern of these maps (with a threshold of 0,01mm/6h) shows also a better agreement between CloudSat and ERA Interim near the coast than in the interior of the ice sheet. Thus, the threshold applied is likely not the only reason of this spatial pattern.

Page 8, lines 245-249. The following sentences have been added : *“Observations of wind, pressure, temperature, cloudiness further help constrain the strength and timing of the perturbations and thus that of the precipitation events. Perturbations are fainter when they reach the interior and, as there are less observations available they are less efficient at controlling the occurrence and timing of precipitation through assimilation.”*

Page 1288 line 6. Consider including the longitudes of Vinson Massif and Prince Charles Mountains, for readers not familiar with the geography of Antarctica.

Page 8, line 266. *“except over parts of the Peninsula, the Vinson massif, and the Prince Charles Mountains”* has been changed for *“except over parts of the Peninsula, the Vinson massif (78°S, 85°W), and the Prince Charles Mountains (around 72°S, 65°E).”*

Page 1289 line 12. Considering the earlier work by Boening et al. (2012), I suggest changing the text to something like "following Boening et al. (2012), its potential has been confirmed".

Page 10, line 313. *“CloudSat is the first spaceborne radar able to observe precipitation in Antarctica, and its potential has been demonstrated in this survey.”* has been changed for *“CloudSat is the first spaceborne radar able to observe precipitation in Antarctica (Boening et al., 2012), and its potential is confirmed here.”*

Page 1289 line 24. The discussion of Figure 8 seems out of place here. It could be inserted into Figure 1 (where it could replace panel #3 "Difference (%)").

The figure 8 has been inserted in figure 2 c), and it replaces the figure “Difference” in figure 2. The discussion about the ratio of the number of flags indicating precipitation possible over the number of flags indicating precipitation possible and certain has been removed from the section discussion and conclusion : *“The reflectivity thresholds applied in this algorithm could be too high for this kind of precipitation. Fig. 8 shows a map of the ratio of the number of flags indicating*

precipitation possible over the number of flags indicating precipitation possible and certain. On the Antarctic plateau, most of the flags indicating precipitation are sorted as possible. Near surface reflectivity is sensitive to the size of hydrometeors, and on the plateau, particles are probably too small to increase the near surface reflectivity above the threshold "precipitation certain."

Page 5, lines 157-163. The following paragraph has been added in section 3.1 Precipitation characteristics from CloudSat.: "In figure 2, the map c) shows the number of flags indicating precipitation possible over the number of flags indicating precipitation possible and certain. While over the periphery of the ice sheet, most of the precipitation events detected are sorted as certain, most of the flags indicating precipitation are sorted as possible in the interior. Near surface reflectivity is sensitive to the size of hydrometeors, and on the plateau, particles are probably too small to increase the near surface reflectivity above the threshold "precipitation certain". The reflectivity thresholds applied in this algorithm could be too high for this kind of precipitation."

Page 1290 line 21. Suggestion: "relatively low" rather than "not really good"

Page 10, line 341. "not really good" has been changed for "relatively low".

Page 1290 line 27. Is there any prospect of improvements in the measurement of precipitation rates over Antarctica with the upcoming satellite missions?

Page 10, lines 349-352. The following sentences have been added : "In addition to the reflectivity profiles, EarthCARE will measure the vertical Doppler velocity which will allow to get new informations about the cloud particles. Moreover, it will have a better sensitivity than CloudSat (-35dBZ compared to -28dBZ for CloudSat), and a better sampling interval (100m compared to 250m for CloudSat) (Nakatsuka et al., 2008)."

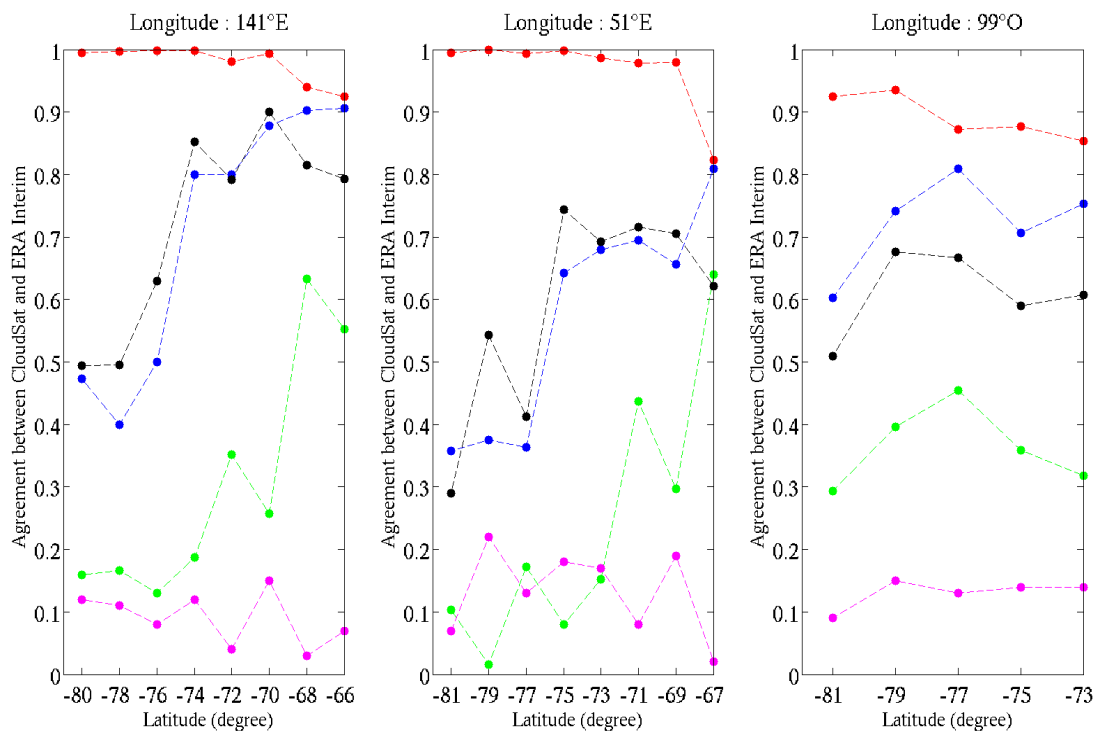


Figure 1 : the same figure than the figure 5 in the discussion paper but with a threshold adjusted to maximize the Heidke skill score at every locations. The pink curve is the value of the threshold

determined to maximize the Heidke skill score (mm/6h). Red curve : proportion of flags indicating periods without precipitation that match with periods without precipitation in ERA Interim. Blue curve : proportion of flags indicating precipitation certain that match with precipitation events in ERA Interim. Green curve proportion of flags indicating precipitation possible that match with precipitation events in ERA Interim. Black curve : Heidke skill score assessed using flags indicating precipitation certain and period without precipitation.

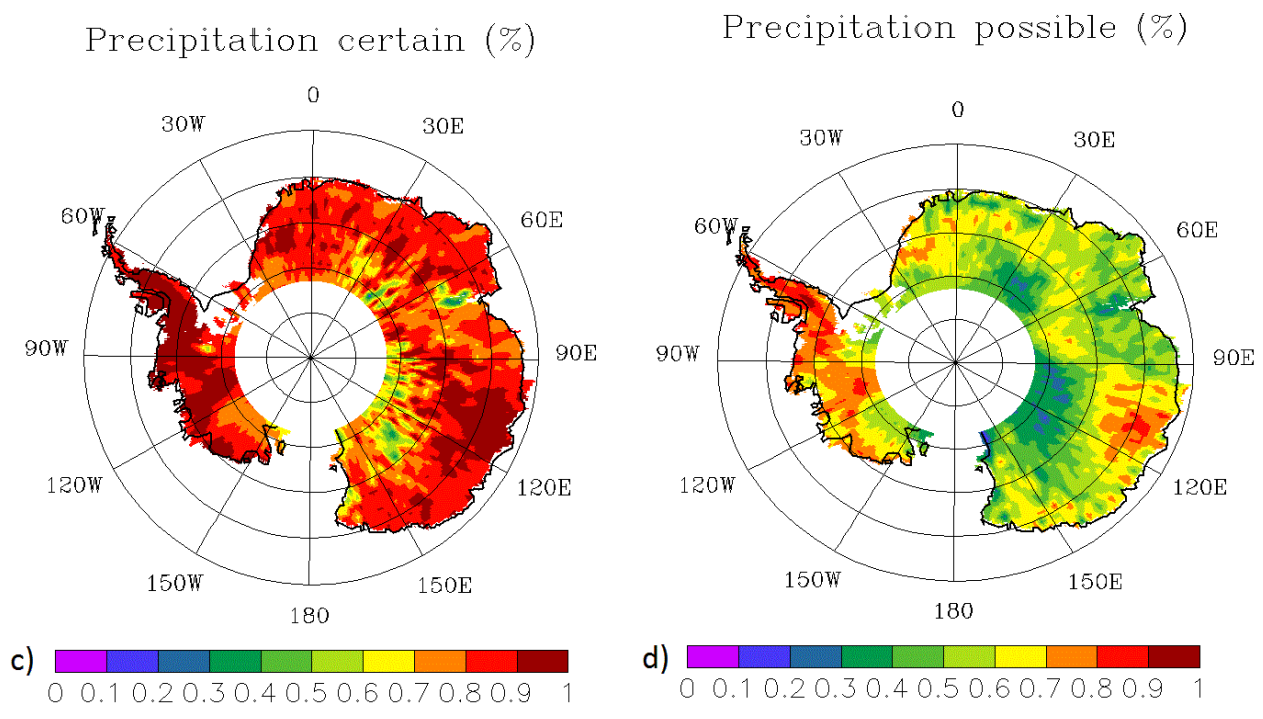
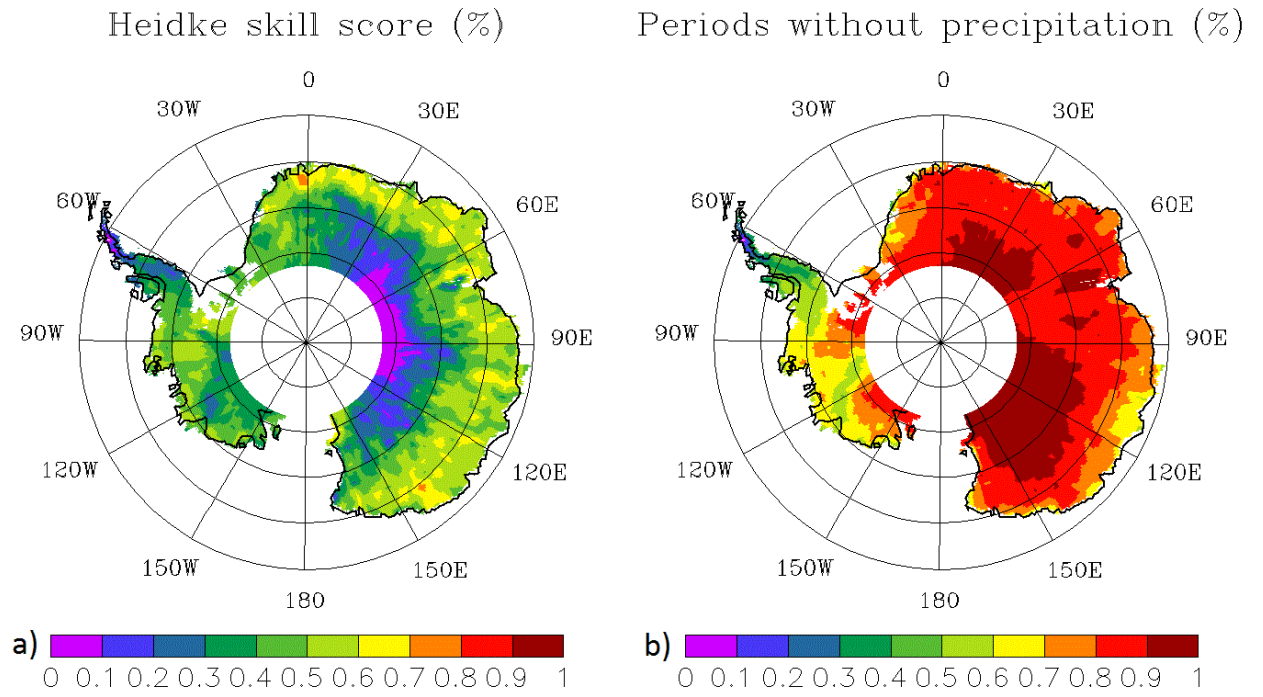


Figure 2 : the same figure as the new figure 4, but precipitation events were defined for a precipitation rate over 0,01mm/6h in ERA Interim reanalysis. a) Heidke Skill Score assessed using flags indicating precipitation certain and period without precipitation. b) Proportion of flags indicating periods without precipitation that match with periods without precipitation in ERA Interim. c) Proportion of flags indicating precipitation certain that match with precipitation events in ERA Interim. d) Proportion of flags indicating precipitation possible that match with precipitation events in ERA Interim.