Author Responses to the Referee Comments 2 on " *Marked decrease of the near surface snow density retrieved by AMSR-E satellite at Dome C, Antarctica, between 2002 and 2011* "

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Referee comments are in normal text ; Author responses are in italic.

In this paper, the authors present a retrieval algorithm for inferring surface density variations from satellite passive microwave observations. Their retrieval indicates that there has been a decrease in surface density in Antartica, at Dome C. They back this up by comparing to in situ density, QuickScat, and EnviSat RA.

We are grateful to the second reviewer for the summary and comments. All comments are addressed in the following.

1. Page 4, line 23: Are you using the Ice-1 retracked data, or something else?

Here, we use the along-track Envisat Radar Altimeter 2 (RA-2) data derived from the Ice-2 retracking algorithm (Legresy et al., 2005). The sentence page 4, line 23, is modified as follow: "The dataset contains the total backscatter power from 12 March 2002 to 8 April 2012 based on along-track data and the Ice-2 retracking algorithm (Legresy et al, 2005 ; Rémy et al., 2014)."

2. Page 4, line 27: More common to say "spatial resolution in the along-track direction is 330 m". More broadly though, I think these comments are a little misleading. The true size of the area measured by the RA-2 (while confusing over ice sheets) is probably closer to 10 km. The footprint separation along track should not be referred to as "resolution", as it will easily mislead readers.

It indeed could have misleading between spatial resolution and spatial sampling. In order to avoid the confusion, we modify the sentence as follows: "The along-track spatial sampling over the Antarctic ice sheet is 330m, and typical footprint is of the order of 5-10 km (Rémy et al., 2009). The sensor precision to determine surface elevation is 47 cm."

3. Page 4, line 28: This precision seems far too high. Please give a reference and say how exactly this number was computed. Additionally, can you please provide a range of references of those who have measured ice sheet elevations from radar altimeters ?

Sorry for the mistake, the precision is indeed 0.47 m instead of 0.047 m. This is corrected in the paper and the unit is changed to centimetre for better clarity. The precision is given in Rémy et al., 2014 (page 5505). The resolution of 47 cm is still high but slightly less than the precision of AltiKa on SARAL which is around 30 cm (Rémy et al., 2014). The precision is calculated with the bandwidth of the radar altimeter (320 MHz for Ra-2/ENVISAT and 500 MHz for SARAL/AltiKa). Additional references could be Rémy et al., 2012, "Radar Altimetry Measurements over Antarctic Ice Sheet: A Focus on Antenna Polarization and Change in Backscatter Problems" ; Thomas et al., 2008, "A comparison of Greeland Ice-Sheet Volume Changes Derived from Altimetry Measurements" ; Brenner et al., 2007, "Precision and Accuracy of Satellite Radar and Laser Altimeter Data over the Continental Ice Sheets".

4. Page 5, line 13: The measurement corresponds to the top 5 cm of the snowpack, whereas the retrieval corresponds to the top 3 cm. I didn't see if these were ever reconciled. Please address.

There is indeed a difference between the retrieved density from satellite and the measured density in the field. The thickness representative of the retrieved density from the satellite is not exactly determined since it depends on many parameters, for example the type of crystals on the surface (page 15, line 5-6). We estimate that the retrieved density is approximatively representative of the mass of snow integrated over 3 times the wavelength that is why, in our model's simulations, we use 3 cm for the topmost layer (page 16, line 4-7). To be clearer in the paper and because this 3 cm value is approximative, we add "approximatively" page 1, line 8 before "representative" and page 16, line 4 before "representative". We also replace "different" by "approximative" page 17, line 14. Finally, we replace "… of the snow density of the top layer." by "… of the snow density very close to the surface (approximatively the top 3 centimeters of snow)." (page 25, line 10).

The variability in the thickness of the snow density retrieved by satellite could be a reason for the higher variability of the satellite density than in situ measurements (page 16, line 13-14) or the different linear trends observed (page 16, line 19-20). However, this difference will unlikely change the sign of the trend (decrease of the surface snow density), neither the order of magnitude (10 kg m^{-3} yr^{-1}). The effect of the topmost layer thickness on PR37 is indeed small (Figure 4.d). As regards snow measurements, samples are carried out in the first 5 cm in order to have a good compromised between being as close as possible to the thickness of the satellite retrieved density (3 cm) and minimizing the error on the density estimate. Indeed, the snow in the first centimetres could be not homogenous, and thus a minimum volume is needed to obtain reliable density values.

5. Page 5, line 15: Should be "The second dataset. . ."

Change done.

6. Page 5, line 24: Should be "datasets".

Change done.

7. Page 5, line 25-28: This is confusing. Are these data being presented for the first time, or part of an existing analysis? Please add citations. These values of course cannot be thought to always represent the quantities as they are named, so this must be a very specific analysis.

Yes, these data are presented for the first time and, to our knowledge, it is the first time that such an assessment of the spatial variability of in situ measurements of the surface snow density is performed. These values can of course not be used to assess the spatial variability at the scales mentioned, and this study probably deserves new measurements to estimate the spatial variability 10-100 km away from Dome C, as well as if the spatial variability changes with time. However, we believe that this is a reliable first guess estimate which can be used in our study to show that the evolution of the retrieved density from satellite has higher amplitude than the spatial variability. In order to be clearer, we do some additions in the text as follow: "For the first time, the spatial variability of surface snow density measurements has been assessed with 3 series of 40 measurements ... This value represents 26.9% of the mean density and is assumed to represent the spatial variability of surface snow density measurements around Dome C. We also assume no change of the spatial variability during the study period (2002-2011)."

8. Page 6, line 9-11: No references are cited, and no justification is given for this analysis. Please either cite a reference for how this was done, and what uncertainty is associated with it, or provide some supporting material in an appendix.

This problem of "burying probes" has been also described in Brucker et al., 2011, "Modeling time series of microwave brightness temperature at Dome C, Antarctica, using vertically resolved snow temperature and microstructure measurements", and in Zwaaftink, et al., 2013, "Event-driven deposition of snow on the Antarctic Plateau: analyzing field measurement with

SNOWPACK". These citations are added. The uncertainty associated with the correction of this problem has indeed not be estimated since we study and use the polarisation ratios which considerably less sensitive to temperature than TB. The uncertainty coming from temperature measurements and their extrapolation to the top of the snowpack is negligible. We can however observe small differences in the Figure 2 during the validation period (especially in January 2011) between the observed and modeled TB19,V and TB37,V that partly comes from the temperature profile. Finally, Picard et al., 2009, Modeling the time series of microwave brightness temperature in Antarctica, conclude that most of the error in modeling the brightness temperatures come from the air temperature. This citation is also added.

9. Page 6, lines 11-12: What is the ECMWF surface air temperature precision over Antarctica?

The ERA-Interim surface air temperature has a warm bias of 1.7K for the East Antarctica region, and usually perform better in the austral spring and worse in winter and autumn. ERA-Interim reanalysis is considered superior in this region to other reanalysis. A detailed assessment is performed by Xie et al., 2014, Assessment of air temperatures from different meteorological reanalyses for the East Antarctic region between Zhonshan and Dome A. The following sentence is added at the end of the page 6, line 12: "considered as the superior reanalysis in the East Antarctica region".

10. I found the presentation of the 19 GHz data a bit confusing. If (as indicated Page 12, lines 1-2) the 19 GHz data are not used in most of the study, why present them here? I think it makes the story much more confusing for readers to try to absorb.

The main reason of presenting the 19 GHz data and modeling is to ensure that our results are not biased by a poor representation of the snowpack below 1 meter deep (penetration depth of the 37GHz frequency). This can be ensured using TB19,V because of its penetration depth around 5 meters. Using 19 GHz modeling also permits to assess the model simulations of brightness temperatures.

11. Page 13, Figure 6. So as I understand the paper, the 37 GHz PR is more-or-less being inverted for surface density. So (in a simplistic reading) we should expect to see a correspondence between Figure 3 and Figure 5. Is that correct? Please comment.

That is more or less correct. First, yes the retrieved surface density from satellite is inversed from PR at 37 GHz, and thus there is similarities between Figure 3 and Figure 5. But many aspects differ between the two curves: 1. PR37 and the retrieved density have the opposite evolution, basically rho = - f(PR37), f a monotonic increasing function; 2. the relationship between PR37 and the retrieved density is not linear, changes for low values of the polarisation ratio involve higher changes in the surface density than for high values of PR (see Figure 4.a) ; 3. the time period of Figure 3 is 2007 – 2012 whereas it's 2002 – 2012 for Figure 5. Finally, looking carefully for the same time period, it can be seen that the opposite variations between the two signals, like the very high values of PR37 in January-February 2009 and 2010 (in Figure 3) corresponding to very low retrieved density values (in Figure 5).