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Interactive comment on "Evaluation of single-band snow patch mapping using high resolution microwave remote sensing: an application to the Maritime Antarctic" *by* C. Mora et al.

G. Vieira

vieira@campus.ul.pt

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Thank you very much for the questions and remarks that we believe contribute to clarify several parts of the manuscript. Below, we present a detailed answer to the questions you have raised concerning the text and tables, while we have clarified the manuscript accordingly, and have also included your technical corrections. We will send this in the revised manuscript and we hope that you find our answers sactisfactory.

Question : ' There is an incidence angle dependency of the backscattered signal. Depending on the local incidence angle of your terrain (SAR scene incidence angle + terrain slope), this can become significant. You cite this effect in the introduction, and you also observe it at steeper terrain slopes, where your classification fails. If

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Discussion paper

your method is intended for wider use (and in your abstract, you mention a possible operational application), how can you handle incidence angle dependency? ' Reply : This is a significant issue that will always include limitations linked to the difficulties on accurately modelling the backscattering, but that we think could be mitigated with improved digital elevation models (e.g. better accuracy and better resolution). An approach could be by using UAV-based aerial photo surveying and DSM generation. However, such models will never be perfect due to temporal changes in snow accumulation patterns inducing varying local snow morphologies. Slope have been widely studied to introduce geometric corrections (e.g. Mi et al, 2014; Small et al, 2010), but we have adopted a simpler but robust approach through Range Doppler Terrain Correction, taking into account the advantage of a 5 m DEM. However, as we show, some incidence angle + slope relationships will remain difficult to resolve. In the procedure that we have applied, the incidence angle and terrain slope are both considered in the absolute radiometric calibration to sigma nougth in ESA-SNAP software (Kellndorfer et al, 1998), and in the subsequent phase of Range Doppler Terrain Correction. Using imagery with showing multiple SAR incident angle backscattering responses would be the best approach to infer a more complete radiometric perfomance of the terrain signal and is a recommended practice to regionalise the results. Unfortunately, in this case only two scenes were available (HH with 45.626 incident angle and VV with 29.875 incident angle). The original plan was to have more imagery, but not all acquisitions were guaranteed. We will improve the discussion of this issue in the revised version of the manuscript.

Question: You found the HH scene to be better suited than the VV scene acquired on the following day. Do you have an explanation for this observation? Reply : We have found a similar behaviour when using Envisat ASAR imagery for Deception Island (Mora et al 2013), as well as other authors, such as Baghdadi et al., 1998 using polarimetric SAR data at C-band for the classification of land covers (open areas, lakes ice, and forests, all covered with wet snow) and they have also concluded that HH-polarisation is better than VV-polarisation. The backscattering behavior is dependent

on the dryness of the snow, on the incident angle and on the roughness of the surface. For classification purposes the most important issue is the separability between classes and in this case, it seems that HH is more appropriate to separate between water, bare soil and wet snow. Additionally, VV polarisation is more sensitive to water roughness changes. In the case of our scenes, the HH scene shows a higher incidence angle, which improves resolution in a terrain with an irregular topography (Woodhouse, I., 2006), such as the study area. We will improve the manuscript, by adding this discussion.

Question : The water bodies you observed show very low backscatter. How would your classifi- cation approach handle wind-roughened water which can become very bright due to Bragg scattering? Reply : This is a very good question. In order to implement our approach operationally, the lake surfaces should be masked after an initial detection. This would pose issues where lake water levels vary very significantly, or where lakes cover a large percent of the terrain, but neither is the case in the ice-free areas of the Maritime Antarctic. So, an initial assessment of lake boundaries, either using imagery in low wind conditions, or using optical imagery, could be used to create a lake mask. We will introduce this discussion in the manuscript.

Question : In line 24-25, you state that 'Most applications have been developed for regional scale mapping, but for higher resolution approaches they lack quality.' This is a very strong remark, please elaborate on that. Reply : You are right. We will clarify the sentence and delete the last part. Essentially, the literature lacks published results on the use of SAR for snow mapping and very high resolution (metric).

Question : 3.1 Field characterization of the snow cover: First of all, I think it is a very good idea to comment on the failed temperature measurements and to give a detailed analysis of the possible cause. Still, I am missing a description of the other methods of measurement. How did you measure grain size and how do you define grain size in the first place? How did you measure snow density? Reply : You are right. We will improve the description of the snow-pit characterization. Grain-size was measured by

carefully collecting small amounts of snow from each of the layers of the snow pack and by depositing them in a black tissue for contrast. They were then observed with a 10x magnifier, which allowing for measuring and describing the grain shape and size. Grain size (or crystal size) showed variability some within each layer and our descrition encompasses the mean grain-sizes, but when variability was large, we included the more frequent dimensions (i.e. 1-2 mm). Snow density was measured by carefully collecting snow from each snow layer without disturbing the density, using a metal box with a volume of 212 cm3. From each layer, 3 boxes were collected, adding up 636 cm3, which were inserted in a plastic bag and weighted using a digital spring scale, and mass converted to density.

Question : 3.2 SAR imagery classification: This section does not actually describe the classification method, maybe you should rename it to 'SAR image processing' or something similar. Reply : You are right. We will change it as suggested.

Question : 4.2 Snow patch temperatures: Did you consider using external temperature measurements, e.g. from AWS or Reanalysis data, for your study? Given the narrow range of temperatures for your test site, it would have been also interesting to have temperatures available for the September image. Reply : No, we only planned to use snow temperatures. The diurnal range is really small, but we will check on the availabilty of daily data for the studied days, including the September scene. Using reanalysis can be an option. We will check the data and use it for improving the characterization of the meteorological conditions.

Question : 4.4 Wet snow patch backscattering characteristics: On page 8, lines 4-5, you state that 'Figure 9b shows that at HH polarization a weak positive correlation exists...'. I cannot see any correlation in the figure and suggest to rephrase this sentence. Reply : The figure is 10b (there is a typo in the text) and if you remove the outlier, which is the snow patch showing a grain-size of 2mm and a backscattering of -9.0 dB, you will find a R2 = 0.23 at $p < 0.14$, thus not statistically significant but with an identifiable weak trend. We could delete this, but we think it might provide leads to future research.

If we calculate the average dB per grain size, the correlation becomes even clearer with an R2 = 0.94 at p < 0.15. We will clarify the text and also the graph, by including the straight line and an indication of the outlier to exclude. However, this is also something that we could easily remove.

Question : 5.3 Classification using an object oriented algorithm: Here, you use a set of morphological filters to suppress speckle and to obtain more homogeneous regions. If the quality of your threshold-based classification suffers from the same noise characteristics, then why didn't you use that set of filters for all classifications? Reply : We avoided using too much filtering in the pixel-based classification since it relies on single pixel backscattering and preferred to only use a majority filter for visualization purposes, after the evaluation of classification quality. For the object-based approach, it was necessary to remove the noise in order to improve the segmentation process and hence filtering was conducted.

Question : Table 3: There is something seriously wrong with this table. From column 7 on, it does not make any sense. Reply : You are right. We have mixed some of the columns when organizing the table for the submission. We are now attaching the correct table.

Question : Table 4: What do you mena by prod. acc. / user acc.? Please explain the abbreviations. Answer : These are two frequently used measures in confusion matrix analysis, the producer accuracy and the user accuracy. The former measures the errors of omission (pixels correctly classified as a percentage of the total nr of pixels that belong to that class), while the later measures errors of comission (the number of correctly classified pixels compared to the total number of pixels assigned to that class).

Question : Figure 12: The legend is very hard to read, please make it bigger. If you have 4 classes in the image (white, light and dark gray, black), why do you only have 3 of them in the legend? Answer : We will enlarge the legend and make it

a single common legend for both figures. We will also add the white class with the indication of unclassified. This class shows very high values of backscattering, which in our classification approach were unclassified, since they are higher than the upper boundary of bare soil. This effect is linked to artifacts associated to relief displacement, which were not resolved even with the 5 m DEM.

Question : Figure 14b: This figure is very hard to interprete, since it looks just like Fig 14a tinted red. Maybe a zoomed-in region could provide a higher level of detail? Answer : You are right. We will provide a zoomed-in window for better visualization in the revised version of the manuscript.

4 Technical corrections: Question : page 3, lines 20-22, 'Mapping of the later...': This sentence got a bit lost, it seems. Answer : We think that this sentence is important, but we will clarify it by indicating ' Mapping of snow patches and monitoring melting patterns. . . '

Question : page 4, lines 14-16, '... geocoding of the TerraSAR-X scenes and ground.': There is something missing here. Answer : You're right. We have added ' . . .and ground truthing. '

Question : page 4, line 30, 'Pervasive moisture...': This sentence appears to be a bit out of context, maybe shift it up a bit, after 'Each of the snow pits...'. Answer : You are right. Thanks. We will move the sentence as suggested.

Question : page 8, lines 15-16, 'Given the best quality...': This sentence is a bit confusing, please rephrase. The next sentence is missing a 'the'. Answer : Right. We will change it to ' The best quality of the discrimination in the HH-polarisation scene of 12 January, when compared to the VV-scene of 13 January, led us to its selection for assessing the application of backscattering thresholds and band maths for the classification. '

Question : page 8, line 24, 'thresholds '": If you use uppercase on the other scenarios,

use it here as well. Answer : You are right. We will change it accordingly.

Question : page 8, line 29, Fig. 10: should probably be Fig 12. Answer : You are right. We will correct this in the revised version of the manuscript.

Question : page 10, line 25: 'snow patches showed rare ice layers': I suggest rephrasing to '...snow patches rarely showed ice layers' Answer : Right. Thanks.

Question : page 11, lines 26-27, 'The acquisition mode is very relevant...': I don't really understand what you mean to convey with this sentence. Answer : You are right. We will remove this sentence. It is a relic from a previous draft and we forgot it here and is not needed.

New references cited:

N. Baghdadi, C. E. Livingstone, and M. Bernier, Airborne -Band SAR Measurements of Wet Snow-Covered Areas, IEEE Transactions on Geoscience and Remote Sensing, vol. 36, no. 6, november 1998 Mi, L., Hoan, N.T., Tateishi, R., Iizuka, K., Alsaaideh, B. and Kobayashi, T. (2014) A Study on Tropical Land Cover Classification Using ALOS PALSAR 50 m Ortho-Rectified Mosaic Data. Advances in Remote Sensing, 3, 208-218. http://dx.doi.org/10.4236/ars.2014.33014 Kellndorfer, J.M., Pierce, L.E., Dobson, M.C. and Ulaby, F.T. (1998) Toward Consistent Regional-to-Global-Scale Vegetation Characterization Using Orbital SAR Systems. IEEE Transactions on Geoscience and Remote Sensing, 36, 1396-1411. http://dx.doi.org/10.1109/36.718844 âĂĺ Small, D., Miranda, N., Zuberbühler, L., Schubert, A. And Meier, E., Terrain-corrected Gamma: Improved thematic land-cover retrieval for SAR with robust radiometric terrain correction. Proc. 'ESA Living Planet Symposium', Bergen, Norway 28 June – 2 July 2010 (ESA SP-686, December 2010). Woodhouse I.H. : Introduction to Microwave Remote Sensing. Taylor and Francis, 2006, 284-285

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	Backscattering (dB)							Surface (0-5 cm)			Subsurface (5-10 cm)		
Snow patch	Mean	std dev	Max	Min	Slope (°)	Aspect	SWE (cm)	Grain Size (mm)	Density (kg/m3)	Ice layer	Grain Size (mm)	Density (kg/m3)	Ice layer
3	-18.2	1.3	-14.1	-22.0	15	N360	4.7	3	472	no	2	487	yes
12	-18.2	1.8	-8.2	-22.7	9	N130	5.5	4	550	no	4	519	no
5	-18.8	1.1	-14.9	-23.0	20	N10	4.7	3	472	no	4	487	no
7	-18.8	1.4	-14.8	-23.5	8	N290	4.6	3	456	no	2	487	yes
1	-15.0	1.8	-9.2	-19.6	11	N270	4.7	3	472	no	4	487	yes
2	-9.0	1.4	-4.5	-14.9	34	N270	5.0	2	503	no	4	550	yes
4	-16.2	2.8	-8.0	-20.7	20	N180	4.7	4	472	yes	3	519	yes
6	-19.6	1.0	-13.6	-22.8	9	N130	4.7	2	472	yes	1	550	no
8	-17.8	1.8	-4.4	-21.6	6	N170	5.2	2	519	no	2	519	yes
10	-18.5	1.6	-13.2	-23.4	8	N70	6.0	3	597	no	1-2	597	no
11	-17.2	1.6	-13.1	-21.4	10	N280	5.2	3	519	yes	3	519	yes
13	-19.8	1.0	-16.6	-23.6	20	N120	5.2	2	519	yes	2	550	no

Table 3: Snow patch characteristics and backscattering in HH-Polarization (12 January 2012). Density measurements exclude the ice layers

Fig. 1. Table_3_reviewed