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Interactive comment on "Hoar crystal development and disappearance at Dome C, Antarctica: observation by near-infrared photography and passive microwave satellite" *by* N. Champollion et al.

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We thank the referee #1 for his questions and comments. All questions and comments were considered and are addressed in the following of the document.

1/ About hoar and remote sensing.Is the hoar really transparency to microwave data ?

Microwave emission of the snowpack is not transparent to presence of hoar on the surface. Indeed, hoar on the surface formed one layer which is similar to a snow layer with low density and large crystals. Like all layers in a snowpack, the hoar layer

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participates to scattering and absorption of the microwave emission. At 19 and 37 GHz, the penetration depth is typically from 1 to 2 meters and hence, the 1 – 2 cm hoar layer contributes only very slightly to scattering and absorption. In opposite, hoar layer is essential for surface reflection and hence for polarization ratio variations, which are mainly influenced by dielectric contrast between air and snow and therefore the snow density (this aspect is presented in the 2.2 section).

2/ How to be sure that the relation between presence of hoar and polarization ratio is only due to the snow density ?

The relationship between presence of hoar and polarization ratio is mainly due to snow density because the Fresnel surface reflection does not depend of snow grain size and depends slightly on snow temperature. The surface roughness might have an influence. However, according to the theory, the impact of surface roughness on microwave emission at 55° is weak (Mätzler, 2005). Moreover, we found similar amplitudes of polarization ratio variations at low frequencies (6 and 10 GHz) than at 19 and 37 GHz frequencies, which suggest that surface roughness is negligible. Indeed, surface roughness is known to have a highly-wavelength dependent influence on microwaves (this aspect is presented as the end of the 2.2 section).

3/ Do the authors try to use higher frequency, to see the difference ?

Our choice to study the 19 and 37 GHz frequencies is based on the works of Shuman (Shuman et al., 1993). However, the brightness temperature at 89 GHz and at 6 and 10 GHz, i.e. lower frequencies available from AMSR-E satellite, were also investigated. We observed that 6, 10 and 89 GHz polarization ratios are, at first order, correlated to the presence of hoar on the surface and their variations are similar to 19 and 37 GHz frequencies. Some discrepancies were however observed. For example, 89 GHz channel was noisy with some variations not correlated to formation or disappearance of hoar. As opposite, all changes in surface state are not detected on the evolution of low frequency polarization ratios. Physical reasons are not totally understood. For

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low frequencies, the thickness of the hoar layer is smaller than the wavelength. Hence, the surface reflection depends also on the snow layer under the hoar and the polarization ratio could not change if the hoar surface layer is thin. For high frequency, other changes on the surface than formation of hoar could affect the polarization ratio.

The following sentence is added line 4, page 185: " Based on the results of Shuman et al. (1993) and the measured thickness of hoar on the surface (1 - 2cm), other channels of AMSR-E satellite, i.e. 6, 10 and 89 GHz, were not used in this study. Wavelengths of the 6 and 10 GHz channels are indeed much larger than the thickness of the surface layer of hoar and conversely for the 89 GHz channel. "

4/ About the characterization of surface state. The characterization of surface state: why use a threshold for hoar presence ? If I have well understand, the surface state (see Figs 5 and 6) is estimated with the "C" of Eq.7 ? This parameter can probably be greater than 0.94 ? It could be interesting to see the evolution of this parameter during hoar presence ? The value of C parameter may be given for the four pictures of Fig. 3 ? I think that the two histograms of C values (for summer and winter) could be shown ?

We answer together to all these questions because they all concern how to derive the presence of hoar from the parameter C derived from texture analyses of the pictures. In addition, we completed the explanations about the C parameter which are not clear on the manuscript. The C value represents the occurrence of small repetitive patterns on the picture, i.e. the small scale heterogeneities of the surface (hoar), calculated with the Eq. 7. Hence, during the summer period where illumination is natural and homogeneous along the picture, C value is higher where hoar is present. Indeed, the hoar-pictures are speckled and the small scale heterogeneities (hoar) on the pictures have similar sizes, shapes and intensities throughout the figure (see Fig. 3.a). In opposite, during the winter period where illumination is artificial and inhomogeneous, C value decreases when hoar formed on the surface. In this case, the light intensity reflected by hoar as well as the apparent size and shape of hoar (small scale heterogeneities) vary from the left to the right of the picture (see Fig. 3.b). By comparing the

C value to a threshold determined with all pictures during a period (summer or winter), we determine if hoar is present on the surface.

The value of C could be much larger than 0,94. Indeed, values of the P matrix (eq. 6) are between 0 and 1 but the C value is the sum of all values of P times the distance to the matrix diagonal. It is of the order of 10000 to 20000. Based on the interdependence of illumination homogeneity and surface texture, we consider that is difficult to estimate a quantitative variable as the percentage of hoar on an image. Hence, we used a threshold for C value in order to determine the presence / absence of hoar, which is more robust and objective, although we miss some information. The evolution of C and the C value histograms could give more information but are more difficult to understand, use and interpret. Finally, it does not deserve our objective with respect to the time and space scale of satellite data. Accordingly, we prefer not to present the values of C in the legend of Fig. 3 in order to not overload the text.

We insert the C value histogram for the 2009 – 2010 summer period between the actual figure 3 and 4, with the following legend: " Histogram of the contrast index (C), which depends on the texture of surface pictures, for the 2009 – 2010 summer period. " In addition, we change the line 0 to 3, page 183: " The histograms of C values for both periods are clearly bimodal (as example, see the histogram for the 2009 - 2010 summer period on Fig. 4) but under natural illumination the hoar-covered pictures correspond to the lower mode while the opposite is observed in artificial illumination. "

We modify the line 16 to 19, page 182: " This period, where the illumination is natural, called "summer" hereinafter, extends from 1 September to 11 April at Dome C. The rest of the year (called "winter"), the illumination is artificial and almost constant. "

We add the following sentence after the line 9, page 183: " The difference between the mode which corresponds to hoar-covered pictures under natural and artificial illumination (respectively summer and winter periods) comes from the inhomogeneity of the illumination throughout the picture when it's artificial (Serra, 1984, 1988, Di Siquiera,

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F., R. et al., Multi-Scale Gray Level Co-Occurence Matrices for Texture Description, Neurocomputing, in press, 2013). “

On figures 5, 6, 7, 11 and 12, the scales do not apply to the surface state variable C. In order to be clearer, we add in the first parenthesis in the legend of Figs 5, 6, 7, 11 and 12: “ (Unscaled black symbols and small pictures above the graph). “

8/ Why do not use artificial light even for the summer period (as it is done for winter period), in order to be less sensitive to cloud and to be reduce the difference of detection between both periods ?

The spots are turned on even during the summer. However, the artificial illumination is much less powerful than the natural incoming solar illumination, even in cloudy conditions. For instance, the exposure time used by the camera is typically between 1/4 s to 1/10 s in summer and 1 s in winter, which indicates the ratio of irradiance between these periods. Even if it would be desirable, it is not possible to maintain the illumination constant.

Interactive comment on The Cryosphere Discuss., 7, 175, 2013.

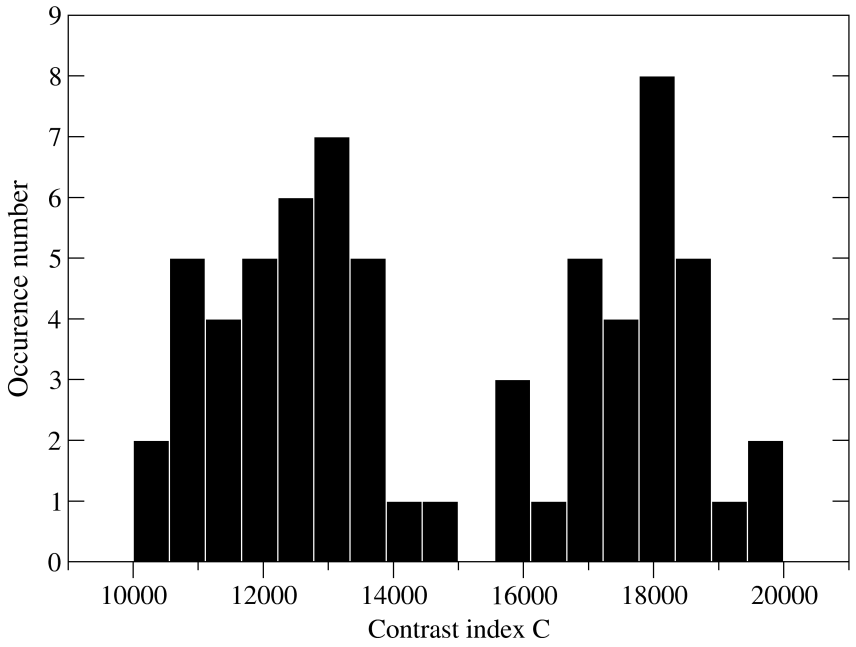

Fig. 1. Histogram of the contrast index (C), which depends on the texture of surface pictures, for the 2009 – 2010 summer period.

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