Interactive comment on "Can C-Band SAR be used to estimate soil organic carbon storage in tundra?" *by* Annett Bartsch et al.

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We would like to thank anonymous Referee #1 for the comments. The questions point to a number of issues which need to be better elaborated in the description of the approach in order to make it more understandable to the reader.

Tundra and in general wetland environments are commonly classified based on non-frozen period data when SAR data are employed. There are to date only very few studies which make use of frozen period acquisitions (Duguay et al. 2015, Widhalm et al. 2015). The advantage for using winter data is that only roughness and volume scattering contributes to the return signal intensity. During summer, there is the influence of liquid water in addition. Increasing soil moisture increases backscatter. High C-band backscatter areas are often open wetlands (especially peatlands, e.g. Bartsch

et al. 2009, Reschke et al. 2012) but can be also areas with high roughness and/or volume scattering. Locations with higher Soil Organic carbon (SOC) are areas with low roughness (with respect to C-band, 5.6 cm wavelength). The higher SOC, the lower is the winter backscatter (since it excludes the soil moisture effect), see also Figure 1 which exemplifies this for Kytalyk. When comparing summer average backscatter with SOC data, no relationship can be found for the SOC zones as soil moisture adds to the backscatter of the wetter (and at the same time higher SOC) sites.

In cases where the near surface soil is close to saturation, C-band can be used to distinguish peatlands to some extent (Reschke et al. 2012). This does however only lead to a yes/no classification. Such maps (or any other appropriate landcover classification) could be used in addition to the presented approach in order to indicate areas where it is expected that SOC is underestimated.

The correlation with winter backscatter is expected to result from a combination of roughness (surface response) and volume scattering within the remains of the vegetation (regarding snow, see below). In order to distinguish the different scattering types, polarimetric SAR data as e.g. used in Ullmann et al. (2014) would be required. Such data are however not available from ENVISAT ASAR GM. Since winter data are used, only interaction with the remaining woody parts is expected. The contribution becomes important when stems reach a certain size with respect to the used wavelength. Figure 2 shows a photograph of a willow tree with stems larger than the wavelength. The used training and validation sites include also willow dominated landcover. The obtained results from these locations do not indicate that the chosen approach is not applicable. SOC derived from ASAR GM is close to SOC from high resolution optical data (Figure 8 of the manuscript) for willow classes. SOC might be however underestimated in case of thicker stems.

L-Band ($\sim$23cm wavelength) would better penetrate to the ground in these environments (a relationship with biomass is expected in forests with thicker tree trunks). It may give better indications of soil moisture during the summer season. The interaction

with the surface material (roughness and volume scattering) is however expected to be much less than with C-band with respect to the surface characteristics (see Figure 2 of the manuscript). The sensitivity to the relevant surface features which are used as proxy for SOC is expected to be lower.

Interaction of the C-band signal with snow grains needs to be accounted for. There is especially an effect when ice crusts form (Naeimi et al. 2012, Bartsch 2010). Backscatter does increase in such cases. C-band is however less sensitive to snow pack changes than shorter wavelengths (such as e.g. Ku-band, Bartsch 2012). Backscatter can increase during the course of the winter by about one db at some locations (Naeimi et al. 2012). In a case study for Yakutia, no increase of ASAR GM backscatter with increasing SWE (snow water equivalent) could be observed (Park et al. 2011, Figure 8). In order to account for possible contributions by snow cover

(1) only December data are used, assuming that there are frozen conditions and snow depth is still limited, and

(2) the minimum from the 5 year period (on average 45 acquiaitions per pixel available) is calculated in order to have the lowest as possible impact (this also accounts for the GM specific noise)

Pedon data represent point locations. Due to the very heterogeneous environment it cannot be expected that they are representative for 1km areas (GM resolution). They are therefore only of limited applicability for validation. The zonal maps which have been made based on high resolution optical satellite data are used for the calibration and validation instead. These maps have been quality checked at all the sites. We have nevertheless decided to show a comparison to the pedon data, since the soil type information (which plays a role in the applicability of the approach, as shown in the comparison with the NCSCD data) is not preserved in the zonal maps. The line in Figure 12 therefore represents only the reference and is not a fitted function.

Many thanks for pointing out the publication by Mishra & Riley.

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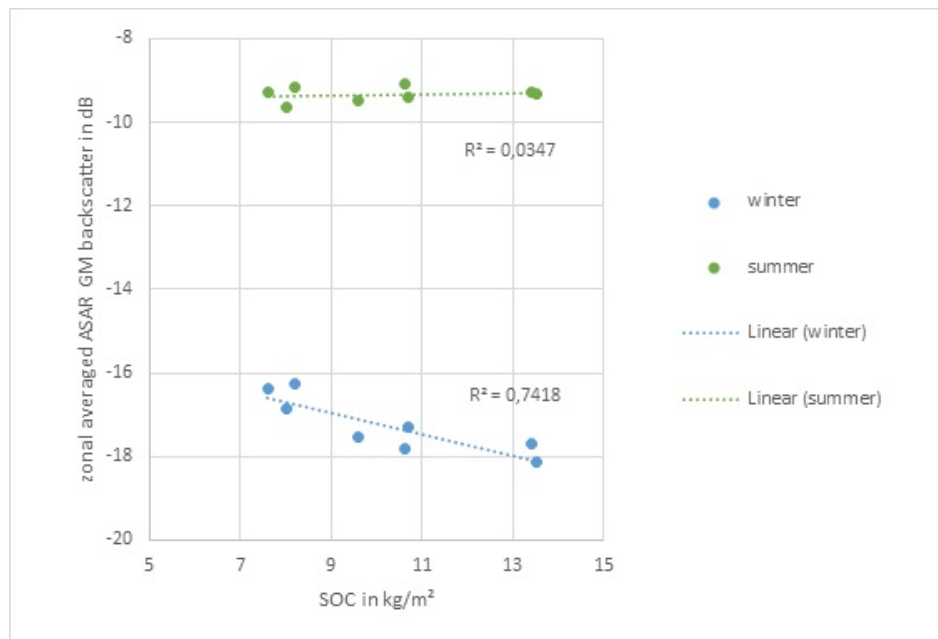
Fig. 1. Comparison of zonal averaged December and Summer average backscatter from ASAR GM with Soil Organic carbon values (0-30cm) for Kytalyk

Fig. 2. Salix vegetation with lens cap (diameter 5.6 cm) as scale (source: Widhalm et al. 2016).

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