THE USE OF RADARSAT-2 AND TERRASAR-X DATA FOR THE EVALUATION OF SNOW CHARACTERISTICS IN SUBARCTIC REGIONS

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ABSTRACT

This paper investigates the potential for the combination of RADARSAT-2 and TerraSAR-X data to evaluate snow characteristics in subarctic regions. The study area situated around the Umiujaq community (56.55° N, 76.55° W) in northern Quebec, Canada. RADARSAT-2 and TerraSAR-X data were acquired between March 2010 and April 2012 during the fall and winter seasons. Snow measurements were made in coordination with satellite acquisitions and vegetation was sampled in the summer of 2009. A temporal analysis is first performed on the fall data to determine when ground freeze-up occurs. The fall image which corresponds to frozen conditions is then compared to winter images using temporal backscattering ratios. This method shows a good sensitivity to varying snow conditions and the different frequencies provide complementary information. However, there is still some ambiguity on the exact influence that shrub vegetation has on the SAR signal.

Index Terms— SAR, Snow, RADARSAT-2, TerraSAR-X, Multifrequency

1. INTRODUCTION

Snow plays an important role in the environmental processes of the subarctic environment. Its insulating properties affect the permafrost's active layer freeze/melt cycle and provide protection for vegetation during the winter season. Vegetation, in turn, intercepts drifting snow causing localized accumulation therefore creating a positive feedback, favoring the expansion of scrublands at the expense of the tundra [1]. Precise mapping of snow accumulation patterns then becomes important to understand the complex ecological processes in subarctic regions, especially within the context of observed climate changes. The objective of this study is to map out snow characteristics (density, depth, Snow Water Equivalent) in subarctic regions using multipolarised and multifrequency Synthetic Aperture Radar (SAR) data. Previous studies have shown the potential of the C and X band SAR data combination to retrieve snow characteristics [2]. The shorter wavelength of the X-band makes it more sensitive to snow characteristics while at C-band the longer wavelength will be more affected by soil properties. Of particular interest to this study is the influence that the vegetation embedded within the snowpack has on the scattering of the electromagnetic wave at different frequencies.

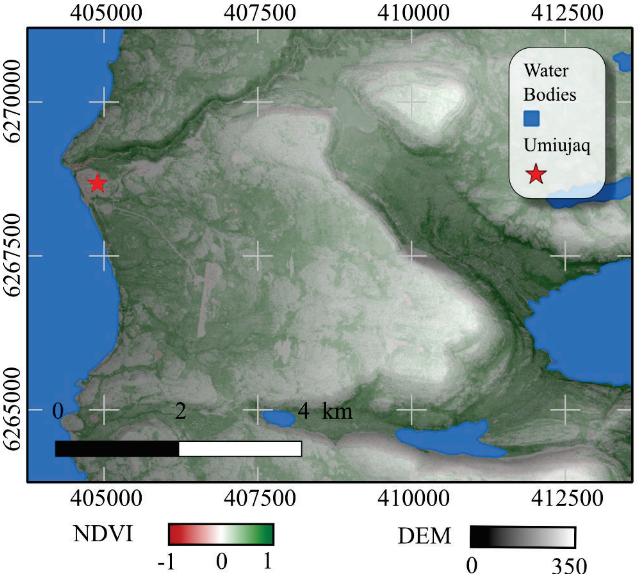

Figure 1: DEM of the study area overlayed with an NDVI map from August 2009. Coordinates are in UTM zone 18 N.

2. METHODS

The study area is a 60 km^2 region situated around the Umiujaq community (56.55° N, 76.55° W) in northern Quebec, Canada. The area can be divided into two distinct environments: the coastal region to the east and the Lac Guillaume-Delisle graben to the west. The vegetation in the coastal region is very sporadic and dominated by tundra vegetation, while the graben vegetation is mainly shrublands with patches of conifers. A Digital Elevation Model (DEM) of the area overlayed with an NDVI map is shown in Fig. 1. A series of polarimetric RADARSAT-2 scenes (HH, HV, VH, VV polarisations) were acquired over the study area during the winter and fall seasons from 2010 to 2012. Dual-polarised TerraSAR-X scenes (HH, HV polarisations) were acquired over the area during the 2011 and 2012 winters and

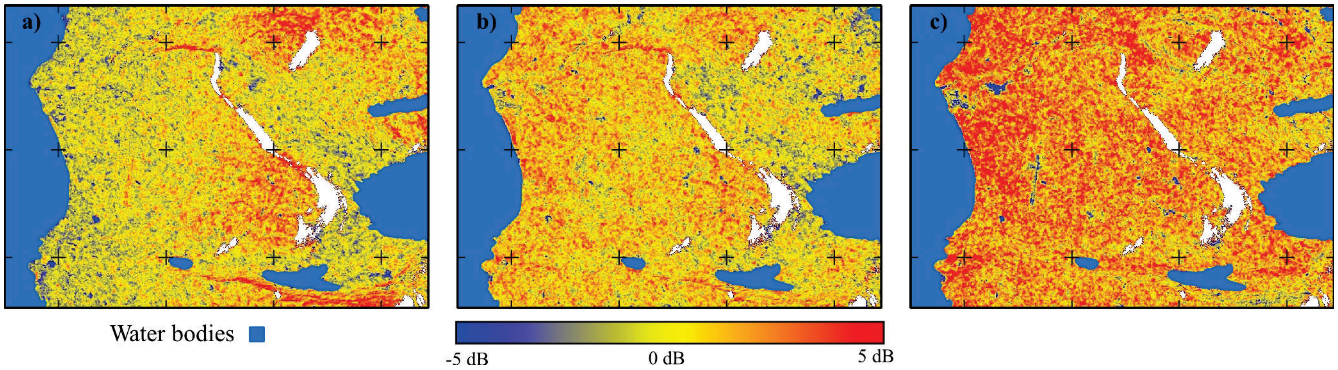

Figure 2: RADARSAT-2 backscattering ratio images of fall 2011 acquisitions at an incidence of 27°. a) October 22/November 15 at HH polarization. b) October 22/December 09 at HH polarization. c) October 22/December 09 at HV polarization.

the 2011 fall seasons. Two incidence angle (θ) ranges were acquired, low incidence at θ≈27° and high incidence at θ≈38°. The winter data are acquired during March and April when the snow cover is at its maximum. The fall data are needed as reference snow-free data and are acquired between late October and early December, at the start of the ground freeze-up and when the snow cover is usually negligible. Six field campaigns were carried out in coordination with satellite data acquisitions during the 2010, 2011 and 2012 winter seasons. Snow depth, density and snow water equivalent, as well as ground temperatures were measured over various terrain types. Snowpits were dug at selected sites to gather information on particle size and shape in addition to snow densities from the different layers of the snowpack. Data on vegetation characteristics have been collected during the summer of 2009. Information on average height and cover percentage of each species were collected within 245 plots.

A temporal analysis is performed on the SAR data, comparing the measured backscattering signal at different dates for various polarization and incidence angles. Backscattering intensity ratios are calculated for two images acquired at different dates. The first objective of this analysis is to identify the moment at which the freeze-up occurs in order to choose the fall acquisition which will have the most similarities in soil and vegetation conditions with the winter acquisitions. The second objective of the temporal analysis is to compare winter with fall data to see if it is possible to remove the influence of the various environmental variables, such as soil and vegetation characteristics, in order to isolate the effect of snow on the SAR signal.

3. PRELIMINARY RESULTS

3.1. Freeze-up time determination

To determine which fall acquisition corresponds to frozen conditions of the soil and vegetation, ratios are performed between images acquired in October, November and December 2011. The dielectric constants of frozen soil and vegetation will be lower than their thawed counterparts, which should lead to lower backscattering from the frozen features. In October, the temperatures are still relatively high and the freeze-up is not initiated yet, backscattering should therefore be stronger compared to other dates for areas where freeze-up has started.

Fig. 2a) shows the backscattering ratio of October/November at HH polarization, with positive values indicating stronger backscattering in October and negative values indicating stronger backscattering in November. While the backscattering is generally stronger in October at higher altitudes (≈ 150 to 350 meters) the lower areas display similar or even stronger backscattering in November. This could indicate that the ground is not completely frozen in November. Fig. 2b) shows the ratio of October/December at HH polarization. The backscattering is generally stronger on the coastal area for the October image, but the graben area still displays higher backscattering for December. Looking at the October/December ratio for the HV polarization (Fig. 2c)), it can be seen that the graben area has consistently higher backscattering in October. Cross polarized signal is generally associated with volume scattering from vegetation. This could indicate that the vegetation has frozen in December, generating less backscattering. Moreover, the October/November ratio for the HV polarization (not shown here) displays similar patterns than the HH polarization (Fig. 2a)), with higher HV backscattering for November in the graben area. This could indicate that the vegetation has frozen between November and December, but that other processes are affecting the HH polarization. One possible explanation is that en early snowfall has left a shallow snow cover, insulating the ground and keeping it at relatively high temperatures. This hypothesis will be confirmed with the retrieval of data from ground temperature sensors installed throughout the area during the 2012 summer season.

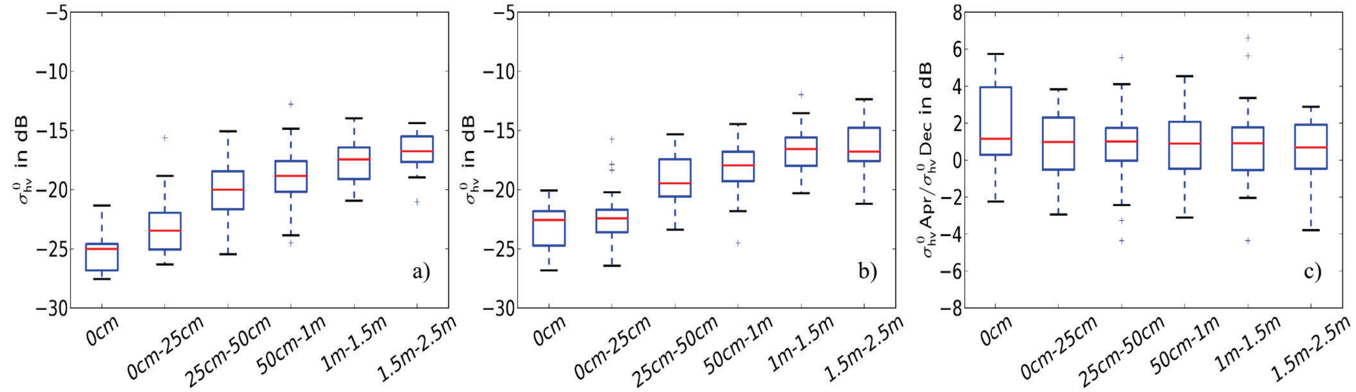

Figure 3: RADARSAT-2 backscattering (HV polarization, θ≈38°) measured at each of the 245 vegetation sampling sites, broken down into 6 vegetation height classes. a) December 6 2011, b) April 4 2012, c) backscattering ratio April/December

3.2. Vegetation and snow

One important environmental phenomenon in subarctic regions is the expansion of shrublands. This can have important effects on the snow cover as shrubs can intercept drifting snow to create accumulation areas and modify the physical characteristics of the snowpack. Shrub vegetation also affect SAR backscattering by increasing volume scattering. Fig. 3a) shows the boxplots of RADARSAT-2 HV backscattering for each vegetation height classes on December 6 2012. A steady increase of the backscattering is can be observed with increasing vegetation height. This trend is also visible during the April acquisition (Fig. 3b)), at the moment when the snow cover has reached its maximum depth, just before the onset of snow melt. By performing a ratio of the April/December images, it is possible to remove this trend.

In this context, taking the ratio of the winter and the fall images seems to reduce the influence that shrub vegetation has on the SAR signal. Taking the ratio of HH backscattering between the March and December acquisitions (Fig. 4a)), it can be observed that there is little difference in backscattering intensity between the two dates except for some areas where it is slightly stronger in the December image. The snow cover in March was subjected to little metamorphosis displaying relatively small grain sizes and an average density of 330 kg/m^3. Between the March and April acquisitions, two episodes of rain occurred which had an important impact on the physical properties of the snow. A thick ice crust formed within the snowpack and the water infiltration caused the aggregation of snow crystals forming large clustered grains. The average density of the snowpack was also slightly lower in April at around 310 kg/m^3 . The ratio between the April and December images (Fig. 4b)) shows a strong increase of the backscattering in April. At the time of the April acquisition, the snowpack had completely refrozen and its water content was practically null. In this case, the increase in backscattering could be explained by the presence of an ice layer and larger snow grains, generating stronger volume scattering from the snow cover. Looking at the April/December backscattering ratio of the TerraSAR-X images, it can be seen that the difference is even more important than with RADARSAT-2. TerraSAR-X operates at X-band, with a shorter wavelength (λ=3.1cm) than RADARSAT-2 (λ=5.6cm). This means that the the snow grains will be larger compared to the wavelength, generating stronger volume scattering.

At closer inspection, the areas with the most important differences in backscattering, either negative for the

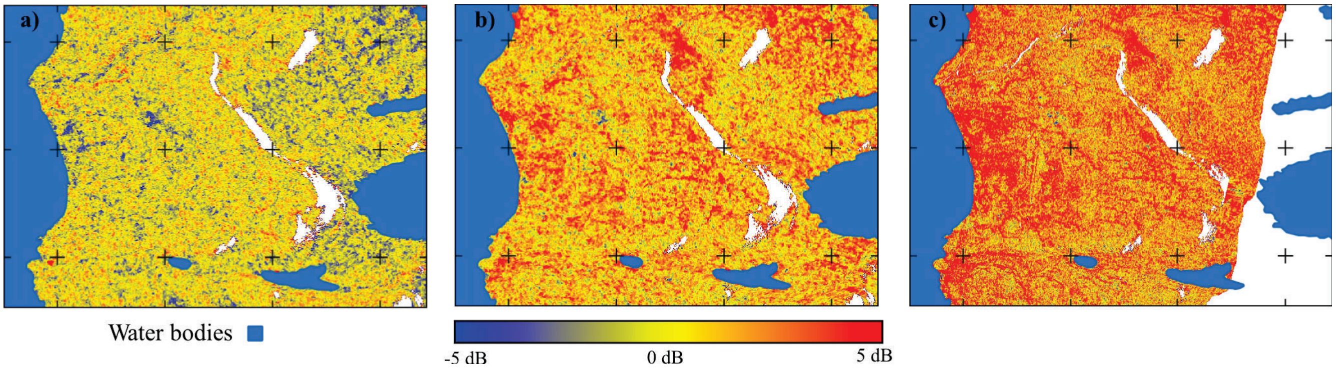

Figure 4: Backscattering ratio images between fall 2011 and winter 2012 acquisitions at an incidence of 27° and HH polarization. a) March 14/December 9 RADARSAT-2 image. b) April 7/December 09 RADARSAT-2. c) April 4/December 05 TerraSAR-X.

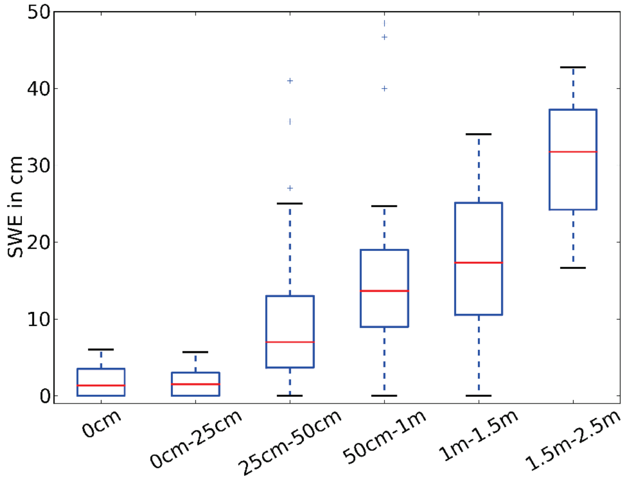

Figure 5: Snow Water Equivalent (SWE) measured in March and April 2011 for 6 vegetation height classes

March/December ratio or positive for the April/December ratio, tend to coincide with areas of stronger NDVI (see Fig. 1). This would tend to indicate that the influence of the vegetation has not been completely removed with the ratio technique. However, Fig.5 shows that snow accumulation (SWE = snow depth * snow density) is highly influenced by the vegetation, so there is a need for further investigation to determine its exact influence on the SAR signal.

4. CONCLUSIONS AND PERSPECTIVES

A temporal analysis of RADARSAT-2 and TerraSAR-X images was performed to investigate the potential to combine data from the two sensors to retrieve snow characteristics in subarctic regions. Fall images were first compared to determine the date of the ground and vegetation freeze-up using backscattering ratios. It was found that the early December acquisitions were made under frozen conditions, but there are some uncertainties concerning the Lac Guillaume-Delisle graben area. Backscattering ratios between the late winter and early December images were then performed to investigate the effect of the snow cover on the SAR signal. The presence of an ice layer in the snowpack as well as larger snow grain sizes in April had an important impact on the backscattering. However, there is still an ambiguity on the exact influence that the shrub vegetation has on the signal.

The next steps will concentrate on theoretical modeling of the backscattering from the snowpack. One limitation of the models commonly used in earlier studies on the electromagnetic scattering from snow is their inability to predict cross-polarised scattering. Kendra et al. [3] showed that cross-polarised scattering increases with snow depth at both C and X bands. Further studies will therefore focus on the evaluation of the importance of cross-polarised scattering from snow at X and C bands using recent advances in electromagnetic modeling of dense mediums [4]. Those should improve our understanding of the measured backscattering and provide some insight on the influence of vegetation contained within the snowpack. Polarimetric decompositions with RADARSAT-2 data will also be used to classify and possibly characterise the vegetation cover, leading to a ground cover based approach to snow characterisation.

5. ACKNOWLEDGEMENTS

The authors would like to thank the Canadian Space Agency for providing RADARSAT-2 images through its SOAR Education initiative as well as the German Aerospace Center (DLR) for providing TerraSAR-X images through the SOAR-DLR initiative. The authors would also like to thank Esther Lévesque from Université du Québec à Trois-Rivières for her collaboration and for providing invaluable vegetation data.

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