MONITORING OF SNOW COVER PROPERTIES DURING THE SPRING MELTING PERIOD IN FORESTED AREAS

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1. INTRODUCTION

Information regarding the status of snow cover during spring is important for hydrological-, meteorological forecasting applications and for climatological models. This includes such operative end-use tasks as flood prevention and the optimization of hydropower production. Snow water equivalence (SWE), regional SCA and snow status (dry/wet) are essential parameters for hydrological models used for forecasting the run-off in a catchment/sub-catchment scale. Space-borne SARs have shown their usefulness in wet snow detection and in SCA estimation for the spring melt period [1], [2], [3]. Even single-channel systems, such as the C-band ERS-2 SAR, have found to be useful. However, in the boreal forest zone, the forest cover deteriorates the accuracy of present empirical algorithms as the level of backscatter and the transmission through the forest canopy significantly change with time depending on weather conditions [4]. As well, the accuracies of algorithms are affected by the temporal changes of snow wetness and snow grain size/surface roughness of (wet) snowpack [5], [6].
We present in this paper an analysis of snow backscattering properties in vicinity of eight weather stations representing open and forested areas in Northern Finland. Analyses are carried out using an extensive multitemporal ERS-2 C-band SAR data set from the snow melting period. We validate the 1) forest backscattering model for forest compensation, 2) TKK fractional snow-covered area (SCA) method with *in situ* observations and 3) inversion of a combined forest/snow/ground backscattering model to yield estimates for the relative changes of snow wetness during full snow cover conditions.

2. TEST SITE AND DATA

The study area includes the eastern-most part of the River Kemijoki basin in Northern Finland. The region represents, in general, a relatively flat relief, even though some mountainous areas (fjelds) are located in the region. The study area is almost totally covered by sparse conifer-dominated forests. The River Kemijoki has a large economical importance due to hydropower production. The river system is regulated through a network of reservoirs. Nevertheless, flooding during the spring-melt period can cause serious problems. Hence, run-off forecasts play an important role both for hydropower production and for flood prevention.
The investigations were performed using 28 ERS-2 SAR data covering spring seasons of 1997-2002. The analyses were performed for eight separate test regions (size 15 km by 15 km), each of which is located around weather station. The available reference data includes land-use and forest map, the weather station observed temperature information, snow depth information, precipitation information, and SCA information at the vicinity of weather station.

3. ANALYSIS AND RESULTS

In the analysis we modeled the backscattering contributions using TKK boreal forest backscattering model [7] and simple multi layer snow backscattering model [8]. The modeled results were used to monitor annual behavior of spring time backscattering from snow covered boreal forest terrain. Additionally, we analyzed the behavior of TKK fractional snow-covered area (SCA) method with *in situ* synoptic station observations and inverted of a combined forest/snow backscattering model to yield estimates for the relative changes of snow wetness during full snow cover conditions.
Figure 1 presents the comparison of SAR-based SCA estimates with weather station-observed SCA. The presented SCA estimates are the values obtained for forested and open areas using TKK boreal forest backscattering model and TKK fractional snow- covered area (SCA) method. The results show that the developed SCA estimation procedure typically yields higher values of SCA for forested areas than for open areas, which is a clear improvement when compared with the results of using linear interpolation algorithms. The results also indicate a relatively high correlation between the weather station-

observed snow conditions and SAR-based SCA estimates. Evidently, this correspondence cannot be perfect as the *in situ* snow class is based on visual observation in the vicinity of the weather station, whereas the SAR-derived SCA estimate is calculated for the region around the weather station, with a size of 15 km by 15 km.

Figure 2 shows the snow wetness estimation results obtained by applying simple multi layer snow backscattering model for all snow observations with 100% snow cover from 1997 to 2002. This analysis includes also forested areas where the contribution of forest canopy is removed using TKK boreal forest backscattering model. The moisture estimates are compared with 3-day mean temperatures. The curve plotted in Figure 2 presents the fitting of logarithmic function to the estimates. The results indicate that even a single channel C-band SAR can be used for detecting temporal changes in snow wetness. Also, estimates from forested areas show logical values and agree well with those from open areas. Obviously, the absolute scale is not accurate as snow grain size and snow surface roughness properties are considered invariant with time.

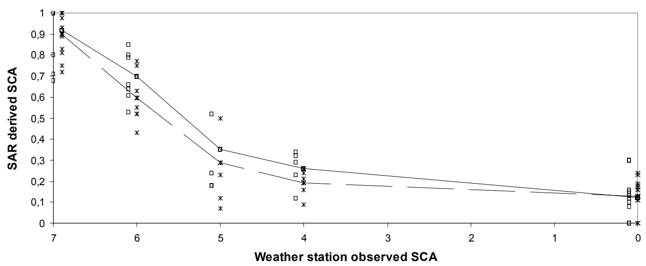

Figure 1. Comparison of SAR derived SCA estimates with weather station observed estimates. The data is from years 1997-2002 and from eight weather stations. Stars denote SCA values for open areas and squares those for forested areas. The dotted line is the average line for open areas and solid line is the average for forested areas.

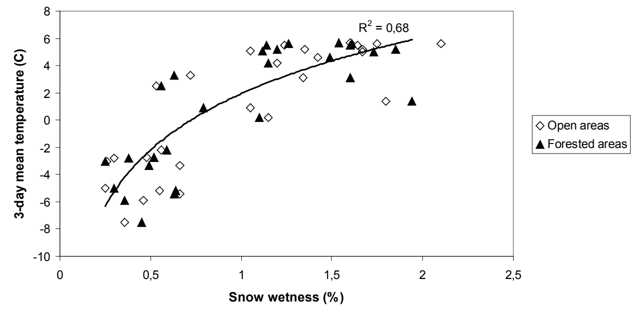

Figure 2. Snow wetness estimates obtained for conditions with 100% snow cover. The results are depicted as a function of weather station-observed 3-day average daily temperature. The used pre-fixed model parameter values are: $\langle s \rangle = 6$ mm, $\langle l \rangle = 5$ cm, $\langle d_0 \rangle = 2.8$ mm (effective snow grain size that is larger than the physical grain size), $\langle \rho \rangle = 0.3$ g/cm^3, $\langle h \rangle = 1$ m, $\langle s_g \rangle = 1.2$ cm and $\langle \varepsilon_g \rangle = 6 - 1j$ (frozen soil with some liquid water inclusions)..

4. CONCLUSIONS

The results of this paper show that the monitoring of snow cover for forested areas from space-borne single-channel C-band SAR data can be improved by using an adaptive forest backscattering model. This model helps us to differentiate the backscattering contribution coming from the forest canopy from the contribution coming from the snow cover. This allows us to calculate more accurate snow cover estimates like fractional snow-covered area (SCA) and effective snow wetness. Additionally, the benefit of employing backscattering model in snow information estimation shows its feasibility to be used with SAR observations representing varying incidence angles.

5. REFERENCES

[1] J. Koskinen, J. Pulliainen, and M. Hallikainen, "The use of ERS-1 SAR data in snow melt monitoring," *IEEE Trans. Geosci. Remote Sensing*, vol. 35, pp. 601-610, 1997.

[2] J. Shi, and J. Dozier, "Mapping seasonal snow with SIR-C/X-SAR in mountainous areas," *Remote Sens. Environ.*, vol 59, pp. 294-307, 1997.

[3] T. Nagler, and H. Rott, "Retrieval of wet snow by means of multitemporal SAR data," *IEEE Trans. Geosci. Remote Sensing*, vol. 38, pp. 754-765, 2000.

[4] J. Koskinen, J. Pulliainen, M. Mäkynen, and M. Hallikainen, "Seasonal comparison of HUTSCAT ranging scatterometer and ERS-1 SAR microwave signatures of boreal forest zone," *IEEE Trans. Geosci. Remote Sensing*, vol. 37, pp. 2068-2079, 1999.

[5] J. Shi, and J. Dozier, "Inferring snow wetness using C-band data from SIR-C's polarimetric synthetic aperture radar," *IEEE Trans. Geosci. Remote Sensing*, vol. 33, pp. 905-914, 1995.

[6] T. Strozzi, A. Wiesmann, and C. Mätzler, "Active microwave signatures of snow covers at 5.3 and 35 GHz," *Radio Science*, vol. 32, 479-495, 1997.

[7] J. Pulliainen, P. Mikkelä, J.-P. Ikonen, and M. Hallikainen, M., "Seasonal dynamics of C-band backscatter of boreal forests with applications to biomass and soil moisture estimation," *IEEE Trans. Geosci. Remote Sensing*, vol. 34, pp. 758-770, 1996.

[8] J. Koskinen, "Snow Monitoring Using Microwave Radars," Ph.D. Dissertation, Helsinki University of Technology, Laboratory of Space Technology, Report 44, Espoo, Finland, January 2001.