L-BAND SAR BACKSCATTER PROSPECTS FOR BURN SEVERITY ESTIMATION IN BOREAL FORESTS

Mihai Tanase[(1)], Maurizio Santoro[(2)], Juan de la Riva[(1)], Eric Kasischke[(3)], Michael A. Korets[(4)]

[(1)] *University of Zaragoza, Dpt. of Geography, Zaragoza, Spain, E-mail:* mihai.tanase@tma.ro
[(2)] *Gamma Remote Sensing, Gümligen, Switzerland*
[(3)] *University of Maryland, College Park, USA*
[(4)] *Sukachev Institute of Forest, Krasnoyarsk, Russia*

ABSTRACT

L-band Synthetic Aperture Radar (SAR) data has been investigated to establish the relationship between backscatter and burn severity in boreal forests. Advanced Land Observation Satellite (ALOS) Phased Array-type L-band Synthetic Aperture Radar (PALSAR) dual polarized images were available for the study of the backscattering coefficient at two locations. Statistical analysis was used to assess the average backscatter coefficient as a function of burn severity level after stratifying the data by local incidence angle. Determination coefficients were used to quantify the relationship between radar data and burn severity estimates.

The analysis for a given range of local incidence angle showed that HH and HV polarized backscatter decreases with burn severity for both polarizations when images are acquired under dry environmental conditions. For data acquired under wet conditions HH polarized backscatter increased with burn severity. The higher backscatter of the severely burned areas was explained by the enhanced contribution of the ground component due to higher soil moisture content. Backscatter variation between burned and unburned forest was around 2-3 dB at HH polarization and around 3-6 dB at HV polarization. This study indicates that L-band SAR backscatter trend as a function of burn severity is not significantly different when compared to previously studied mediterranean forests.

1. INTRODUCTION

Boreal forests cover approximately 15 % of Earth's land surface and contain over 35 % of all carbon stored in the terrestrial biome playing a significant role as carbon pool [1]. These forests are vulnerable to fire especially while considering their slow recovery rate and the potential of carbon release into atmosphere. The fire regime across North American boreal region changed during the last decades, the annual burned area and large fires frequency recording a twofold increase since 1950 which may alter post-fire ecosystems processes [2]. Variations in burned area and fire severity control fire emissions from boreal forest which in turn affect the atmospheric concentration of atmospheric CO at global scale [3]. Burned area estimation is the simplest and most common remote measure of fire effects and has been conducted using a wide variety of satellite sensors at local to regional scales [4]. Mapping studies used mostly information of the difference in spectral response before and after fire which allowed accurate detection of the burned areas [5, 6]. Active sensors such as synthetic aperture radar (SAR) were also found useful for discriminating fire affected areas [7, 8]. SAR data could be more useful in boreal or tropical forests where algorithms based on optical data are more likely to be limited by persistent cloud cover [6].

Estimation of fire effects has received considerable interest in the recent literature since it determines post-fire ecosystems processes [9] and has a significant influence on gas emission from burned areas [10]. Fire ecological effect is expressed by burn severity which estimates the degree of environmental changes caused by fire. The difficulty associated with field data collection made remote sensing the method of choice for burn severity assessment across large areas. One of the most widely employed spectral index is the normalized burn ratio (NBR) [11] used in a bi-temporal approach with pre- and post-fire datasets (dNBR). However, reflectance based indices are sensitive to plant phenology and solar elevation, so that monitoring severity trends over time or across regions can be subject to errors especially at high latitudes [12].

Recently it has been shown that burn severity is directly related to information provided by SAR sensors in mediterranean pine forests [13, 14]. The removal of leaves and branches by fire and the increased soil exposure influenced the backscattering from fire affected areas. L-band cross-polarized backscatter showed the highest sensitivity to burn severity. The current study complements these investigations focusing on boreal forests affected by fires. The main objective was to provide a preliminary assessment of Advanced Land Observation Satellite (ALOS) Phased Array-type L-band Synthetic Aperture Radar (PALSAR) L-band SAR backscatter sensitivity to burn severity in boreal forests. Signatures of fire affected areas and the prediction power of SAR intensity data for burn severity estimation were studied.

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2. STUDY AREA AND DATASETS

Two sites located in the boreal zone were considered. The first site was located in interior Alaska, approximately 200 km west of Fairbanks. The area stretches on a gently sloping alluvial outwash plane north of the Alaska Range, with elevations ranging between 100 and 400 m. In this region, the average annual temperature is -2.1 °C, with the warmest month being July (15.6 °C) and the coldest January (-19.7 °C). Average annual precipitation is 29 cm, with three-quarters of this amount occurring during the growing season (May to September). Three fires were selected for the study (Table1) using information provided by the Monitoring Trends in Burn Severity (MTSB) project. Two of the fires burned during the 2007 summer season (Mooseheart and Jordan Creek) whereas the third (Boney Creek) burned in summer 2005. The second site was located in central Siberia, approximately 200 km NW of Ust-Ilimsk, nearby the Angara river. The area is characterized by annual average temperature of -2 °C, the warmest month being July (18 °C) and the coldest January (-23°C). The average annual precipitation is 43 cm. The relief was represented mainly by plateaus and small hills, with elevation ranging between 200 and 400 meters. Two fires (Angara1 and Angara2) which burned during summer 2006 were selected for the analysis (Table 1).

The SAR dataset (Table 2) was acquired by ALOS PALSAR in Fine Beam dual polarization mode (FBD) with a 34 degrees look angle. SAR images were absolutely calibrated, multi-looked to obtain the desired 30 m spatial resolution and geocoded to Universal Transverse Mercator (UTM) projection using a digital elevation model [15]. Although most of the area was located on a flat or nearly flat terrain, topographic normalization of the backscatter was applied in order to obtain similar metrics (γ°) as for the previous studies [13, 14].

Fig. 1 shows the fire locations using a composite of L-band backscatter (HH and HV) and their ratio overlaid on the MODIS Vegetation Continuous Fields (VFC) product. In the PALSAR color composite, the fire scars can be distinguished from the surrounding forests. The green areas correspond to high cross-polarized (HV) backscatter and low backscatter ratio, which is characteristic for dense vegetation. The blue/purple areas correspond to low cross-polarized backscatter and high backscatter ratio, which is typical for areas with no or low vegetation. The fire scars appear in purple in consequence of the lower HV backscatter when compared to adjacent unburned forest.

For each fire a pair of Landsat TM images (pre- and post-fire) was used to estimate burn severity levels by means of dNBR index (Table 1). Terrain corrected

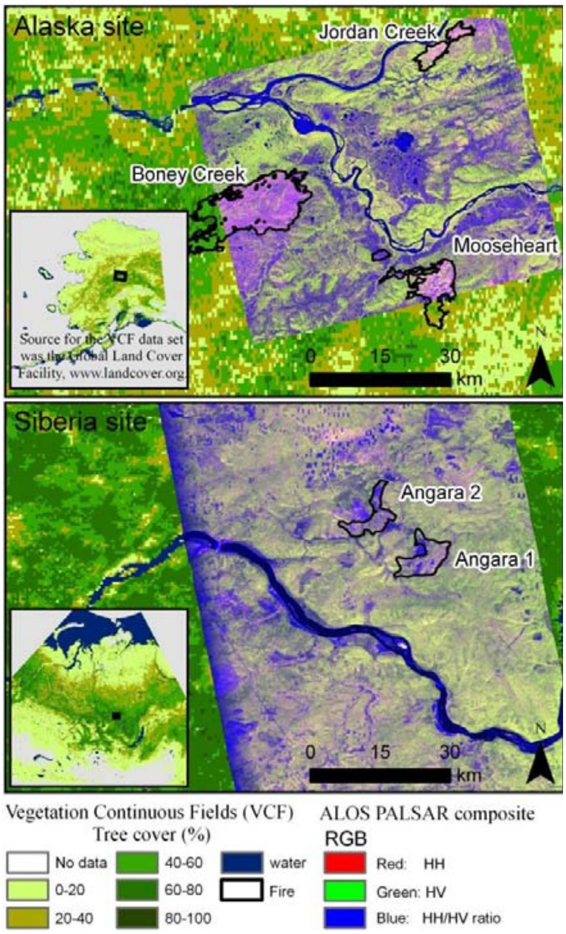

Fig. 1 Study sites and the fire perimeters. ALOS PALSAR images are overlaid on tree cover percentage map.

Table 1 Analyzed fire scars and the affected area together with the acquisition date of the Landsat images

Fire	Area (ha)	Landsat Pre-fire	Landsat Post-fire
Mooseheart[A]	8150	2005.07.20	2008.08.21
Jordan Creek[A]	3700	2001.09.02	2008.08.21
Boney Creek[A]	24700	2002.09.21	2006.09.08
Angara 1[S]	5700	2004.06.28	2007.09.01
Angara 2[S]	4500	2004.06.28	2007.09.01

A Alaskan site // S Siberian site

Table 2 ALOS PALSAR acquisitions and climate data (AcPp in mm and Tmax. and Tmin. in °C)

Date	AcPp	Tmax	Tmin
2007.06.10[S]	20.6	22.5	4.1
2007.07.09[S]	27.4	32.4	14.9
2007.07.26[S]	12.2	30.2	14.0
2007.08.24[S]	63.0	19.8	7.9
2008.08.03[A]	53.5*	12.7	3.3

A Alaskan site // S Siberian site
* precipitations registered partly during the day of SAR acquisition

Level 1T) Landsat scenes were acquired from U.S. Geological Survey (USGS) in UTM projection (Table1). From each image the additive haze component was removed using the dark-object subtraction technique.

To aid the interpretation, meteorological data collected from the nearest available meteorological station were used. For the Siberian site meteorological data were available from the Bogucany station located at approximately 150 km west of the fires whereas for the Alaskan site meteorological data were available from The Tanana station located 25 km N of the Boney Creek fire. The daily maximum and minimum temperature is presented in Table 2 for the dates of acquisition of the SAR images. Accumulated precipitation (AcPp) was computed taking into account the last two weeks before acquisition.

3. METHODS

The study was focused on relatively small size fires in order to assure certain forest homogeneity. Thus, any variability of the backscatter coefficient could be assumed to be related primarily to different burn conditions rather than to differences in forest structure and species composition. To understand the relationship between forest burn severity and backscatter coefficient dNBR based pseudo-plots were used. The reason for using pseudo-plots was the lack of field assessed estimated of burn severity. Pseudo-plots were generated by averaging pixels of similar burn severity (expressed by the dNBR index) for the same local incidence angle. The quality of these pseudo-plots with respect to field assessed conventional plots has been discussed in [13] for mediterranean pine forests. For Alaskan boreal forests, weaker relationships were reported between dNBR and a field assessed indicator of burn severity, the composite burn index (CBI) at some locations [16, 17]. Therefore, the relationship between SAR backscatter and burn severity could be hindered by inaccuracies of dNBR based estimates of burn severity.

Detailed information on pseudo-plots generation process is given in [13]. To avoid bias related to size, only pseudoplots containing a constant number of pixels were considered. For consistency with the previous studies nine pixels per pseudo-plot were used. Descriptive statistics were applied to analyze and compare backscatter as a function of burn severity. The potential of backscatter coefficient for burn severity estimation was assessed using inferential statistics. To minimize the effect of topography on the backscatter coefficient the analyses were carried out by 5º groups of local incidence angle as for the previous studies [13, 14].

4. RESULTS AND DISCUSSION

4.1. Signature analysis

Co- and cross-polarized backscatter coefficient as a function of burn severity are presented in Fig. 2 and 3 for slopes oriented towards the sensor (31-35°), flat or near flat areas (36-40°) and slopes oriented away from the sensor (41-45°). For the Siberian site two images acquired under different environmental conditions (dry and wet) are shown whereas for the Alaskan site the available image was acquired under wet conditions.

For the image acquired under dry conditions (2007.07.26) HH and HV backscatter decreased with the increase of burn severity in accordance with the results reported for mediterranean pine forests [14]. The backscatter variation from unburned to burned forest (dynamic range) was around 2-3 dB at HH polarization and between 3 and 6 dB at HV polarization, depending on the local incidence angle. The largest dynamic range

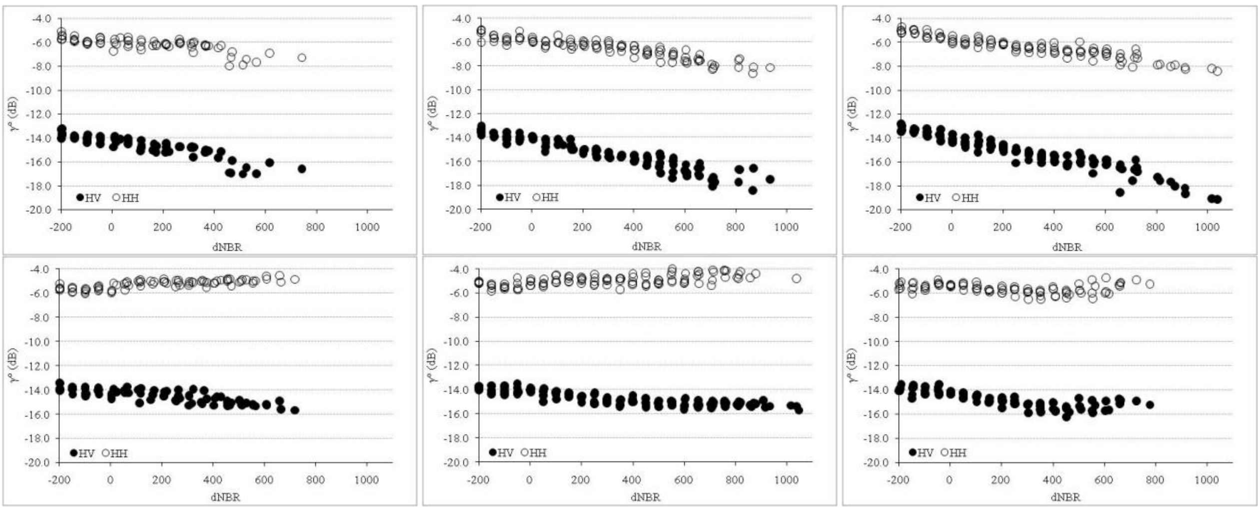

Fig. 2 HH and HV backscatter (γ^0) with respect to burn severity for the Angara2 (Siberia) fire for slopes oriented towards the sensor (left), flat areas (center) and slopes oriented away from the sensor (right). Dry (top, 2007.07.26) and wet (bottom, 2007.08.24) environmental conditions.

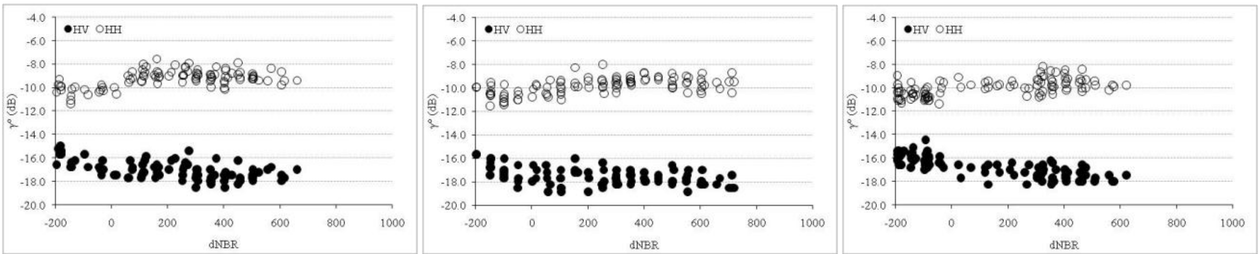

Fig. 3 HH and HV backscatter (γ^0) with respect to burn severity for the Boney Creek (Alaska) fire for slopes oriented towards the sensor (left), flat areas (center) and slopes oriented away from the sensor (right). Wet environmental conditions (2008.08.03).

was recorded for the higher local incidence angles. This could be explained by the higher severity recorded for the slopes oriented away from the sensor when compared to flat areas or slopes oriented towards the sensor. For the image acquired under wettest conditions (2007.08.24), the backscatter at HH polarization increased slightly with increasing burn severity for slopes oriented towards the sensor or flat areas. For slopes oriented away from the sensor the sensitivity of L-band co-polarized backscatter to burn severity was low (Fig. 2). The increased co-polarized backscatter for severely burned areas was explained by the enhanced contribution from the ground due to higher moisture content. The HV polarization trend did not change when compared to the image acquired under dryer conditions. Nonetheless, the increased moisture negatively affected the dynamic range with respect to the dry conditions case. It decreased to around 1.5 dB for HH polarization and 2 dB for HV polarization. The remaining two images acquired under wet environmental conditions (2007.06.10 and 2007.07.09) showed low sensitivity to burn severity especially at HH polarization. The dynamic range of co-polarized backscatter was below 1 dB for both fires. The reason for the different behavior of the HH backscatter should be attributed to local dielectric properties of the scatterers. Knowledge of the forest conditions and soil conditions at the time of image acquisition would have helped substantially in understanding these signatures.

Similar backscatter trends and dynamic ranges as those reported for the Siberian site under wet conditions were observed for the Alaskan site (Fig. 3) for which the image was acquired after a period of intense precipitations (see Table 2). HH polarized backscatter increased whereas HV polarized backscatter decreased with increasing burn severity.

4.2. Statistical analysis

To infer the utility of PALSAR FBD SAR backscatter for burn severity estimation, linear regression determination coefficients (R^2) expressing the proportion of burn severity variance predicted by SAR backscatter and the standard error are presented in Table 3 and 4. Beta standardized regression coefficients (Beta°) which express the relative strength of metrics have been included for multiple regression analysis. The statistics were computed for all the generated pseudo-plots and by local incidence angle intervals of 5º. Values are reported for images acquired under dry and wet conditions at the Siberian site (Angara 2 fire) and for wet conditions at the Alaskan site (Boney Creek fire).

Empirical fitting showed strong relationships between backscatter coefficient and dNBR for data acquired under dry conditions at the Siberian sites (Table 3). Slightly higher determination coefficients and smaller errors were observed for HV polarization. The simultaneous use of co- and cross-polarized channels resulted in increases of the determination coefficients, HV polarization explaining most burn severity variations (higher Beta° coefficients). The influence of the local incidence angle on the determination coefficient was negligible due to the relatively flat topography.

For the image acquired under wet conditions (2007.08.24) the association strength to burn severity decreased for both polarizations. The combined use of the co- and cross-polarized channel partially compensated this loss of sensitivity, the determination coefficients increasing up to 0.85. However, for the remaining two images acquired under wet conditions at the Siberian site (2007.06.10 and 2007.07.09) the association strength to burn severity was much lower ($R^2 < 0.4$) for both fires (Angara 1 and 2) at HH polarization. Low association strength to burn severity was observed at the Alaskan site (Table 4). For HV polarization slightly higher determination coefficients were recorded when compared to HH polarization (Boney Creek fire). The combined use of HH and HV polarization increased the association strength to burn severity levels. Similar results were obtained also for the remaining two fires. The high precipitation levels throughout 2008 summer season and the rainfall recorded during the acquisition of the SAR image negatively influenced the sensitivity of the backscatter coefficient to burn severity. The lower determination coefficients found for the Alaskan fires could also be.

Table 3 Determination coefficients explaining the agreement between burn severity expressed as dNBR and L-band backscatter (Siberia site, Angara 2 fire)

Scene	2007.07.26 (dry)								2007.08.24 (wet)							
	HH		HV		HH & HV				HH		HV		HH and HV			
	R^2	Std. err.	R^2	Std. err.	R^2	Std. err.	Beta° HH	Beta° HV	R^2	Std. err.	R^2	Std. err.	R^2	Std. err.	Beta° HH	Beta° HV
all pseudo-plots																
	0.793	135.4	0.875	105.1	0.875	105.3	-0.024	-0.913	0.266	251.2	0.583	189.1	0.824	122.7	0.492	-0.748
pseudo-plots grouped by local incidence angle																
31-35°	0.574	152.5	0.815	100.6	0.837	95.2	0.351	-1.222	0.590	164.6	0.666	148.5	0.841	103.1	0.482	-0.577
36-40°	0.817	138.2	0.850	124.8	0.862	120.3	-0.319	-0.623	0.473	250.5	0.709	186.4	0.859	130.4	0.422	-0.675
41-45°	0.862	119.3	0.908	97.4	0.909	97.4	-0.118	-0.839	0.046	261.4	0.634	161.8	0.806	118.4	0.551	-1.160
46-50°	0.872	82.0	0.949	51.6	0.950	52.0	-0.140	-0.961	0.628	108.1	0.821	75.0	0.853	68.8	0.530	-1.405

Table 4 Determination coefficients explaining the agreement between burn severity expressed as dNBR and L-band backscatter (Alaska site, Boney Creek fire)

Scene	2008.08.03 (wet)							
	HH		HV		HH and HV			
	R^2	Std. err.	R^2	Std. err.	R^2	Std. err.	Beta° HH	Beta° HV
all pseudo-plots								
	0.232	220.4	0.384	197.4	0.581	162.4	0.448	-0.595
pseudo-plots grouped by local incidence angle								
31-35°	0.190	203.0	0.315	186.6	0.539	153.9	0.475	-0.593
36-40°	0.260	227.5	0.227	232.6	0.557	177.0	0.579	-0.549
41-45°	0.294	214.7	0.595	162.8	0.714	137.4	0.359	-0.673

the result of inaccurate estimation of the burn severity by dNBR index.

The results here presented are similar to those obtained with PALSAR data in mediterranean forests [14], with higher association strength to burn severity and lower estimation errors for data acquired under dry conditions. Slightly lower dynamic range from unburned to severely burned forests was observed for boreal forests at both HH and HV polarization. As for the mediterranean forests the simultaneous use of HH and HV polarizations did not improve burn severity estimation when using images acquired in relatively dry environmental conditions. For images acquired after precipitation the estimation error increased significantly.

5. CONCLUSIONS

The properties of ALOS PALSAR L-band dual polarized backscatter were investigated for burned boreal forests. The influence of the weather conditions on backscatter response was also studied.

Co- and cross-polarized backscatter decreased with the increase of burn severity due to decreasing volume scattering component under dry and unfrozen environmental conditions. For images acquired under wet environmental conditions an opposite trend was observed for HH polarization in consequence of higher soil moisture. The highest sensitivity to burn severity was observed for HV polarized backscatter acquired under dry conditions. Precipitations negatively influenced the association strength to burn severity at both HH and HV polarizations. The simultaneous use of both polarizations within a linear regression model seemed to compensate this decrease in sensitivity to a certain extent. This study indicates that L-band SAR backscatter is useful for burn severity estimation in boreal forest. However, the work points out the strong dependence of the results on weather conditions.

Several aspects of this study could limit drawing conclusions for the entire boreal zone: *i)* no field estimates of burn severity were available which hindered the assessment of dNBR reliability when estimating severity; *ii)* only images from summer season were studied. SAR images acquired during winter season could present completely different trends since the environmental conditions are significantly different; *iii)* the study took into consideration a small number of burns located within relatively small areas. Therefore it is essential to extend the analysis over larger areas with higher variability of forest biomass and species composition; and *iv)* the influence of environmental conditions should be more thoroughly studied. Soil and vegetation moisture content could prove a decisive factor when estimating burn severity in such environments. Further studies should also consider interferometric coherence which was more useful than SAR backscatter for burn severity estimation in mediterranean environments.

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