USE OF RADARSAT-2 POLARIMETRIC SAR IMAGES FOR FUEL MOISTURE MAPPING IN THE KRUGER NATIONAL PARK, SOUTH AFRICA

Martin Kong (1) (2), Brigitte Leblon (1)(*), Renaud Mathieu (3), Claus-Peter Gross (2), Joseph Buckley (4), Laven Naidoo (3) and Laura Bourgeau-Chavez (5)

(1) Faculty of Faculty and Environmental Management, University of New Brunswick, Fredericton, NB, E3B 5A3, Canada, Phone +1-506-453-4932; Fax: +1-506-453-3538; Email: bleblon@unb.ca
(2) Faculty of Environment and Natural Resources, Albert-Ludwigs-Universität, Freiburg, Germany
(3) Ecosystem Earth Observation, Natural Resource and the Environment, CSIR, Pretoria, South Africa
(4) Royal Military College of Canada, Kingston, Canada
(5) Michigan Tech Research Institute, Michigan Technological University, Ann Arbor, MI, U.S.A
(*) Corresponding author

ABSTRACT

Fully polarimetric Radarsat-2 imagery from wet and dry conditions over the South African *Lowveld* is compared to assess its value for fuel moisture mapping. Imagery was acquired at two different dates, in May (end of summer, wet) and in August (mid of winter, dry). Sample plots were classified into two broad *Lowveld* site types (herbaceous-dominated and shrub and tree-dominated). Linear and circular polarized backscatters, polarimetric discriminators and polarimetric decomposition parameters were computed to find suitable parameters for fuel moisture estimation. The results show a significant distinction between wet and dry conditions for C-HH, C-HV, C-RR, and C-LL, all Freeman-Durden and van Zyl decomposition parameters and some polarimetric discriminators (d_{min}, Pr_{max}, Pr_{min}, S_{max}, S_{min}). In almost all cases the normalized difference between wet and dry condition is lower for the shrub and tree-dominated sites. The Freeman-Durden double bounce scattering decomposition parameter performs best in both site types.

Index Terms— Polarimetric SAR, RADARSAT-2, grassland, South Africa, savanna, fuel moisture

1. INTRODUCTION

Fire is a key environmental process which contributes to shape many world ecosystems, including African savannas. Ignition and spread of wildfires depends on fuel moisture and weather conditions as well as on fuel types and topography. These parameters are used as inputs into fire danger prediction systems such as the Canadian Forest Fire Danger Rating System (CFFDRS). One of the CFFDRS subsystems, the Fire Weather Index (FWI) system, computes three fuel moisture codes (drought code DC, duff moisture code DMC and fine fuel moisture code FFMC) from noon-time weather records [1]. The availability of satellite images coupled with the development of geographic information technology allows moving FWI code computation from point-based weather station estimates to spatially-explicit estimates. As reviewed in Leblon et al. 2012 [2], the first remote sensing studies on FWI codes estimation used optical and thermal infrared images, but these images are restricted to cloud-free daytime conditions, a limitation that can be overcome with synthetic aperture radar (SAR) images, while microwaves are particularly sensitive to the moisture content of targets. Good correlations were obtained between DC and single polarized C-band SAR data over boreal forests [2]. Recently, multi-polarized and fully polarimetric SAR sensors have become available. Multi-polarized SAR images allow selecting the optimal polarization for fuel moisture estimation. Polarimetric SAR images allow additional analysis tools, such as new polarization synthesis, polarimetric variable computation, and polarimetric decompositions. These tools may be useful to improve fuel moisture estimation by reducing the confounding factors because they decompose the backscattered energy of the imaged area into dominant scattering mechanisms. Following the method developed over boreal forests by Bourgeau-Chavez et al. 2013 [3], fully polarimetric RADARSAT-2 C-band images were acquired in South African savannas during dry and wet conditions and compared with the aim to identify the best polarimetric SAR variables for estimating fuel moisture in these ecosystems.

978-1-4799-5775-0/14/$31.00

2. MATERIALS AND METHODS

The study area is located in the *Lowveld* of South Africa, in the northeast of the country, north of Skukuza in the Kruger National Park (S 24° 58' 48", E 31° 36' 0"). The *Lowveld* is a savanna biome, ranging from wide open herbaceous dominated landscapes with only sparsely distributed individual trees to dense, near-closed canopy woodland, with a canopy cover of up to 60% and in riparian areas up to 80% [4]. Mean annual precipitation is 630mm, and occurs mostly between October and May. Field visits during the image acquisition of May 2009 allowed separating the 9 visited plots into two types: 1) 4 shrub and tree plots, where the shrub and tree cover is between 40%-50% (canopy is fairly open with occasional clearings and fairly dense undergrowth); and 2) 5 herbaceous plots with predominantly herbaceous (grass) vegetation and a low shrub and tree cover between 5%-20%. One 25 x 25 km C-band RADARSAT-2 FQ15 SLC image was acquired in May 2009 (end of summer, wet) and another in August 2009 (mid of winter, dry), with the same incidence angle (35.2°). They have a 4.7x5.1 m nominal pixel spacing in range and azimuth. Late afternoon ascending pass images were preferred to reduce effects of dew on the backscatter. Skukuza weather station records were used to compute DC values beginning 5 days prior to the highest rainfall event in the wet season (3/2/2009) and using the standard starting value (DC=15). The May image exhibited moist conditions (DC=232.6 and a total of 26.9 mm precipitation 3 days prior to image acquisition), while the August image exhibited dry conditions (DC=785.5 and a total of 0.0 mm precipitation 3 days prior to image acquisition). Image processing of the RADARSAT-2 polarimetric SAR images was done in PCI Geomatica 2013, except the polarimetric decompositions that were performed in PolSAR Pro 4.0. The processing involved first speckle noise reduction with a 7x7 polarimetric Lee sigma filter [5]. The filtered polarimetric images were used to produce 1) circular-polarized (C-LL, C-RR, and C-LR) images; 2) polarimetric variables: extremes of the degree of polarization (d_{max} , d_{min}) and dynamic range of the degree of polarization (Δd) [6], extremes of the wave intensity (S_{max}, S_{min}) and the normalized difference of it (ND_S) [6] [7], extremes of the received signal power (Pr_{max}, Pr_{min}) and the coefficient of fractional polarization (FP) [8][9]; and 3) parameters of the Freeman-Durden [10], Cloude-Pottier [11] and van Zyl et al. [12] decompositions. The Freeman Durden and the van Zyl decomposition both decompose the covariance matrix into three types of scattering mechanisms: single bounce scattering with an odd number of bounces (surface scatterer), dihedral reflection with an even number of bounces (double bounce or dihedral scatterer), and randomly oriented dipole scatter (diffuse or volume scatterer). The eigenvector based Cloude-Pottier decomposition has three parameters describing the polarimetric state, Entropy *H*, Anisotropy *A,* and alpha angle *α*). A low Entropy *H* (CP-*H*) value implies the dominance of one scattering mechanism while a high value implies equality of all scattering mechanisms. Anisotropy *A* (CP-*A*) measures the relative importance of the second and third scattering mechanisms and Alpha α (CP-α) indicates the average dominant scattering mechanism in the case of a low *H.*

All these polarimetric product images were then orthorectified using a 20m digital elevation model (DEM) and ground control points (GCPs) extracted from the image files. Based on the GPS plot location, a 100x100m square was delineated in ArcGIS, covering a homogenous area around each plot. Digital numbers of the polarimetric product images were extracted and the median value for each variable was computed for further analysis. The comparison of the variable values between the wet and the dry dates was performed using a normalized difference (in %) that allows expressing the changes in variable values between wet and dry dates with a single unit. A one-way ANOVA was also performed to test if the difference in variable values between the wet and dry dates is significant.

3. RESULTS

As shown in Table 1, the linear and circular polarized intensities, C-HV and C-LL are the most sensitive to changes between wet and dry dates for both site types. C-HH and C-RR are less sensitive, while C-VV and C-LR show the least changes between both dates. The change between dates is statistically significant for all intensities and sites, except C-VV over the shrub and tree plots. The eigenvector based Cloude-Pottier decomposition parameters show only minor changes between the dates. This was expected since the Cloude-Pottier decomposition measures the relation of the scattering mechanisms to each other rather than changes in the backscatter values of each scattering mechanism [11]. All parameters of the Freeman-Durden (FDvol, FDsurf, FDdbl) and the van Zyl (vZvol, vZsurf, vZdbl) decompositions showed significant changes between both dates. The double-bounce component of both decompositions performed best out of all parameters. Among the other polarimetric variables, only d_{min}, S_{max}, S_{min}, Pr_{min} and Pr_{max} show significant differences between wet and dry dates for both plot types. The largest difference occurs with Pr_{min} (48%) for the shrub and tree plots and with dmin (-86%) for the herbaceous plots. Combinations of polarimetric variables (NDs, FP, and Δd) generally produce

Table 1: Normalized difference between the wet and dry dates for each variable and each plot type and p-value of the one way ANOVA.

Variable	**Shrub/Tree (N=4)**		**Herbaceous (N=5)**		**Variable**	**Shrub/Tree (N=4)**		**Herbaceous (N=5)**	
	Difference (%)	**p-value (N=4)**	**Difference (%)**	**p-value (N=5)**		**Difference (%)**	**p-value (N=4)**	**Difference (%)**	**p-value (N=5)**
C-HH	40.5	0.0014	64.1	0.0000	**FD vol**	46.2	0.0035	73.0	0.0000
C-HV	45.4	0.0040	72.5	0.0000	**FD surf**	36.9	0.0226	56.1	0.0061
C-VV	17.1	***0.0914***	41.4	0.0050	**FD dbl**	77.3	0.0001	79.0	0.0001
C-RR	48.0	0.0008	75.1	0.0000	$\mathbf{d_{max}}$	-2.4	***0.1824***	-2.6	0.0075
C-LR	34.4	0.0043	58.3	0.0000	$\mathbf{d_{min}}$	-44.0	0.0116	-86.0	0.0057
C-LL	54.5	0.0013	75.13	0.0000	$\mathbf{\Delta d}$	3.1	***0.2408***	16.4	***0.0753***
CP *H*	8.0	0.0064	8.8	0.0064	$\mathbf{Pr_{max}}$	42.1	0.0009	65.3	0.0000
CP *A*	0.4	***0.7126***	1.9	***0.7142***	$\mathbf{Pr_{min}}$	48.0	0.0011	72.8	0.0000
CP α (°)	16.0	0.0067	21.7	0.0048	**FP**	-2.4	***0.1177***	-2.3	0.0047
vZ vol	44.3	0.0044	71.4	0.0000	$\mathbf{S_{max}}$	42.1	0.0009	66.5	0.0000
vZ surf	36.0	0.0028	62.4	0.0000	$\mathbf{S_{min}}$	36.8	0.0057	62.4	0.0000
vZ dbl	62.4	0.0002	79.1	0.0000	$\mathbf{ND_S}$	7.8	0.0097	20.0	0.0071

(C-HH, C HV, C-VV: Linear polarizations; C-RR, C-LR, C-VV: Circular polarizations; CP H, A, α: Cloude-Pottier Entropy Anisotropy and alpha angle; vZ vol, surf, dbl: van Zyl volume, surface and double bounce; FD vol, surf, dbl: Freeman-Durden volume, surface and double bounce; d_{max} , d_{min}*: extremes of the degree of polarization; Δd dynamic range of the degree of polarization;* S_{max} ,S_{min}*: extremes of the wave intensity;* ND_S *normalized difference of the extremes of the wave intensity;* Pr_{max}, Pr_{min}*:extremes of the received signal power; FP: coefficient of fractional polarization .)*

a smaller difference than their individual components. In all cases, the normalized difference for the shrub and tree sites is lower than the one for the herbaceous plots.

4. CONCLUSIONS

Two fully polarimetric RADARSAT-2 C-band images that were acquired during a dry and wet date are compared with the aim to identify which polarimetric variables are the best indicators of moisture change in the case of South African *Lowveld* savannas in Kruger National Park. Linear and circular polarized intensity backscatters (C-HH, C-HV, C-RR, and C-LL), Freeman-Durden and van Zyl decomposition parameters (particularly the double-bounce component), and polarimetric variables such as d_{min} Pr_{max}, Pr_{min}, S_{max}, S_{min} expressed statistically significant differences between wet and dry conditions, for both the herbaceous and shrub and tree plots. The generally higher difference for the herbaceous plots between the dates is likely a result of a buffer effect of the denser vegetation in the shrub and tree plots. Using longer wavelength bands could decrease the impact of this effect. Both images were acquired during different seasons and some observed changes can be due to seasonal vegetation changes. For instance, most trees are deciduous, and in May still have leaves, while they have shed their leaves in August. This seasonal effect should be investigated further. The SAR images were acquired using a rather shallow incidence angle, thus testing other beam modes is recommended for future studies. Finally the study only compares two SAR images, and a model to estimate fuel moisture from SAR variables is still to be developed.

5. ACKNOWLEDGEMENTS

Weather data was provided by the South African Weather Service (SAWS). Radarsat-2 imagery was provided by the Canadian Space Agency under a SOAR-E grant awarded to Leblon et al. The study is funded by a NSERC Discovery Grant awarded to B. Leblon and by a TRANSFOR-M scholarship awarded to M. Kong. Further thanks go to Philip Frost (CSIR).

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