Utility of SARs for mapping forest disturbance in Siberia

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***Abstract* –Radar backscatter data from multiple SAR satellites were acquired and analyzed for two sites subject to the forest disturbances in Western Siberia, Russia. The backscatter from disturbed and non-disturbed sites were analyzed and the individual and combined capabilities of ERS, JERS, and Radarsat evaluated. JERS was the single most useful radar for this analysis. The combination of radars improved the results.**

I. INTRODUCTION

Disturbance is an important factor in determining the carbon balance and succession of forests. Until the early 1990 s researchers have focused on using optical or thermal sensors to detect and map forest disturbances from wild fires, logging or insect outbreaks. A major problem with optical systems for northern forest studies was the lack of available data caused by cloud cover and low solar illumination in winter. With the launch of the synthetic aperture radar (SAR) systems: European Resource Satellite (ERS) -1 and 2, Japanese Earth Resources Satellite (JERS) —1 and Canada s Radarsat the problems of cloud cover and low illumination have been eliminated. Kasischke et al. [1] found ERS data could be used to detect fire scars in the boreal forest because the fire scars were 3-6 decibels (dB) brighter than the rest of the landscape. This brightness is a result of physical changes that occur due to fire including increased surface roughness, removal of tree canopies, and alteration of soil moisture patterns [2]. While optical and thermal sensors are sensitive to the initial changes in temperature and vegetative cover, SAR is sensitive to the longer-term roughness and moisture patterns that occur post-fire. There is a paucity of reported radar analysis of insect damage for boreal forests. This paper reports on our work to use combined data from orbiting radars to recognize disturbance in Siberian forests.

II. STUDY SITES

The areas studied for this analysis are part of the Siberian Mapping Project, a joint study by GSFC and the Sukachev Institute of Forest. Disturbance from wildfires and logging were studied in the Boguchany area that has prominent fire scars and logged areas. The site is located at 97° 25 E and 59° 2 N, 75 km North of the Angara River and 350 km east of the Yenisey River in central Siberia. The Priangar e insect damage site is located to the west of the Boguchany site 94˚ 30' E and 57˚ 30' N, and was plagued by a severe insect outbreak in the last decade.

In the Boguchany area pine (*Pinus* spp.) and larch species (*Larix* spp.) cover most of this landscape, however other conifers, such as Siberian pine (*Pinus sibericus*), spruces (*Picea spp.*) and fir (*Abies* spp.), can also be found in patches in the area. Deciduous stands such as birch (*Betula spp.*) and aspen species (*Populus* spp.) cover the areas of lower elevation in this region. In Priangar e, the dominant species are Siberian fir (*Abies sibirica*); other species include Siberian pine (or cedar) (*Pinus sibirica*), Siberian spruce (*Picea obovata*), Scotch pine (*Pinus silvestris*), larch (*Larix sibirica*), aspen (*Populus tremula*), and birch (*Betula verrucosa*). In the summer, smoke plumes from burning wild fires obscure the ground. Scientists from the Sukachev Institute of Forest surveyed the sites in the fall of 1999 and in August 2000. The GSFC-based research team conducted field surveys in the Priangar'e test area in August 2000.

III. DATA ANALYSIS

A. Microwave Data

JERS (LHH, March 31, 1997), ERS-1 (CVV, June 7, 1998), and Radarsat (CHH, Sept. 7, 2000) images were used for the Boguchany fire disturbance study. JERS (May 19, 1997 and Radarsat (August 18, 2000) images were used to study the insect damage area. (ERS data was not available for this site). The ERS, JERS and Radarsat data were resampled to 25 m pixel size. The data were filtered using a 3 by 3 Frost filter and reprojected to the Lambert Conformal Conic projection with the WGS 84 datum. There was no radiometric terrain correction applied to the radar images because of the low topographic gradient across the 75 km by 75km study areas).

B. Vegetation classes

The following land cover classes were identified for the two sites: *coniferous forest (CF), broadleaf deciduous forest (DF), regeneration/sparse forest (RS), bare surfaces (BS) and clear cut (CC)*. For the Boguchany site the following disturbance classes were added: *burned coniferous forest (BC), burned deciduous forest (BD), and burned logged areas (BL)*. Additionally, two classes of insect damage were identified in the Priangare area: *severely damaged (IS)* with complete defoliation of a stand and *moderately damaged (IM*) with only conifer trees defoliated. Since the insect outbreak had occurred in 1996 and subsequently subsided the latter two classes represent severity of damage rather than stage of insect attack.

C. Training site selection

The training sites for the classes mentioned above were determined based on the information gathered in the field, the multi-year and multi-season coverage provided by Landsat scenes and the contextual information provided by individual Landsat scenes. IKONOS images were available for the Boguchany site. Once the training sites were determined, histograms were examined for each class in each radar band. If the histogram showed a multimodal distribution, these training sites were displayed using the radar bands and training sites divided into more homogeneous subclasses. Then the histograms for these subclasses were once again reviewed to make sure that the distribution of the values was normal. As a result, the deciduous forest and bare ground classes was split into three subclasses on the Priangare site, and the burned-logged class was split into two subclasses on the Boguchany site. Approximately one-third of the training sites were set aside for testing the classification and two-thirds were used for training the classifier (not discussed here).

D. Separability Analysis

The analysis procedure consisted of Transformed Divergence [3] analysis. Transformed Divergence (TDM) is a measure of separability between classes and may therefore be used to assess the quality of the class spectral mean vectors and covariance matrices. A high TDM (> 1.80) indicates good statistical separation of the classes and indicates how well each sensor or sensor combination detected each land cover class.

IV. RESULTS AND DISCUSSION

A. Burned and Logging Disturbance

Table 1 lists the TDM values for all classes for the JERS, ERS and Radarsat data. High TDM values exist between logged areas (CC and BL), unburned and burned conifer (CF, BC, respectively), and unburned and burned deciduous stands (DF, BD, respectively). Unburned forest stands were not separable from burned forest stands with standing trees. High TDMs exist between RS and BD classes indicating that forested classes and classes lacking tree cover are easily separable from each other using JERS data regardless of their burned state. ERS and Radarsat TDM values were generally lower than those for JERS. The exceptions were for ERS data that had much higher separability values for burned forest (BC and BD) and unburned forest (CF and DF)

ERS data appears most useful for discriminating between burned standing forest areas and unburned forest, regeneration and clearings. Low TDMs were found between CF and DF classes indicating that CVV data cannot be used to distinguish between coniferous and deciduous forest classes. TDM values were also minimal between CF and CC. It appears that ERS data can be used to discriminate between the burned and unburned land cover classes, regardless of other characteristics of the site, and between post cutting regeneration classes and burned forest classes. JERS data at the L-band is able to detect larger structural differences between forest types that are caused by logging (i.e. removal of large trunks). At the same time ERS C-band data seem to detect soil moisture differences (and perhaps structural and moisture differences at a leaf level associated with burning). This indicates that the combination of the two sensors should provide improved results in discriminating logged and burned areas. Radarsat TDM values were quite low and indicates that the Radarsat data alone is not suitable for distinguishing any of the classes from each other.

Also included in Table 1 are the TDM values generated based on the three sensor data combined. The average separability increased to 1.55. Although this is an increase from using each sensor alone (JERS average separability: 1.23, ERS: 0.64, and Radarsat: 0.16), on the whole, combining the three sensors does not provide very good distinction between these eight classes since TDM values under 1.8 are considered poor. Combining the radars provided the greatest increases in useful separability ($\geq$ 1.80) over individual radars between burned classes (BC, BD, BL) and regenerating forest (RS). Overall, forest (CF, DF) could be separated from disturbance classes (RS, CC, and BL), but not from burned standing forest (BC,BD). Burned forest could be separated from regeneration and clear cut. This is mostly due to the LHH band JERS data, since these class pairs had reasonably high TDM values (around 1.7) using JERS data alone.

B.. Insect Disturbance

Table 2 shows the radar separability values for the Priangar e site. JERS and Radarsat can distinguish water from the land cover classes very successfully, including the bare surface subclasses. JERS and, for the most part, Radarsat were also successful at distinguishing bare surfaces from the vegetated classes (1.92-2.00). Radarsat has low TDM values between bare surfaces and clear cuts and fails to separate the BA-2 class from all the vegetated classes. For JERS, TDM values are very low between coniferous forest (CF) and insect damage classes (IS, IM)) and the deciduous forest subclasses and the moderate insect damage class.

Radarsat separability of the forests classes was poor($\leq$ 1.31), as was separability of damaged forest classes from each other and with undamaged conifer forest ($\leq$ 0.97). The TDM values between deciduous subclasses and both damaged classes were also extremely low ($\leq$ 0.28). However the separability between coniferous forest and clear cuts was higher (1.77).

With the combined use of the two radars the distinction between the clear cuts and coniferous forest (TDM=1.96) and clear cuts and severe insect damage (1.86) increased (Table 2). There was no large increase in the separabilities between the other classes. In addition, there was good separability of confier forest and the deciduous subclass (DF3). Low TDMs were found for CF and the other two deciduous subclasses suggesting a possible mixture of conifer and deciduous trees or forest density differences among these deciduous classes. Overall, the combination of JERS and Radarsat maybe useful for separating clear cuts from other forest types, but is not useful separating insect damaged stands from undisturbed forest.

V. CONCLUSIONS

From these results it is clear that any single radar sensor used alone cannot be used to discriminate between burned and unburned forest classes, between deciduous and coniferous forest classes, and between unburned and burned non-forested classes. However, JERS data can be used to discriminate between forest and non-forest classes regardless of burning, and between post-logging regeneration and forest classes also regardless of burning. Classes can be separated successfully that have different structural characteristics determined by the presence or absence of large trunks and branches, such as forest and non-forest classes. These results are encouraging in terms of multi-sensor detection of logging and fire disturbance in the boreal forest.

TABLE1

TRANSFORMED DIVERGENCE MEASURE (TDM) VALUES FOR VEGETATION CLASSES AND RADAR SENSORS (ORDER OF TDM VALUES: JERS (J), ERS (E), RADARSAT (R) AND COMBINING RADAR SENSOR DATA(C) FOR BOGUCHANY.

class	Sensor	CF	DF	RS	CC	BC	BD	BL1
DF	J	0.06						
	E	0.01						
	R	0.01						
	C	0.10						
RS	J	1.69	1.58					
	E	0.20	0.24					
	R	0.20	0.15					
	C	1.74	1.64					
CC	J	1.94	1.88	0.38				
	E	0.08	0.14	0.04				
	R	0.56	0.48	0.12				
	C	1.97	1.92	0.57				
BC	J	0.06	0.11	1.39	1.82			
	E	1.18	1.40	1.49	1.23			
	R	0.04	0.02	0.06	0.36			
	C	1.35	1.54	1.86	1.95			
BD	J	0.05	0.04	1.80	1.97	0.20		
	E	1.35	1.48	1.73	1.55	0.18		
	R	0.06	0.04	0.05	0.33	0.01		
	C	1.40	1.53	1.96	1.99	0.37		
BL1	J	1.86	1.81	0.06	0.25	1.68	1.92	
	E	0.32	0.47	0.74	0.46	0.43	0.51	
	R	0.30	0.24	0.01	0.08	0.13	0.10	
	C	1.94	1.92	0.91	0.64	1.78	1.94	
BL2	J	1.99	1.99	1.63	0.86	1.99	1.99	1.54
	E	0.12	0.25	0.28	0.11	0.75	1.12	0.15
	R	0.38	0.31	0.03	0.03	0.19	0.16	0.01
	C	1.99	1.99	1.81	1.11	1.99	2.00	1.56

Avg.	J	1.23
	E	0.64
	R	0.16
	C	1.55

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TABLE II.

TDM VALUES FOR PRIANGAR E INSECT DAMAGE STUDY SITE FOR. JERS (J) AND RADARSAT (R) AND COMBINED DATA (C).

Class	Sens-or	CF	DF1	DF2	DF3	IS	IM	CC	BA1	BA2	BA3
DF1	J	0.47									
	R	0.59									
	C	0.92									
DF2	J	0.49	1.18								
	R	0.45	0.01								
	C	1.04	1.22								
DF3	J	1.77	1.98	1.52							
	R	1.31	0.57	0.61							
	C	1.88	1.99	1.75							
IS	J	0.06	0.26	0.45	1.84						
	R	0.65	0.15	0.15	0.18						
	C	0.72	0.45	0.59	1.86						
IM	J	0.53	1.49	0.19	0.93	0.69					
	R	0.97	0.25	0.28	0.07	0.04					
	C	1.32	1.62	0.59	1.04	0.74					
CC	J	1.50	1.97	1.43	0.07	1.70	0.76				
	R	1.78	1.46	1.46	0.59	0.91	0.85				
	C	1.96	1.99	1.95	0.78	1.86	1.42				
BA1	J	2.00	2.00	2.00	1.99	2.00	2.00	1.99			
	R	1.99	1.98	1.99	1.92	1.92	1.95	1.20			
	C	2.00	2.00	2.00	2.00	2.00	2.00	1.99			
BA2	J	2.00	2.00	2.00	1.99	2.00	1.99	1.96	0.54		
	R	1.42	0.76	0.79	0.02	0.28	0.17	0.40	1.85		
	C	2.00	2.00	2.00	1.99	2.00	2.00	1.97	1.95		
BA3	J	2.00	2.00	2.00	1.99	2.00	2.00	1.99	1.92	1.29	
	R	2.00	2.00	1.99	1.98	1.97	1.95	1.51	0.25	1.95	
	C	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.93	1.99	

WR	J	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.87	1.99	2.00
	R	2.00	2.00	2.00	2.00	2.00	2.00	1.99	1.98	1.99	1.99
	C	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Avg.	J	1.58									
	R	1.23									
	C	1.73									