Applicability of JERS-1 SAR Data for Monitoring of Forest Function and Environment

—Preliminary analysis of forest stand structure using JERS-1 SAR data for forest management—

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ABSTRACT

A verification study has been done using JERS-1/SAR data for forest stand structure analysis. The initial survey conducted at a relatively flat forest at in the Mt.Fuji area showed that there was a relationship between the radar backscatter intensity and the forest tree parameter in the azimuthal slope direction. In the secondary survey, investigation of the relationships between forest tree parameters (tree height, diameter at breast height (DBH), stand volume, stand density, stand coverage etc.) and the SAR data showed that JERS-1/SAR data were highly applicable for analyzing forest stand structure.

To obtain normalized backscattering coefficients with exclude topographical effects for any specified direction, we must develop an estimation formula for key parameters of stand analysis.

Keyword: L-band Synthetic Aperture Radar (SAR), Forest stand structure, backscattering coefficient

INTRODUCTION

The first Japanese Earth Resources Satellite (JERS-1) was launched successfully on February 11, 1992. It was equipped with an L-band Synthetic Aperture Radar (SAR) and Optical Sensor (OPS) which consists of a Visible and Near Infrared Radiometer and a Short Wavelength Infrared Radiometer (VNIR & SWIR). JERS-1 is a joint project of the National Space Development Agency of Japan (NASDA) and the Ministry of International Trade and Industry (MITI). The verification program by MITI and NASDA is pioneering global monitoring through the use of this satellite system.

The forestry industry in Japan has deteriorated due to a decrease in the number and advancing age of foresters resulting from a long term slump in domestic wood produc-

tion demand. It is difficult to obtain accurate forest information because of insufficient inventory data. Periodical and simultaneous wide area observation provided by satellite remote sensing are useful for forest observation.

Although, data on forest stand structure parameters are difficult to acquire from satellite optical sensor systems, we obtained SAR data from both JERS-1 and the first European Remote Sensing Satellite (ERS-1). The SAR, situated on satellite platforms, transmits microwaves through the atmosphere to the ground and receives the scattered waves (backscattering). Compared with an optical sensor, it better enables high-resolution, high-contrast observation, and accurate determinations of topographical features such as undulations of slopes, independently of weather conditions including fog or cloud cover (KIMURA 1993; SUGIMURA et al. 1993; TAKEUCHI 1995; WAKABAYASHI and ARAI 1995). SAR can detect microwaves scattered at the tree crown or stem of the forest.

Our objective is to find the correlation between the backscattering coefficient and the stand tree parameters. As the first step, we conducted a survey on forest management using SAR data on a uniform slope in the Mt.Fuji

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area to avoid the effects of terrain on SAR images.

STUDY AREA AND METHODOLOGY

The Initial Survey

The study area was the lower slope of Mt. Fuji around the Subaru Highway in Yamanashi prefecture. (See

Fig. 1 Location of study area

Fig.1). The area encompasses about 430 km² of forest between 900~2,300 meters in elevation on the northern slope of Mt.Fuji. Forty-four ground truth plots were selected for the verification in this area (NISHI et al 1993). The forest area extends from the warm temperate forest zone to the subalpine zone. The soil consist of basalt lava. Four forest types occur within the study area; Japanese red pine (*Pinus densiflora* S. et Z., 900~1,300m), coniferous wood (Hemlock: *Tsuga diversifolia* M., Veitch fir: *Abies veitchii* L., and Spruce: *Picea jezoensis* CARR.H., 1,600~2,300 m), deciduous broad leaved forest (Birch: *Betula ermani* CHAM., 2,200~2,400m) and larch (*Larix leptolepis* GORD., 800~1,600m). Larch and spruce are planted on good sites on plane slope.

The Secondary Survey

From the results of the initial survey, we focused on the northern slope of Mt.Fuji, which lies along the azimuth direction of the radar. The ground truth plot areas were selected from artificial forest stands of over 10,000m² to obtain a good position for image analysis. The topographic conditions of the selected plots were 2.2~37.6 hectare, 1,125~1,490 m in elevation, S190W~S230W in slope direction, 3°~9° in slope angle. Tree species in the artificial stands were red pine, larch, fir, a mixed stand of red pine and larch, fir and larch. The total number of ground truth plots was 51 from 11 forest stands, with plot size ranging from 10m×10m to 20m×20m.

ANALYSIS METHOD

JERS-1/ SAR data and EERS-1/SAR data acquired on 23 April 1992 and 4 December 1991 were chosen for this study because of their high quality. Since SAR data are influenced by slope direction and angle on the Earth's surface, it is difficult to determine the relationship between stand structure parameters and SAR data in complex terrain areas. In the initial survey, the uniform terrain in all directions on Mt.Fuji was examined to identify complex topography. The ground truth area of 44 plots (20m × 20 m) seemed to provide standard growth conditions for each tree species throughout the study area. In each plot, vegetation was classified by the Brown-Blanquet method, and diameter at breast height (DBH), relative illuminance, stand density, slope direction, slope angle and mean tree height were measured. The SAR data characteristics are shown in Table 1 and the process flow chart is shown in Fig.2. The SAR images were converted to orthographic projections using a 1:5,000 topographic map. Using the above data, correlation analysis was done between each tree parameter for every tree species and the SAR data intensity (digital numbers), which were picked up from the

Table 1 Characteristics of EERS-1 and JERS-1 SAR sensor

	EERS-1/SAR	JERS-1/SAR
Frequency	5300MHz	1275MHz
Wavelength	5.66cm	23.5cm
Polarization	HH	VV
Incidence angle	23	35
Resolution	30m	18m
Swath width	100km	75km
Date	1991.12.4	1992.4.23

Fig. 2 Flowchart of study

Fig. 3 Flowchart of geometric correction

pixels corresponding to the ground truth plots. The image processing method (geometric correction and map projection) used in this study is shown in Fig.3. Statistical approaches such as principal component analysis, regression analysis and correlation analysis were also employed.

Table 2 Forest stand factors

Area	Stand density (n/ha)	Stand density* (n/ha)	Mean DBH (cm)	Mean DBH* (cm)	Basal area (m ² /ha)	Basal area* (m ² /ha)	Mean tree height (m)	Mean tree* height (m)	Stand volume (m ³ /ha)	Stand volume* (m ³ /ha)	Stand coverage (%)	Stand coverage* (%)
A	1945	765	18.5	23.8	55.5	35.2	14.2	17.3	452.6	317.7	141.0	100.0
B	1490	365	16.5	21.6	33.9	13.5	11.0	16.9	260.4	117.1	154.2	98.4
C	1900	705	17.6	24.7	53.5	36.1	13.4	17.1	437.3	316.9	179.5	100.0
D	2100	1900	25.6	26.5	112.1	48.8	15.3	15.7	838.2	815.9	175.4	100.0
E	1500	867	20.1	23.9	50.9	39.4	12.3	14.1	324.6	265.6	189.0	100.0
F	2550	0	12.9	0.0	35.0	0	9.0	0.0	167.2	0.0	200.0	100.0
G	525	495	31.6	32.5	42.9	42.4	17.9	18.2	358.9	355.7	169.8	100.0
H	788	700	22.7	23.2	32.0	29.8	15.9	16.2	255.8	240.4	118.4	50.0
I	800	508	22.0	29.2	39.2	37.1	14.1	17.6	334.5	324.7	208.1	100.0
J	1867	375	16.7	21.2	42.5	14.0	10.8	13.2	238.3	90.2	190.4	100.0
K	1275	621	22.5	28.7	55.1	44.6	15.8	19.1	520.1	433.9	162.9	100.0
L	5200	0	3.1	0.0	8.2	0	1.1	0.0	14.5	0.0	130.9	0.0
M	1350	920	23.6	29.5	69.6	64.9	16.1	19.2	675.0	674.1	128.6	100.0
N	2200	0	7.6	0.0	11.3	0	6.5	0.0	46.3	0.0	128.6	100.0
O	1065	840	26.9	30.4	66.5	62.8	17.8	19.5	649.5	623.4	173.6	100.0

* : Results for trees greater than or equal to 20 cm in DBH

Table 3 Topography information of forest stand and SAR data

Area	Tree species	Survey area (ha)	Stand area (ha)	Number of Plot	Slope Direction	Slope Angle (°)	Elevation (m)	JERS SAR (CCT count)	EERS SAR (CCT count)
A	A/L	0.04	37.6	5	N31E	6	1490	97.6	97.4
B	A/L	0.04	10.8	5	N34E	6	1355	95.8	107.0
C	A/L	0.04	19.4	5	N24E	5	1295	102.4	113.3
D	P	0.01	11.1	2	N35E	5	1220	109.3	108.6
E	P	0.0175	12.6	2	N30E	5	1210	97.1	119.7
F	P	0.02	5.8	1	N10E	5	1240	96.5	112.4
G	P/L	0.04	11.0	5	N32E	5	1125	107.3	110.1
H	L	0.04	9.0	2	N50E	5	1130	102.2	106.3
I	L	0.04	5.4	3	N18E	9	1140	105.7	105.7
J	P	0.04	5.6	3	N38E	6	1255	94.7	99.9
K	A	0.037	14.8	6	N48E	7	1317	112.5	95.0
L	A	0.01	2.4	1	N40E	7	1455	78.8	81.3
M	A	0.037	3.6	5	N19E	6	1475	106.7	91.8
N	L	0.02	2.2	1	N28E	8	1465	94.9	92.6
O	A	0.04	20.2	5	N30E	3	1430	103.4	95.9

* A: *Abies veitchii* L. L: *Larix leptolepis* GORD. P: *Pinus densiflora* S. et Z.

RESULTS AND DISCUSSION

The results of the initial survey are shown in Table 2, 3 and 4. It was recognized that JERS-1/SAR data correlated with the per hectare basal area and the stand coverage. The stand coverage was calculated as the projected floor space of every tree crown. The second survey showed the relationship between JERS-1/SAR data and mean stand height, mean DBH, stand forest volume, stand density and

stand coverage as shown in Figs. 5, 6, 7, 8 and 9, respectively. Table 5 shows the result of principal component analysis. Finally, Fig.4 shows the relation between tree height and DBH estimated by the regression analysis.

Relation between Basal Area and JERS & EERS Data Intensity

To find the relationship between diameter classes and SAR signal intensity, the correlation coefficients were

Table 4 Correlation matrix

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
A: stand density (n/ha)	1													
B: stand density* (n/ha)	-0.342	1												
C: mean DBH (cm)	-0.820	0.652	1											
D: mean DBH* (cm)	-0.759	0.658	0.899	1										
E: basal area (m ² /ha)	-0.339	0.933	0.667	0.634	1									
F: basal area* (m ² /ha)	-0.594	0.751	0.838	0.869	0.757	1								
G: mean tree height (m)	-0.867	0.640	0.961	0.897	0.663	0.853	1							
H: mean tree height* (m)	-0.744	0.628	0.840	0.981	0.602	0.835	0.877	1						
I: stand volume (m ³ /ha)	-0.433	0.888	0.739	0.739	0.954	0.887	0.762	0.722	1					
J: stand volume* (m ³ /ha)	-0.426	0.884	0.756	0.740	0.902	0.920	0.750	0.700	0.972	1				
K: stand coverage (%)	-0.219	0.089	0.245	0.204	0.257	0.072	0.169	0.120	0.133	0.048	1			
L: stand coverage* (%)	-0.674	0.300	0.500	0.447	0.478	0.384	0.567	0.432	0.462	0.345	0.474	1		
M: JERS-1/sar(cct)	-0.796	0.610	0.845	0.757	0.671	0.752	0.886	0.720	0.750	0.741	0.233	0.643	1	
N: EERS-1/sar(cct)	-0.483	0.283	0.407	0.290	0.269	0.110	0.375	0.254	0.125	0.052	0.596	0.482	0.343	1

* : Results for trees greater than or equal to 20 cm in DBH

Fig. 4 Tree height and DBH (Larix Leptolepis)

Fig. 5 JERS DATA and mean Tree height

Fig. 6 JERS DATA and mean DBH

Fig. 7 JERS DATA and stand volume

Fig. 8 JERS DATA and stand density

calculated for the following five tree diameter classes: below 5cm, 6~10cm, 11~20cm, 21~30cm, over 30cm. All correlation coefficients between the basal area and JERS-1/SAR data intensity were high.

As a result, the relation with EERS-1/SAR data intensity (digital numbers) did not depend on the basal area

(Table 4). Thus, it appears that the EERS-1/SAR beam did not permeate through tree stems or branches because of its short wavelength (CHUAH and KANG 1994; HIROSAWA et al. 1987; HOEKMAN 1987; MATZLER 1994; MOUGIN et al. 1993; ULABY et al. 1984).

Fig. 9 JERS DATA and stand coverage

Table 5 Result of Principal component analysis

Accumulated proportion(%)	Parameter	Factor loading
First principal component 65.09	JERS SAR	0.890
	EERS SAR	0.377
	stand density	-0.761
	stand density (DBH ≥ 20 cm)	0.805
	mean DBH	0.933
	mean DBH (DBH ≥ 20 cm)	0.915
	basal area	0.836
	basal area (DBH ≥ 20 cm)	0.912
	mean tree height	0.947
	mean tree height (DBH ≥ 20 cm)	0.882
	stand volume	0.897
	stand volume (DBH ≥ 20 cm)	0.879
	stand coverage	0.302
	stand coverage (high layer class)	0.606
Second principal component 78.96	JERS SAR	0.121
	EERS SAR	0.706
	stand density	-0.450
	stand density (DBH ≥ 20 cm)	-0.348
	mean DBH	0.105
	mean DBH (DBH ≥ 20 cm)	0.007
	basal area	-0.257
	basal area (DBH ≥ 20 cm)	-0.264
	mean tree height	0.101
	mean tree height (DBH ≥ 20 cm)	-0.021
	stand volume	-0.337
	stand volume (DBH ≥ 20 cm)	-0.420
	stand coverage	0.614
	stand coverage (high layer class)	0.531

Relation between Stand Density and SAR Data

To find the relationship between the tree diameter class in the forest stand stratum and the stand density, the stand diameter class was divided into 2 groups: all stand diameter class, and the other diameter class with DBH bigger than 20 cm which occupied upper layer class in vertical distribution. Table 2 shows the area parameters. The results of correlation analysis (Table 4) show that JERS-1/SAR data was more highly correlated with the stand density of all trees. We should especially note that JERS-1/SAR beams permeate tree leaves and are scattered after hitting stems or branches (MATZLER 1994; MOUGIN et al. 1993; ULABY et al. 1984).

Correlation between Tree Stem Parameters and JERS-1/SAR Data

Fig.5 to 8 show that SAR data had a high correlation with every tree stem parameters. In all cases, correlation coefficients between tree stem parameters and SAR data were obtained at a level more than 0.75. Thus, there are obvious quantitative relationships between SAR and mean DBH, mean height and stand tree volume.

Correlation between Stand Density and JERS-1/SAR Data

Fig.8 shows that the stand density (as expressed by the number of trees per hectare) had a negative correlation with SAR data. The opposite tendency appeared for the stand density to the stem parameters agrees with the results of field surveys indicating that stand density increases with a decrease in mean stand height and DBH.

This is proof that the radar back scatter increases against large objects and decreases against small trees. In forest stands, the stand density, i.e., number of trees per hectare, decreases when the mean DBH and height

increase.

Correlation between Stand Coverage and SAR Data

It was found that EERS-1/SAR data has a high correlation with coverage as shown in Fig.9. However, JERS-1/SAR data was not correlated if tree crowns were closed, apparently due to differences in microwave wavelengths.

Results of Principal Component Analysis

From the results of principal component analysis (Table 5), it became clear that the first principal component is composed of stem parameters such as height, DBH, basal area, and tree volume. The first principal component with JERS-1/SAR data had a high correlation because the factor loading was 0.89. From the factor loading in principal component analysis, it was assumed that the second principal component may be related to tree leaves, due to the mixture of deciduous and evergreen trees. This may also be due to the differences in tree crown volume among plots with falling leaves.

CONCLUSION

Considering all the possible items relating to the stand structure, results obtained so far are as follows:

1. JERS-1/SAR data are potentially applicable to stand analysis since SAR data intensity and tree stand parameters were apparently highly correlated.
2. EERS-1/SAR data intensity had little correlation with stand coverage. The correlation with this parameter was likely caused by the differences in microwave wavelengths.
3. The results of principal component analysis showed that JERS-1/SAR data had high correlation with tree stem parameters such as tree height, DBH, basal area and tree volume. EERS-1/SAR data, however, had little correlation with tree parameters. This may have been caused by differences in microwave wavelengths.
4. SAR data without radiometric corrections are difficult to be applied to stand structure analysis because of terrain

effects. To obtain normalized backscattering coefficients for any direction free from topographical effects, we must develop an estimation formula for key parameters of stand structure analysis.

LITERATURE CITED

- CHUAH H.T. and KUNG W.L., (1994): A microwave propagation model for estimation of effective attenuation coefficients in a vegetation canopy. *Remote Sensing Environment* **50**: 212-220
- HIROSAWA H., MATSUZAKA Y., DAITO M., and NAKAMURA H., (1987): Measurement of backscatter from conifers in the C and X bands. *International Journal of Remote Sensing* **8** (11):1687-1694
- HOEKMAN D.H., (1987): Multiband-scatterometer data analysis of forests. *International Journal of Remote Sensing* **8** (11):1695-1707
- KIMURA H., (1993): Feasibility of vegetation analysis with multi parameter SAR data. *Journal of The Remote Sensing Society of Japan* **13** (1):36-47
- MATZLER C., (1994): Microwave transmissivity of a forest canopy — Experiments made with a beech. *Remote Sensing Environment* **48**: 172-180
- MOUGIN E., LOPES A. and MOSTAFA A., (1993): Effect of tree structure on X-band microwave signature of conifers. *Transactions on Geoscience and Remote Sensing* **31** (3): 655-666
- NISHI T., SENOO T., OHTE K., TANAKA S. and SUGIMURA T., (1993): Applicability of JERS-1 /SAR data for analysis of forest stand structure. *Transactions of the 15th Japanese Conference on Remote Sensing*: 203-206
- SUGIMURA T., INANAGA A., NAKAYAMA Y. and NISHIKAWA H., (1993): Observation of vegetation around Mt. Fuji using ERS-1 and JERS-1 / SAR data. *The 5th International Symposium, Remote Sensing Global Environmental Change, Graz, Austria*: 4-8
- TAKEUCHI S., (1995): A method of correction for SAR standard product. *Journal of the Japan Society of Photogrammetry and Remote Sensing*, **34** (2):54-64
- ULABY T., MOORE R.K. and FUNG A.K., (1984): *Microwave Remote Sensing — Backscattering properties of tree canopy*. ARTEC House New York: 1882-1984
- WAKABAYASHI H. and ARAI K., (1995): A method of speckle noise reduction for SAR data. *Journal of the Japan Society of Photogrammetry and Remote Sensing*, **34** (2):15-24

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