Phenological Characteristics of Cultivated Vegetation Covers in JERS-1 and ERS-1 Synthetic Aperture Radar Data - Preliminary Results -

Åke Rosenqvist
National Space Development Agency of Japan - Earth Observation Center
1401 Numanoue, Ohashi, Hatoyama-machi, Hiki-gun, Saitama 350-03, Japan

Hiroyuki Oguma
National Space Development Agency of Japan - Earth Observation Research Center
Roppongi First Bldg. 13F, Roppongi 1-9-9, Minato-ku, Tokyo 106, Japan

ABSTRACT

JERS-1 and ERS-1 SAR data have been used to investigate the usefulness of space borne synthetic aperture radar for monitoring of three different vegetation types and their subsequent growing stages. One study area is located on Peninsular Malaysia, where rice paddy, rubber and oil palm are the dominating crop types, and the other in Niigata, Japan, where rice paddy is being studied.

Results show a clear (positive) correlation between the L-band backscatter and the different growing stages for all three vegetation types. For rubber and oil palm the correlation is most pronounced during their early growing stages after which the signals become saturated before the plants reach their fully grown stages. For paddy, the backscattered signal appears to be sensitive even for fully grown plants. The behavior of paddy in SAR data is however different when comparing the paddy sites in Malaysia and in Japan. This is a result of different geometrical properties of the paddy fields, which, in turn, are due to special growing practices in the both countries. For rice fields in Japan, preliminary results show a significant difference in backscatter response dependent on the planting direction of the rice. This feature is not apparent for rice paddy in Malaysia.

C-band backscatter proved virtually insensitive for detecting different growing stages for rubber trees, but, surprisingly enough, showed a clear correlation for oil palms. This effect is due to the different architecture of the two tree types. Due to lack of multi-temporal ERS-1 data, rice paddy has not been investigated for C-band.

Keywords: SAR, rice paddy, rubber, oil palm.

INTRODUCTION

Space borne SAR is a very interesting complement to traditional optical sensors for vegetation monitoring, in particular for monitoring of agricultural crops where its all-weather capability enables regular data takes during the growing season.

Preliminary results from two efforts to monitor the growth of irrigated rice with JERS-1 L-band SAR, one in Malaysia and one in Japan are being presented in this paper. Although the projects are on-going, results obtained up to date are being discussed. The paper also briefly presents results obtained from studies of C- and L-band backscatter for rubber trees and oil palms in Malaysia.

WORKING APPROACH

Fieldwork in Malaysia were conducted in April '94, one week prior to the JERS-1 pass, and in August '94, during acquisition. In total, some 150 test fields were selected for ground truth. For rubber and oil palm the following parameters were measured or estimated: tree/plant height, stem dbh, planting density, canopy closure, planting direction, ground vegetation and slope. For rice paddy, information about growing stage, plant height, soil condition and soil texture were collected.

Fieldwork in Niigata, Japan, is currently being conducted every 44 days, i.e. at every JERS-1 pass, for detailed study of the relationships between radar response and relevant parameters for rice growth, such as plant height, planting density, planting direction, plant moisture content and leaf area index.

The JERS-1 and ERS-1 data was processed to level 2.1 and "PRI", respectively (3 looks intensity image; range and azimuth correlated; ground range). Sub-images covering the test fields were co-registered with an overall RMS accuracy of 0.5 - 0.7 pixels. The pixels covering the selected test fields were extracted and the normalized radar cross section, σ^o, was computed for each field as follows:

$$\sigma^o = 10 * \log_{10}[(DN^2)_{mean}] + CF$$

where,
DN is the digital number of a pixel in the SAR image and CF is an offset calibration factor.

The fields were then divided into groups corresponding to vegetation type and growing stage, after which group means and std.dev. were computed.

RESULTS

Irrigated rice in Malaysia

Rice paddy in Kedah and Perlis states in the northern part of West Malaysia is planted in April and May and harvested about 120 days later, in August and September. A second season stretches from October-November to February-March. One full growing season typically comprises the following stages: plowing, soil preparation/inundation, planting, plant growth, budding, ripening and harvest. In order to preserve the water for the following season, the fields are normally not drained before harvest.

Planting is performed either by manual planting in inundated fields or by so called broadcasting, where seeds are spread on wet bare soil fields. In the former case, the inundated fields appear black in the SAR image as the backscattered signal from the water surface is very low, between -17 and -15 dB. Ripples or waves on the water caused by wind or rain have no effect on the L-band backscatter. As for broadcasted fields, the soil surface is typically wet and very smooth, giving rise to about the same low backscatter as for inundated fields.

The target response increases only slowly during the first 1.5 month after planting, with about 1 dB in average, as the tender plants barely affect the signal. Throughout the following 1.5 months however, as the plants grow to their full length of about 100 cm, a significant change can be seen in the backscatter which apparently follows the plant growth. It reaches its maximum value about 3 months after planting.

During the last month before harvest, a decrease of about 1.5 dB can be observed in the SAR data. This event coincides with the final growing stage of the rice plants when the moisture contents in stalks and leaves decrease and the rice begins to ripen.

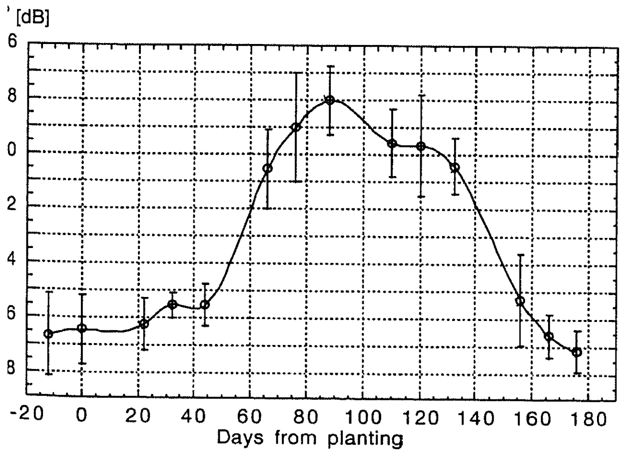

Figure 1. Temporal behavior of JERS-1 L-band backscatter observed for irrigated rice in Malaysia. Day 0 corresponds to the day of planting, day 120 to the day for harvest. Errorbars show +/- 1 standard deviation.

As the plants finally are removed during harvest, a significant decrease in the backscatter would be expected. The large harvesting machines however, leave deep wheel tracks in the soft smooth soil and the increased surface roughness partly compensates for the above loss. The net effect is a mere decrease of about 1 dB.

After harvest however, σ^o again undergoes a drastic change, falling some 6-7 dB in 1.5 months. Although it has not been verified more than once during field work, it is believed that weathering and additional water supply contribute to breaking down the rough soil surface.

Fig.1 shows the temporal change of the radar backscatter during the full growing season April-October 1994. The error bars show ± 1 standard deviation for σ^o for each respective growing stage. Day 0 indicates (estimated) day for planting; day 110 ripe fields; day 120 a mix of ripe and harvested fields; and day 132 harvested fields.

Irrigated rice in Japan

Rice cultivation in Japan is in many respects different from that in Malaysia, both physically and with regard to growing practices. In the Niigata area, the paddy fields are very small, typically only some 60 by 70 meters in size and neighboring fields are separated by low mud barriers, some 10 cm high. Roads large enough to carry a car run parallel with the fields at a distance of no more than 200 meters from each other.

Planting is performed by mechanical planting devices mounted on the back of small tractors. This results in near-perfect straight lines of rice plants, which as we shall see later, has a most significant effect on the radar backscatter. The fields are always irrigated at the time of planting, which in this area of Japan occurs during the first week of May every year. Depending on the species, the growing period varies between 120 and 135 days. As a part of the normal practices, fields may be irrigated and drained several times during the growing period, depending on weather conditions, need for additional nutritions etc.

Due to the above circumstances, monitoring of rice growth in Japan is not as straight forward as e.g. in Malaysia. The fact that different species well may be planted at fields next to each other, or that one field may be irrigated while the next one is drained further complicates the picture. On the other hand, as almost all fields are planted within a period of a week or 10 days, they are all at approximately the same growing stage, independent of the species. The fact that the soil surface of drained fields normally is moist and very smooth, also decreases the difference in backscatter between drained and irrigated fields.

Dependent on the geometric properties of the fields, the radar backscatter varies significantly. Fields with rows oriented in range direction have a

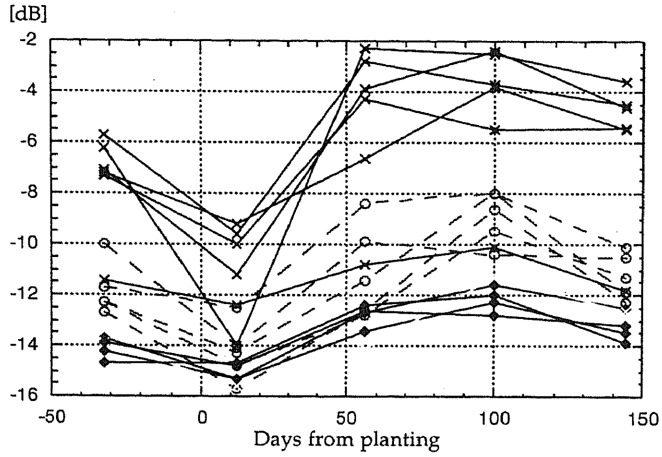

Figure 2. Temporal behavior of JERS-1 L-band backscatter for irrigated rice fields in Niigata, Japan. "x" corresponds to fields planted in range direction, "o" to fields planted in azimuth and "♦" to fields planted in other directions.

very different appearance compared to fields with other planting directions, both in terms of total temporal radiometric dynamic, as well as in terms of the initial intensity for bare soil fields. A dynamic range of about 7 dB for fields planted in range direction has been observed, compared to only some 3 dB for fields planted in other directions. A second peak of has been observed for fields planted perpendicular to range, i.e. in azimuth direction, showing a total radiometric range of approximately 5 dB (Fig. 2). An important observation, however, is that the overall shape of the temporal curve, resembling the temporal curve for fields in Malaysia (Fig. 1), appears to be the same for any planting direction.

Analysis of the variations in the total temporal radiometric ranges between fields with different planting directions is apparently not trivial. At first thought, one could expect that fields planted in range direction would give rise to a lower backscatter, opposite to what has been observed, since the open spaces of water or bare soil between the plant rows are most visible then and a large part of the transmitted signal therefore would not be scattered back. In any other direction, the ratio of rice plants vs. open space would be much larger and thus result in a stronger backscattered signal. But as we have seen, this is not the case. A possible explanation to the strong backscatter is that the strict geometry of the planting rows and columns result in that all plants within one resolution cell (18*18 meters) interact to give rise to a uniform strong backscatter response. For fields oriented in other directions than range direction, the strict geometry will instead cause the backscatter to decrease. The fact that the planting geometry is strict in row direction, i.e. the direction which the tractor has been moving, but less strict in the direction perpendicular to this, may explain the second peak that occurs for fields planted in azimuth direction. Here, the lines of plants are not as straight as the rows in the planting direction. Nevertheless, it appears to be sufficient to enhance the backscattered signal above the level of fields oriented in other directions.

The initial offset variation in the backscatter for fields with different planting direction can be explained as resulting from backscatter caused by the roads and mud barriers which contaminate pixels near the edges of the fields. Roads oriented perpendicular to the range direction give rise to a strong backscatter caused by a dihedral type of double bounce of the radar signal on the smooth soil and the road sides. Due to the very small sizes of the fields however, it is difficult to exclude such pixels.

It is obvious that the above discussion about the backscatter mechanisms are mere speculations and that a more thorough study is required. Such a study is currently under way, aiming at providing a more solid theoretical background to the directional behavior of paddy fields in Japan.

Rubber

Next, let us return to Malaysia, to have a look at the backscatter behavior at L- and C-band for two common tree crops; rubber trees and oil palms.

Rubber trees in Malaysia normally grow to a total height of 12 - 20 meters, depending on the soil and terrain conditions. The trunk diameter seldom exceeds 30 cm. After 20 - 25 years, the productivity decreases and the fields are normally cleared for a new generation of trees to be planted.

Results from the current study show a clear correlation between JERS-1 L_{HH} band backscatter and tree height (Fig. 3). The dynamic range is about 5 dB, with the signal saturating at a tree height of about 12 meters. Tree height is closely correlated to growing stage for individual stands but depending on

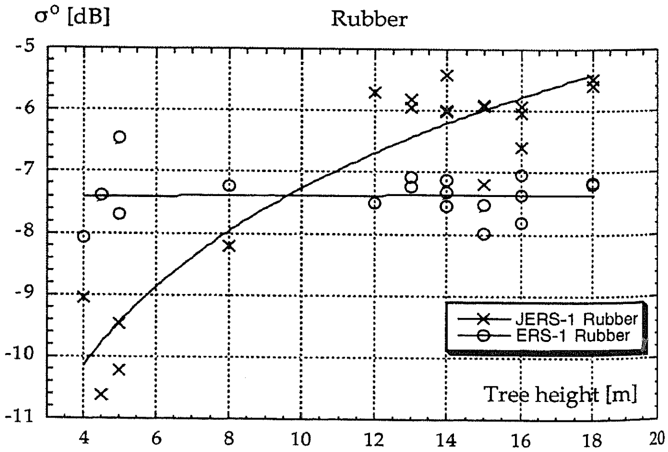

Figure 3. L- and C-band backscatter vs. rubber tree height.

soil and terrain conditions, growing speed and height at full growth vary between stands. In general however, 12 meters will correspond to an intermediate growing stage, implying that saturation occurs before the stands reach their full growths. The major scattering mechanism for rubber trees is ground /trunk interaction and scattering on twigs and branches. The leaves have little effect on the total backscatter.

ERS-1 C_{VV} band data shows no correlation between backscatter and tree height for rubber, σ^o varying between -7 and -8 dB even for newly planted fields. The major scattering mechanism at C-band is scattering on the leaves and twigs. This insensitivity even for the young stages when the canopy is not yet fully developed may be due to that the ground is covered by grass and/or so called legumes with leaves of about the same size as rubber leaves.

<u>Oil palm</u>

Oil palms normally grow to a total height of about 12-16 meters, including the large fern-like branches which extend from the top of the trunk like an umbrella. The trunk is very rough, with scales like a large spruce cone. As with rubber, the oil palms are productive for about 20 - 25 years, after which they also will start to fall over if they are not cleared.

For L-band, the dynamic range between newly planted and old oil palm plantations is about 4 dB. The signal saturates at a level of around -7 dB, which is about 1 dB lower than for rubber. This difference can be attributed to the difference in structure between oil palms and rubber trees. Due to the very rough surface of the trunks of the palm trees, the ground/trunk interaction is likely contribute less to the total backscatter, while, on the other hand, the contribution from the canopy with its large branches can be expected to contribute more. Attenuation by the canopy layer in both directions can be assumed to further weaken the double-bounce effect from the trunks and the ground.

For C-band, there is a clear correlation between radar backscatter and growth of the palm trees, in strong contrast to the situation for rubber. The dynamic range is about 3 dB with saturation around -6 dB, about 1.5 dB higher than the saturation level for rubber. With the large leaves and branches of the palm trees, the canopy layer is expected to be the by far most dominating scatterer for C-band.

Fig. 4 and 5 show the L- and C-band backscatter as functions of the height of the trunks and the length of the branches, respectively. Notable is that the radar responses are very similar for L- and C-band, for both trunks and branches, indicating that the major scatterers for both frequencies may be the same. Given the better separability by branch length than trunk height for young palms further leads to the conclusion that the large branches are the most significant scatterers also at L-band.

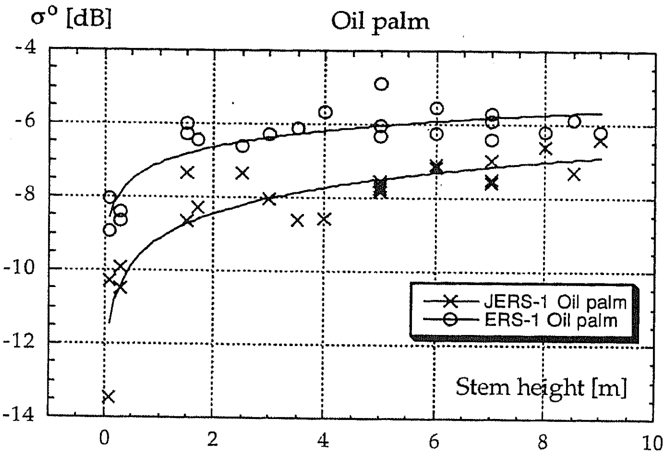

Figure 4. L- and C-band backscatter vs. oil palm stem height.

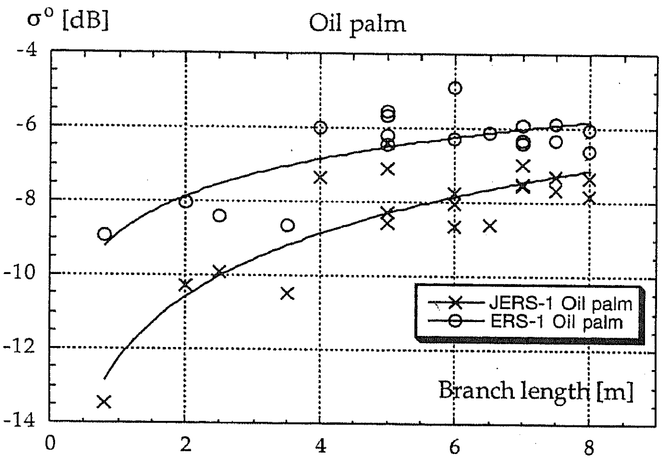

Figure 5. L- and C-band backscatter vs. oil palm branch length.

SUMMARY

Results presented in this paper show that L_{HH}-band SAR is sensitive for different growing stages of irrigated rice. The backscatter reaches it peak value about one month before harvest, after which it drops about 1.5 dB. The total radiometric ranges for paddy fields in Malaysia and paddy fields in Japan were however found to be different. The backscattered intensity for paddy fields in Japan were found to be strongly dependent on the planting direction of the fields, while in Malaysia, the backscattered signal was very homogeneous. The difference between the backscatter behavior can be explained by that in Malaysia, where manual planting broadcasting is practiced, the rice plants can be considered spread randomly over the fields, while in Japan, mechanical planting result in fields with strict geometrical patterns. The difference in size of the fields was found to be another factor which had significant effect on the radar backscatter.

The results from the study of rubber and oil palm show that L_{HH}-band SAR is sensitive for monitoring the growth of the two tree crops to a certain level. C_{VV} band in turn, proved to be virtually insensitive to the growth of rubber in the test area, while being correlated with the growth of young oil palm up to a (trunk) height of 2 meters after which the signal saturated. The saturation levels for rubber and oil palm were found to be different. In conclusion, L- and C-band SAR appear to complement each other quite well for monitoring of the two tree crops. C-band seems suitable for distinguishing the two species as it saturates at different levels already for young growth. L-band appears more useful for monitoring growth, as well as for distinction between the species for fully grown plantations.

ACKNOWLEDGEMENTS

The study of the Malaysian crops was performed as a part of a joint research cooperation between the National Space Development Agency of Japan (NASDA), the Malaysian Centre for Remote Sensing (MACRES) and the Malaysian Department of Agriculture (DoA). Field work was performed jointly by the agencies, while the data analysis presented in this paper was performed at NASDA by Å. Rosenqvist.

The study of irrigated rice in Japan was performed by NASDA in cooperation with local farmers in the Niigata area. Field work was performed by Å. Rosenqvist and H. Oguma, analysis work performed by Å. Rosenqvist.

REFERENCES

Dobson M.C., Ulaby F.T., Le Toan T., Beaudoin A., Kasischke E.S. and Christensen N. (1992). Dependence of Radar Backscatter on Coniferous Forest Biomass. *IEEE Transactions on Geoscience and Remote Sensing,* 1992, Vol. 30, No. 2, pp 412-415.

Hsu C.C., Shin R.T., Kong J.A., Le Toan T. and Beaudoin A., (1993). Application of Theoretical Model for Microwave Remote Sensing of Forest. *International Geoscience and Remote Sensing Symposium (IGARSS'93).* Tokyo, Japan, August 18-21, 1993. Digest, pp 595-597.

Karam M.A., LeVine D.M., Amar F., Fung A.K., Mougin E. and Lopes A. (1993). Understanding the Relation between Forest Biomass and the Radar Backscatter Signals. *International Geoscience and Remote Sensing Symposium (IGARSS'93).* Tokyo, Japan, August 18-21, 1993. Digest, pp 573-575.

Kurosu T., Fujita M. and Chiba K. (1994). Rice Crop Monitoring with ERS-1 C-band SAR. *Final Report of JERS-1/ERS-1 System Verifivation Program, Vol 2, pp 120-126.*

Miranda F.P. and Carr J.R. (1994). Application of the Semivariogram Textural Classifier (STC) for Vegetation Discrimination Using SIR-B Data of the Guiana Shield, Northwestern Brazil. *Remote Sensing Reviews,* 1994, Vol 10, pp 155-168.

Ramberg E. (1984). Zeroes in the Gauss-Doolittle Scheme. *Lantmätar Digest 1984.* Royal Inst. of Technology, Stockholm. KTH-fmi/Lmk-84.

Rosenqvist Å. (1995). Evaluation of L-, C- and S-band SAR for Characterization of Tropical Tree Crops. *Remote Sensing in Action '95; 21st Annual Conference and Exhibition of the Remote Sensing Society.* Southampton, UK, Sept. 10-14, 1995.

Le Toan T., Laur H., Mougin E. and Lopes A. (1989). Multitemporal and Dual-Polarization Observations of Agricultural Vegetation Covers by X-Band SAR Images. *IEEE Transactions on Geoscience and Remote Sensing,* 1989, Vol. 27, No. 6, pp 709-718.

Yamagata Y., Shibayama M., and Akiyama T., (1987). Measuring equipment for all weather monitoring of agricultural fields - estimation of LAI and dry weight. (Japanese). *56th Japan Symposium on Agricultural Crops, 1987.*