Synthetic Aperture Radar Data As A Sustainable System For Monitoring The Rice Cropping Systems - An Analysis

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Abstract

Satellite radar data is of particular interest for crop monitoring as the probability of obtaining data from optical sensor during the growth period of rice is very low. At present Synthetic Aperture Radar (SAR) data is available from ERS and RADARSAT satellites. Studies carried out using SAR data from these have established the feasibility of rice crop monitoring using multi-date SAR data. Two to three date ERS SAR data gave better than 90 per cent classification accuracy for rice crop grown under lowland condition in the eastern Indian region. As such lowland rice, which includes shallow, intermediate, deep water and irrigated rice cultures accounts for more than 90 per cent of the rice lands of Asia. Estimates could be obtained as early as 15-25 days of transplantation. In addition to this it was feasible to discriminate the early maturing and late maturing rice varieties. This information is required for accurate yield estimation. Two date data of Radarsat Standard beam Shallow mode (S7) gave better than 95 per cent classification accuracy for irrigated rice. It was feasible to obtain the area estimation as early as 15 days after transplanting of the crop. The HH polarisation of RADARSAT SAR data gave high accuracy of classification of water bodies than that of the VV polarised SAR data of ERS. The separability of rice from other land cover classes like water/water logged area, forest and home steads etc. was high in multi date SAR data. These classes in general confuse with rice in optical data. The backscatter derived using temporal SAR data showed a distinct profile associated with the crop growth. This indicates the feasibility of growth modelling for yield forecasting using SAR data alone.

Thus, it was observed that C band SAR data available from the present microwave satellites is useful for timely estimation of area and monitoring the growth of rice crop. The present paper highlights these findings from the studies carried out using SAR data for different rice growing regions in India.

Key words: SAR, ERS, RADARSAT, S7 beam, rice, temporal, backscatter, cultural types, classification, accuracy, area, production

1.0 INTRODUCTION

Rice is grown in 111 countries occupying around 148 Mha, the highest area occupied by a crop. The crop is concentrated in the developing countries of Asia, and Africa. Highest number of people depend on it for food and employment. The rainfed cultivation and management practices in the region result significant year to year fluctuations in production. Thus, the need to have a timely forecasting of the crop prospects is critical for planning for food security. Satellite remote sensing based crop production forecasting is one of the reliable methods towards large area crop production forecasting. The technical precision of such procedures has improved through years and at present is accepted to meet the requirement of routine gathering of timely information on crop prospects. In India, Crop Acreage and Production Estimation (CAPE) is an on-going project which uses optical remote sensing data to forecast production of major cereals, oilseeds, and fiber crops (SAC, 1995). However, data availability from optical sensors caused by cloud cover is the limitation of such studies. In general there are fewer images available during the entire 120 day growth period of the crop, with virtually no images during the early vegetative stage (Currey et. al., 1987). The probability of cloud free data did not improve using high temporal resolution of meteorological satellites like NOAA AVHRR.

The advantage of radar remote sensing for rice crop lies in its independence from cloud and solar illumination. Sensitivity of SAR to canopy geometry and moisture can be suitably exploited not only for crop discrimination but also to model moisture status and yield. Usefulness of radar backscatter for crop type classification has been demonstrated by many studies using airborne SAR data (Hoogboom 1983, Brown et. al. 1984, Foody et. al. 1989). Bush and Ulaby (1978) showed that use of multi-date data improves the crop type discrimination. The possibility of examining space borne radar data for large area agricultural application was realised with the successful launch of ERS-1 Synthetic Aperture

Radar (SAR). The C band ERS-1 SAR with 23° incidence angle, though designed primarily for monitoring the snow and ice covered surfaces of the earth, has been evaluated by various workers for land applications including agriculture (ESA, 1995).

Preliminary analysis of ERS-1 SAR data for crops grown in India showed good results for rice crop identification (Patel et. al. 1995, Premlatha and Rao, 1994). Similar results have been reported for other rice growing areas of the world (Kuroso et. al. 1994, Paudyal and Aschbacher, 1993, ESA, 1995, Ewe et. al. 1995). ERS-1 was followed by the launches of ERS-2 and RADARSAT. This has widened the scope of obtaining space-borne SAR data. However, operational use of SAR data for rice area monitoring calls for critical evaluation of accuracy of classification in various rice growing environments. Rice being the most climatically adaptable cereal, variety of land management systems for rice cultivation exists. In agricultural terminology, these variation in growing environment of the rice crop is known as *cultural types*. There are two predominant cultural types, the lowlands or wetlands and the uplands. The crop establishment method, the depth and duration of standing water in the fields during crop growth period and the per cent plant cover vary as per the cultural practice (Table-1). Thus, this will have a direct bearing on the SAR backscatter and accordingly on classification accuracy. The lowlands are the most dominant ones in Asian region. These are further classified as rainfed shallow, intermediate, deep, and irrigated (DeDutta, 1981, Huke, 1986). Fig.1 shows the per cent area occupied by different rice cultures in the world. As observed, the dominant culture type is lowland shallow and lowland intermediate. Same status also holds good for India. Shallow incidence angle of more than 40 degree is considered more suitable for crop type discrimination (Ulaby et.al., 1987). Hence, RADARSAT S7 data having 47-49 degree angle was investigated for identification of rice with an aim of developing a remote sensing based rice monitoring system.

2. STUDY AREA

The study area is spread over different sites in states of Assam and West Bengal states of India. Rice is the major crop, occupying more than 60 percent of agricultural area in *kharif* or monsoon (June-October) season. Jute and sugarcane are the other crops generally grown in small parcels. The crop calender varies as per the local climate. The crop is transplanted in July / August months with the onset of southwest monsoon and harvested in November-December. Traditional tall varieties of rice of 120-140 days duration are grown in fields with deep water whereas semi-dwarf varieties of 110 days duration are grown in intermediate and irrigated lands.

3. DATA USED

ERS-1 data of 1995, 1996, 1997 and RADARSAT S7 data of 1997 were used. ERS-1 SAR data of both ascending and descending modes have been used to increase the temporal coverage. Data were acquired between last week of August and first week of November, 1995 for kharif rice. For rabi rice, the data were acquired during January - March. RADARSAT data were obtained as a part of the ADRO project. The incidence angle of RADARSAT S7 data ranges from 45°-49°, covering nominal area of 100*100 kms. with nominal resolution of 30 metre (ground*range 20.09*27 m.). Data products were of 16 bit with 8 meter pixel spacing.

Ground truth data were collected by field survey during the acquisition periods. It included collection of all relevant information on the crop type, stage, height, per cent cover, field background, moisture status, as per the standard procedures followed for such study (AGRISAR 1986, Panigrahy,1996). For few villages, field-wise ground truth data were collected on the cadastral survey maps (1:10,000 scale). Information on irrigation schedule and meteorological data like rainfall, wind speed were also collected from the nearest meteorological stations.

4.0. METHODOLOGY

Representative sites from different cultural practice and crop proportion were selected using the first date data. Around 10-15 sites of 10 km*10 km. area was selected in each scene. Ground truth data were collected within these sites. These sites were used as training class sites and generate class statistics.

The digital numbers were converted first to β° using the calibration coefficients provided in the leader file of the data using the following:

$$\beta^\circ_j = 10 * \log_{10}[\,(DN_j^2 + A3) / A2_j]\ \text{dB}$$

The β° was then converted to s° using the following:

$$s^\circ_j = \beta_j + 10 * \log_{10}(\sin I_j)\ \text{dB}$$

Where A2 is the scaling gain value for the j th pixel and A3 is the fixed offset and I_j is the incidence angle at the j-th range pixel.

The data were classified using per pixel Artificial Neural Network (ANN) classifier with one hidden layer(Benediktsson et al., 1990). The temporal SAR data were used as multi-channels in the classification process. Various combinations of dates were used to select the optimum date combination.

The classification accuracy was evaluated using the J-M distances, Kappa-coefficient for overall classification and the confusion matrix for the crop classification. Some sites, cadastral maps were used to compare the accuracy of the classification.

4.0 RESULTS

4.1 Land cover and SAR response

High backscatter of -6 to -5 dB characterised the urban areas and villages in ERS SAR data, thus appeared bright in all the dates. Similarly very little change in backscatter was observed from forest and homesteads. Low backscatter of less than -15 dB characterised open water bodies like river, ponds and lakes. However significant variation in backscatter was observed from the water bodies on different dates. This was mainly due to change in roughness of the surface caused by variation in wind speed. Backscatter of the fallow fields varied depending upon the presence of grasses, crop residue and moisture status.

Similar observations were made in RADARSAT data (Fig.2). However, very small variation in backscatter was observed from the water bodies on different dates. *This is in sharp contrast to that observed from ERS SAR data*, where the backscatter from water bodies varied significantly from date to date mainly due to variation in wind speed (Fig.3). This may be attributed to the polarisation difference of the two sensors. HH polarisation of RADARSAT SAR data is considered to be less sensitive to wind induced roughness in water. This has a direct bearing on the classification accuracy of rice. In addition, identification of each village pond was possible. These were used as ground control points for map to image and image to image registration.

It was feasible to identify aquaculture ponds from the surrounding lowland rice fields and water bodies. The ponds invariably appeared dark in temporal dates. The pond ridges appeared brightness, thus, increasing their identification accuracy. The lowland rice fields in the vicinity of these ponds in South 24 Paraganas were generally also used for pisciculture during kharif season. The per cent crop cover in these fields were very poor (25-30%). In the initial growth period, these fields also appeared very dark with bright field ridges. But in temporal data, the ponds were separable from these fields.

4.2 SAR response from rice fields

Rice is grown in the area in a rice-fallow or rice-rice rotation practice (kharif-summer). Kharif rice was studied using ERS SAR data, where as the summer rice was addressed in case of RADARSAT data. The characteristic management practice used for wetland rice was evident in the temporal backscatter of SAR data. All the rice fields showed a distinct decrease in backscatter in the data which corresponded to the transplanted fields of rice. Very low backscatter was observed from rice fields during the early vegetative stage irrespective of the cultural type, thus appearing dark. Surface scattering from the field water does not contribute much to the backscatter and the per cent plant cover being very low, the volume scattering from the canopy was assumed to be low. This may be the reason for very low backscatter from the rice fields during the early vegetative stage. Maximum contrast of rice fields was observed during this period. The field ridges, trees lining the ridges were very bright due to corner reflection. The field boundaries, canals lined with trees and small drainage channels are very prominant. Fig.4 shows ERS SAR image of a site in West Bengal in August with prominent field boundaries. A gray scale inversion was adopted to highlight the boundaries.

In the subsequent dates, a considerable increase in backscatter was observed from all categories of rice fields. It peaked around 80 days after transplantation. Since the field conditions were similar to the first date, this increase can only be attributed to the volume scattering from the crop canopy. The contrast of rice fields decreased sharply and field boundaries were then no longer visible. As the crop reached towards maturity, the backscatter increased significantly and the separability between classes decreased sharply. Fig. 5 a shows the SAR image for a typical lowland rice site acquired during early vegetative stage. Note that all the rice fields appear dark and distictly identifiable from all other vegetation. The SAR image of the same site acquired in November corresponding to the grain filling stages is shown in Fig.5b. The rice fields appear bright. Earlier contrast that was observed between rice fields and other classes were not found in this. Also note that the waterlogged area, the river water appear bright in the first date and dark in the second date. This variation was mainly due to variation in wind speed.

4.3 Classification accuracy

4.3.1 ERS SAR

It was observed that the temporal response of rice crop is distinctly different from other classes. It indicates that the acquisition date will have a strong bearing on the classification accuracy of rice crop. The two dimensional scatter-plots of the pixels belonging to various classes showed high separability of rice fields from water, homestead/forest classes in any two date data when first-date data is included. This indicates that acquisition of SAR data during the early growth stage is essential for rice crop identification.

Three date ERS SAR data acquired during puddling, vegetative and grain filling stages resulted more than 90 per cent accuracy for all cultural types of rice. High accuracy of more than 95 per cent was obtained for lowland intermediate and irrigated rice (Table-2).

The classification accuracy of rice using ERS SAR data was affected mainly by the presence of water bodies and flooded fallow fields. The presence of rivers and streams lowered the accuracy significantly. In all cases, misclassification from stagnant water bodies, water logged areas and fallow fields reduced significantly due to the use of temporal signature. However, it was observed that temporal data had little or no effect on misclassification caused by rivers and streams.

4.3.2. RADARSAT SAR

RADARSAT four-date data were used in various combinations to classify rice crop. Combinations of two, three and four-date data resulted more than 90 per cent classification accuracy for rice crop (Table-3). The highest classification accuracy of more than 94 per cent was obtained using the four-date data. However, two-date data acquired on January 02 and February 19 was of particular interest for early detection of rice crop. This combination resulted more than 92 per cent classification accuracy for all the sites, which is generally not feasible using optical data and ERS data. In ERS SAR data, early detection of rice using two-date data was poor due to misclassification mainly with water bodies. The classification accuracy of water was more than 95 per cent in two-date RADARSAT data due to small temporal variation in the backscatter. This can be attributed to the HH polarisation of RADARSAT which is expected to be less sensitive to wind induced roughness unlike the VV polarisation of ERS SAR. The confusion matrix of the training class pixels for one site using these two-date data is shown in Table-4. Using data from optical sensors, one can estimate rice acreage using late March data corresponding to peak vegetation stage for correctly classifying rice areas. Single-date IRS LISS II data acquired during late March generally result 94 per cent classification accuracy.

4.4 Crop growth modelling

Rice crop showed the largest dynamic range of backscatter of -18 to -8 dB during the study period. The change of backscatter in relation to rice growth stage was analysed using the training site fields having different growth stages of rice. The temporal backscatter of rice from transplanting to panicle initiation stage is shown in Fig. 6. The backscatter showed a decline of 6 to 7 dB with the puddling of fields and came very close to that of water bodies. Within 30-40 days of transplantation, the crop showed rapid rise in backscatter. There after, from 40-45 days onwards, the rise was slow. On the average, around -8 dB backscatter was observed on the data acquired in March, corresponding to the peak vegetative to panicle initiation stage (Fig.7). This can be used to model the agronomic parameters with backscatter to estimate crop yield. Rice crop exhibited a similar temporal signature and dynamic range in ERS SAR data as reported in earlier studies (Kurosu et al., 1995, Chakraborty et al., 1997).

4.5 Discrimination of autumn and winter rice

Rice crop grown in kharif season were categorised as autumn and winter rice based on the harvesting dates. The crop harvested in October is called autumn and that harvested later in season is known as winter rice. The yield of these two types of rice vary significantly. Temporal SAR data was found to be useful in identifying these varieties as the rate of change in backscatter were different.

4.6 Identification of field operations

The high sensitivity of radar to soil roughness, makes it an ideal tool for monitoring agricultural activities. Data acquired 8 days apart was used to discriminate ploughed field from other fields. The ploughed fields appeared very bright due to high backscatter characterizing the rough clodded surface. The direction of ploughing was found to have little effect on this change in backscatter.

5. CONCLUSION

The investigations using SAR data from ERS and RADARSAT S7 beam has shown promising results for rice crop inventory. The 23° C band ERS-1 SAR data, though not considered ideal for vegetation identification, was found to be useful for monitoring rice fields due to the prevailing management practice. Rice crop showed a characteristic temporal behavior and a large dynamic range of backscatter during its growth period. This enabled to achieve more than 90 per cent classification accuracy of rice using temporal data, provided that the data at the puddled stage was included. Similar results were obtained using RADARSAT S7 beam data. The HH polarisation data of RADARSAT was found to result in less temporal variation in backscatter from water bodies compared to the VV polarised ERS SAR data. This resulted in better discrimination of rice fields from water in temporal data. Detection of rice crop using a data acquired during the preceding fallow period and another during the puddling/early tillering (10-20 days) is of particular advantage for early crop area estimation. Thus RADARSAT data has the potential to estimate rice area early in the season as well as for making multiple forecasts of the crop area as the growing season progresses. Thus, SAR is a sustainable system for remote sensing based rice area monitoring programme.

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Table-1 Characteristics of rice lands belonging to different cultural practices (DeDutta, 1981).

Type	Method of crop planting	Maximum Field water (cm)
Shallow	Transplanting	5-15
Intermediate	-do-	16-50
Deep water	Broadcasting dryseed	50-100
Floating	do-	>100
uplands	Broadcasting or drilling	No standing water

Table-2 Confusion matrix of training class pixels of a lowland rice site in West Bengal using three and two date ERS SAR data.

GT Class	No. Pixels	Classified as RI	HS	WR	OC	FL
Three date data						
RI	5453	97.9	0.5	1.2	0.0	0.4
HS	3567	1.6	92.7	0.9	1.3	3.5
WR	824	4.2	1.7	93.3	0.0	0.7
OC	191	0.5	22.0	0.0	77.5	0.0
FL	384	0.3	10.4	1.0	0.0	88.2
Two date data						
RI	5453	95.0	1.0	3.6	0.0	0.3
HS	3567	1.7	85.8	3.3	6.1	3.1
WR	824	2.5	0.8	96.2	0.0	0.4
OC	191	0.0	13.6	1.6	84.8	0.0
FL	384	0.3	16.9	2.6	0.0	80.2

Note: RI-rice, HS-homesteads, WR-water, OC-other crops, FL-fallow

Table-3 Classification accuracy of rice crop using different combinations of RADARSAT SAR (S7 beam) data sets.

Data set	Class. accuracy	Kappa	Overall Accuracy
1+2+3+4	94.22	0.8200	85.73
1+3	93.7	0.6810	74.70
1+2+3	93.61	0.7511	80.33
3+4	92.91	0.7710	81.80
2+3	88.99	0.7179	77.49
2+4	82.18	0.7711	81.89
2+3+4	83.38	0.7925	83.65

1= Jan02., 2= Jan.26., 3= Feb.19., and 4= March 15, 1997.

Table-4. Confusion matrix of training class pixels of a site in two date RADARSAT S7 data (Jan.02 and Feb.12' 1997) adjudged optimum for early detection of rice.

Class	Total pixels	Ri	Fa	Po	Pu	Wa	Vi	Clas.acc%
Ri	3936	3675	171	1	38	37	0	93.70
Fa	3432	1315	1199	309	533	16	46	35.08
Po	2226	5	62	1482	335	0	342	66.58
Pu	302	35	45	56	166	0	0	54.97
Wa	3279	102	49	0	0	3126	0	95.39
Vi	1096	0	0	81	18	0	997	90.97

Overall Accuracy =74.74%, Kappa = 0.6817

Note: Ri=rice, Po=potato, Pu=pumpkin, Fa=fallow, Wa=water, Vi=village.

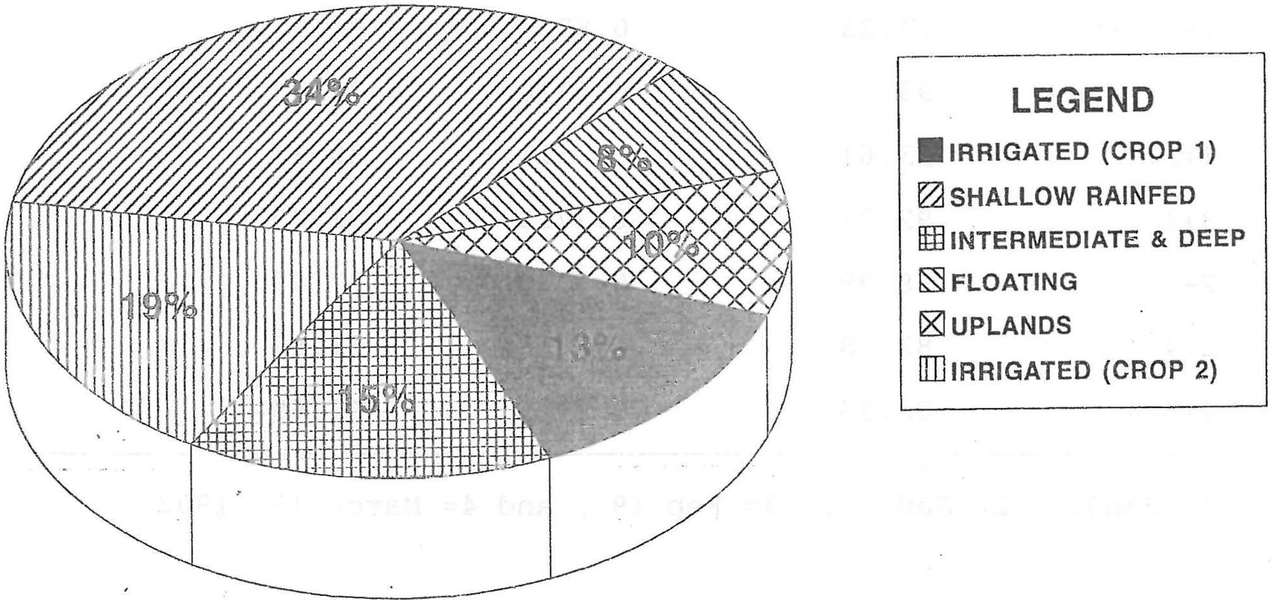

Fig.1: PERCENT OF RICE CROP AREA OF THE WORLD BY SPECIFIC CULTURAL TYPE

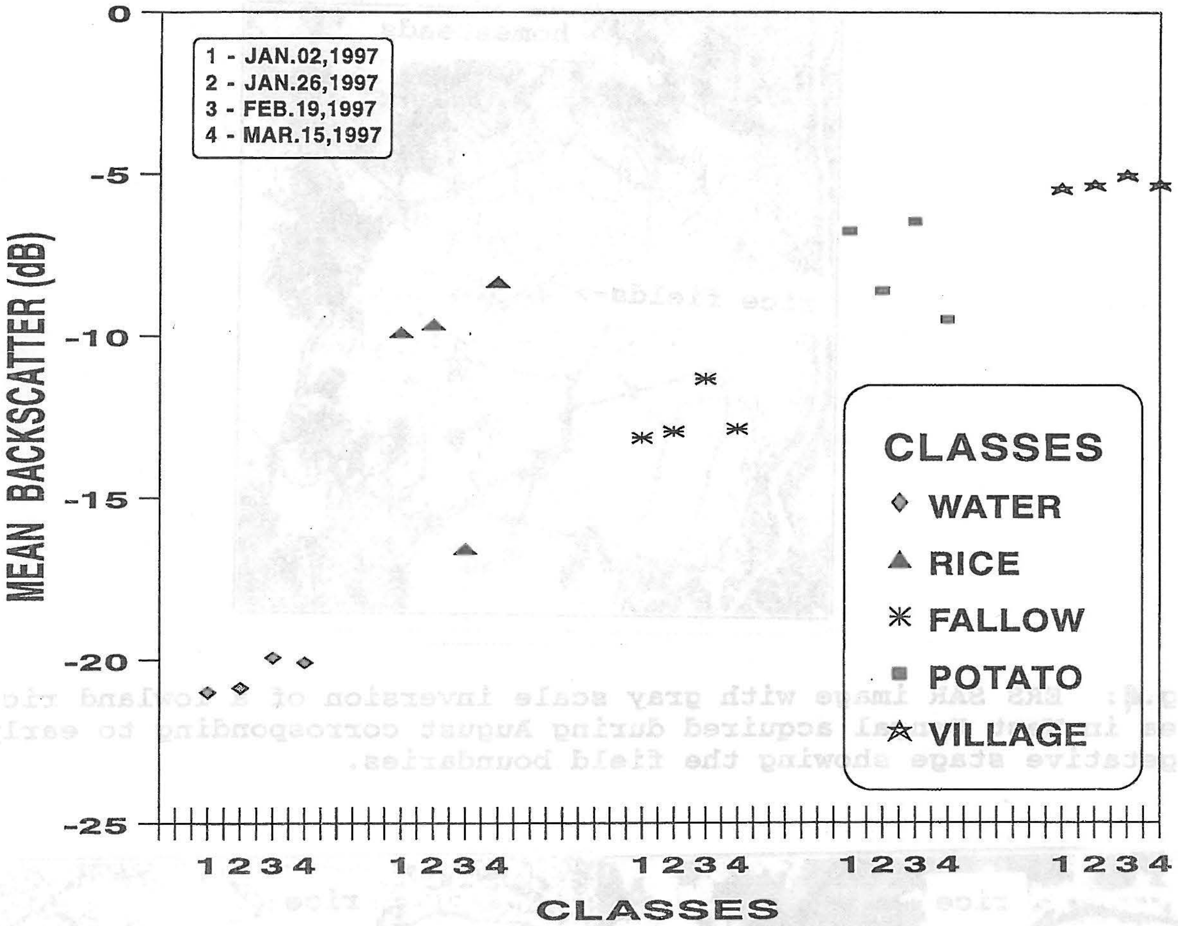

Fig.2:Temporal variation of different land cover classes in RADARSAT S7 SAR data.

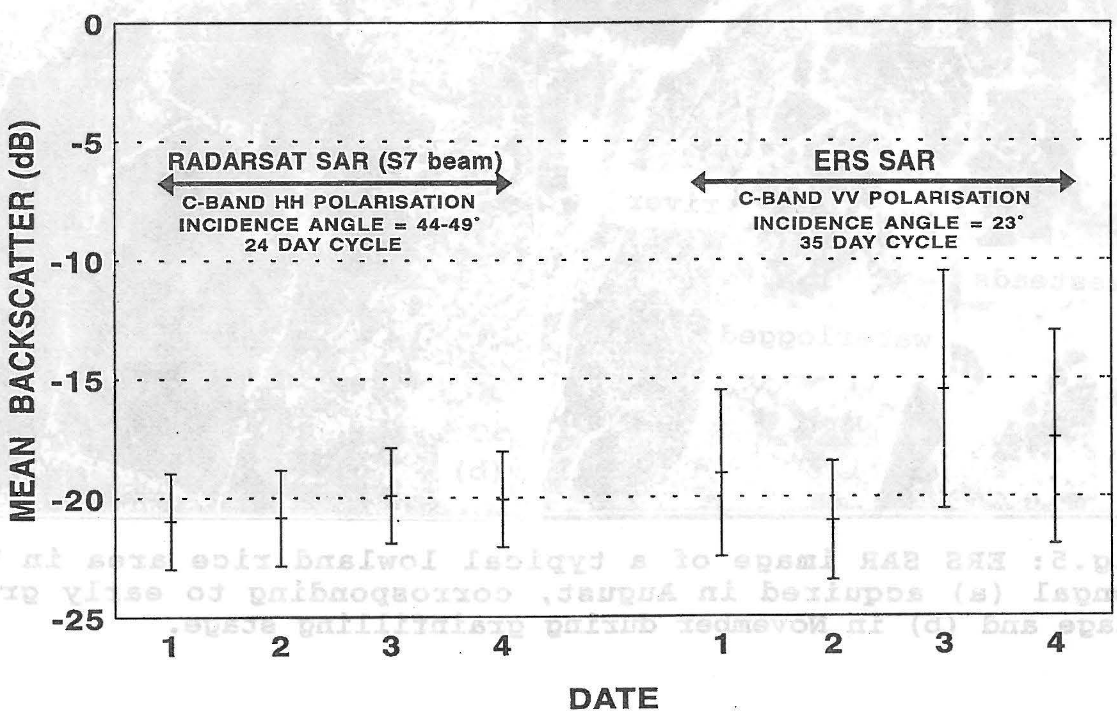

Fig. 3: Temporal variation in backscatter(dB) of bodies in RADARSAT SAR(S7 beam) and ERS SAR.

Fig.4: ERS SAR image with gray scale inversion of a lowland rice area in West Bengal acquired during August corrosponding to early vegetative stage showing the field boundaries.

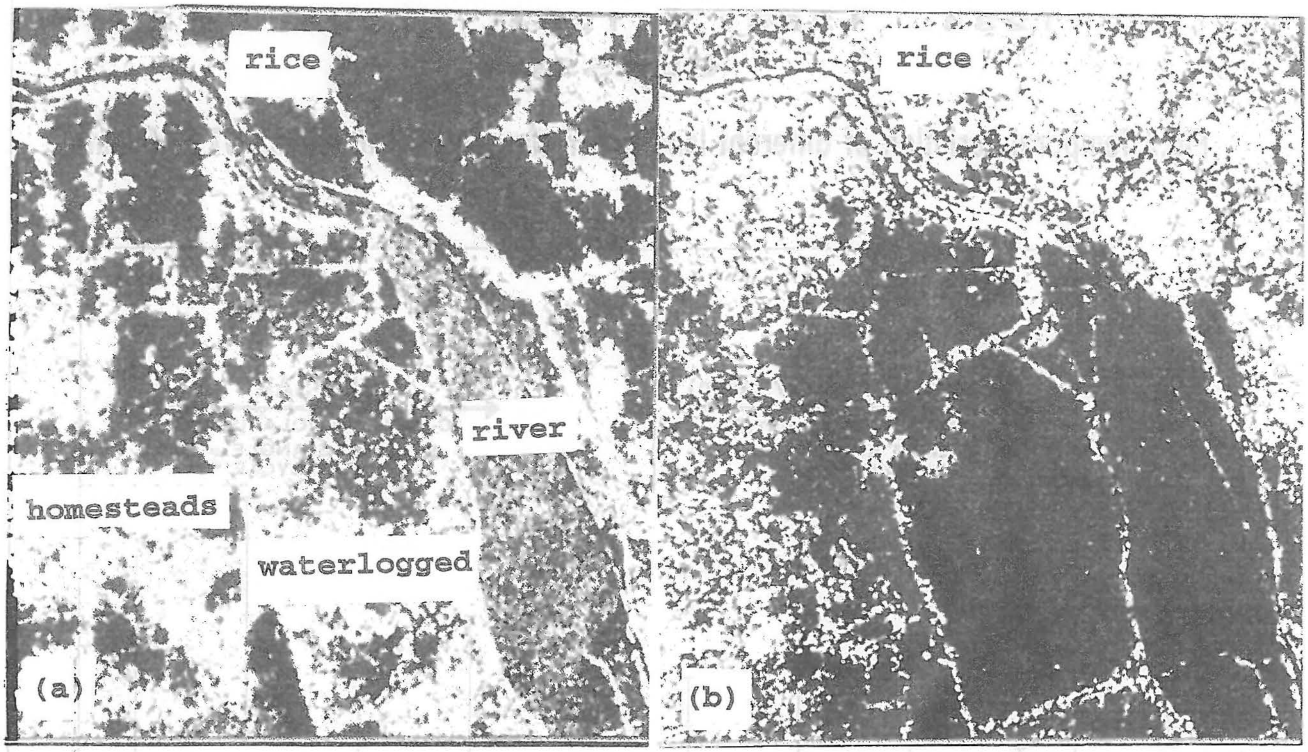

Fig.5: ERS SAR image of a typical lowland rice area in West Bengal (a) acquired in August, corrosponding to early growth stage and (b) in November during grainfilling stage.

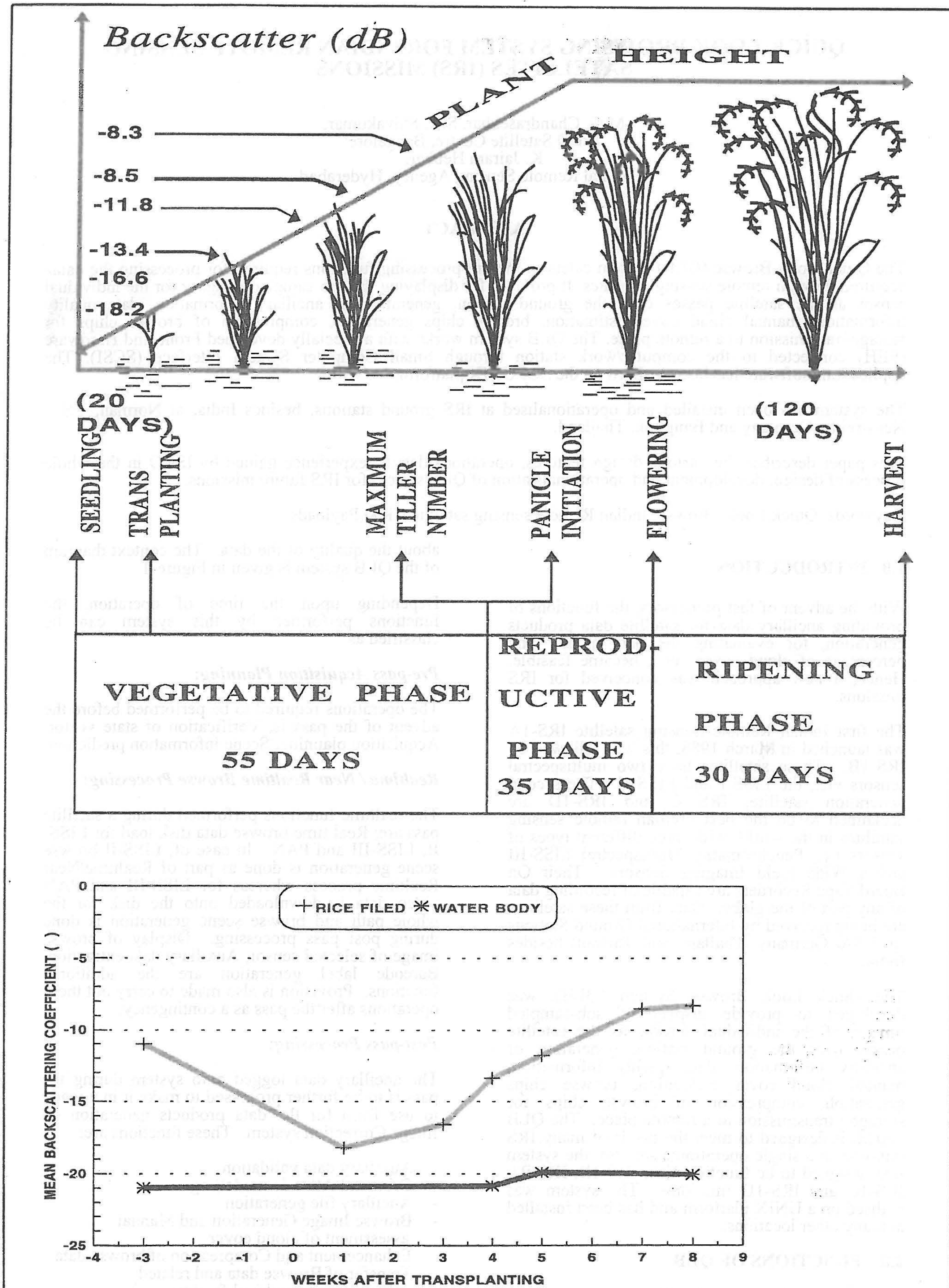

Fig.6: SAR backscatter in relation to rice crop phenology (RADARSAT S7 Beam)