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Early estimation of rice area using temporal ERS-1 synthetic aperture radar data—a case study for the Howrah and Hughly districts of West Bengal, India

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Abstract. The characteristic temporal backscattering signature of rice crop grown under flooded condition was used to estimate rice acreage for a region in West Bengal, India. To date ERS-1 Synthetic Aperture Radar (SAR) data, one acquired within 30 days of transplantation and another after 30–40 days was found to be optimum for early estimation of rice acreage. The rice crop was found to be distinctly separable from forest, tree vegetation, village/urban areas. Misclassification of rice was observed mainly with water, waterlogged areas and fallow fields.

1. Introduction

Radar remote sensing has the potential to play an important role in agricultural crop monitoring due to its independence from solar illumination and cloud cover, besides its sensitiveness to canopy geometry and moisture content. The successful launch of ERS-1 Synthetic Aperture Radar (SAR) in 1992, followed by ERS-2 in 1995 provided space borne radar data for large area applications. Preliminary analysis of ERS-1 SAR data for identification of different field crops showed promising results for rice, wheat and rape seed/mustard crops (ESA 1995). Studies using ERS-1 SAR data over different agroclimatic regions of India for different crops indicate it is essential to have multi-temporal data for such studies (Patel *et al.* 1993, 1995, Premlatha and Rao 1994, Rao *et al.* 1995). The rice crop was found to undergo a very distinct change in backscattering during its growth period (ESA 1995). This was observed to be due to the system of growing rice under flooded conditions, where standing water in fields initially cause very low backscatter. As the crop grows extending the canopy in vertical and horizontal direction, volume scattering increases the backscatter. Thus, multi-date data acquired during early and late growth phases enhance the identification accuracy of the rice crop.

In India, Crop Acreage and Production Estimation (CAPE) is a semi-operational project which uses remote sensing data from satellite sensors to forecast acreage and yield of major field crops grown in the country (SAC 1995). As a step towards operational use of SAR data for acreage estimation of rice crop grown in India, a feasibility study was carried out for 1995–96 season. Acreage estimates were made using two and three date ERS1-SAR data for the 1995–96 season for two districts

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in the absence of data from optical remote sensing due to cloud cover. This is the first time that SAR data were operationally used to obtain acreage estimates in India. This Letter describes the procedure adopted and the results obtained.

2. Study area

The Howrah and Hughly districts of West Bengal state lying on the east coast of India between 22·00° to 23 °15″ N latitude and 87° ″ to 88° 45″ to 88° 30″ E longitude were the study districts. The districts are administrative units with in each state and are spread over an area of around 5000 km^2. The terrain is almost flat. Rice is the dominant crop in the kharif or rainy season (June–October) occupying more than 85 per cent of the agricultural area. It is grown both under irrigated and rain-fed condition. Rice is transplanted in July and harvested in November–December. A typical rice growth cycle in the study site lasts between 115–120 days from planting to harvest (July–December). The vegetative stage starts with the transplanting of 15–20 day old seedlings in flooded fields. During the vegetative stage, which lasts about 60–70 days, the plants emerge above the water surface, grow vertically through stem and leaf expansion and horizontally through tillers. The reproductive stage starts with the beginning of flag leaf, followed by flowering. The reproductive and ripening stages last about 40 days. Harvesting starts by end of November to mid-December.

2. Materials and methods

ERS-1 SAR data of 35 day cycle acquired between 24 August to 6 October, 1995 were used in this study. Data were procured from the National Remote Sensing Agency (NRSA), Hyderabad, India, which receives and supplies ERS SAR data for users in India. Both ascending (24 August, 28 September, 1995) and descending (1 September, 6 October 1995) mode data were used to increase the temporal resolution of the data. The study area is covered by two rows of same path of ERS-1 SAR scenes. Thus, eight scenes were used for the study. Data acquired on 24 August were georeferenced using Universal Transverse Mercator (UTM) projection. For this the Survey of India (SOI) topographic maps of 1 : 50 000 scale were used to develop image to map transformation through well distributed ground control points (GCPS). All other images were registered to this image through image to image transformation. The district boundaries were digitised from a 1 : 250 000 scale Survey of India topographic map and stored as bit maps for generating district masks.

Speckle suppression was carried out using enhanced Frost filter (Frost *et al.* 1982). Four different combinations of data sets were used to evaluate the classification accuracy in relation to timeliness. The combinations were data acquired on (*a*) 24 August and 1 September (*b*) 24 August and 28 September (*c*) 24 August and 6 October and (*d*) 24 August, 28 September and 6 October. Data beyond this period were not considered as the objective was pre-harvest estimation of rice area.

Field information (FI) were collected near-synchronous to date of passes. Initially, the sites for agricultural crops were selected using the images from optical remote sensing sensors of the previous year. This area is cover under the on going CAPE project for the rice crop production estimation. Stratification based on crop concentration is used to select sites for collection of FI for rice crop in this area. Initially these sites were visited during 24 August. The sites were marked in 1 : 50 000 scale topographic maps and crop information collected in a FI proformas. Later on, data acquired on 24 August was georeferenced and hard copies at 1 : 50 000 scale were generated. This was used as a base map to verify the sites and collect field information in subsequent passes. Pixels of these sites were used to generate the training statistics for classification. The data were classified using per pixel maximum likelihood classifier (MLC). The amplitude value (DN) from each image were used as an element in a feature vector to classify multi-date data. The district boundaries were used as a mask to estimate area under rice crop. Alternatively, the spatial resolution of the data were degraded to 70 m and classification of multi-date data were carried out as described above.

3. Results and discussion

Image speckle in SAR data hampers the application of standard pixel-based classification techniques normally used for optical sensor data. It is advisable to apply some form of image filtering or segmentation to reduce image speckle, if one uses per-pixel classification (ESA 1995). Performance of various speckle suppressing filters in terms of improvement of signal-to-noise ratio, preserving linear features, small scatters had been assessed by various studies (ESA 1995). In this study, the enhanced Frost filter was used for speckle suppression, before using MLC classification. Details about the performance of this filter are not discussed here, as they are not within the scope of this Letter.

Very low backscatter (−15 dB mean) was observed from rice fields in the data acquired on 24 August. Low backscatter in early stage was attributed to the standing water background in fields and poor canopy coverage at this stage causing less or no volume scattering. Invariably, the rice fields appeared very dark. The backscatter from homesteads, villages/urban areas and forests were high, highest for urban areas (mean around −5 dB). This gave maximum contrast to rice fields. The fields having high field ridges (>50 cm.), the field ridges were distinctly identifiable as bright lines against the dark backdrop of rice fields. In subsequent passes this contrast of agricultural fields decreased steadily, and the images appeared more noisy. Hence, data acquired on 24 August was found useful for image to map registration due to accurate identification of a number of ground control points. Also as mentioned earlier, this was useful as a base map to collect field information during subsequent passes. Also, it can be mentioned that use of data of same mode (ascending/descending) resulted more accurate image to image registration with less number of GCPs than that of two different modes.

In this study, we have used data acquired between 25–30 days of transplantation to the initiation of flowering stage (60–70 days). Within this period, the rice fields exhibited a significant change in backscatter. The mean dynamic range of backscatter coefficient from rice fields during this period changed from −15 dB to −10 dB, showing a constant increase with time. The increase was more rapid between 1 September to 28 September. This corresponded to the rapid increase in height as well as canopy. Similar results were reported for other rice growing areas of Asia using ERS SAR data (Aschbacher and Paudyal 1993, Aschbacher *et al.* 1994). This increase in backscatter had been found significantly correlated with plant height (Kurosu *et al.* 1993, and ESA 1995). In contrast, the backscatter from other classes like forest, urban, villages and homesteads did not vary much. This characteristic of rice fields enabled to classify rice crop in temporal data set.

The backscatter coefficient from rice fields increased slightly (>1 dB) from 24 August to 1 September. As observed in the field, there was not much change in the plant growth as well as field condition in this period. However, the Õ° from the water bodies like rivers, streams, ponds showed significant change (>2 dB). This was attributed to the wind induced roughness on water surface, particularly in the case of stagnant water bodies, as all other conditions were observed to be same in these two dates. It also indicated that the rice plants probably prevent roughness caused by mild wind in the flooded fields. This characteristic of rice fields enhanced the separability of rice field from water bodies using two date data acquired only eight days apart during the early growth stage (24 August and 1 September). Figure 1 shows a ERS-1 SAR multi-temporal composite of a site in the Howrah district (24 August: red, 1 September: green and blue). The rice fields appear dark blue where the canopy cover was poor, and greenish blue where the canopy cover was higher (>30 per cent) and the homesteads, forest appear bright.

The classification accuracy of rice for training site pixels as observed in the confusion matrix were 85 to 88 per cent using two-date data of 24 August and 1 September. There were 7–8 training classes used to classify the data. The classes were: rice, forest, homesteads/villages, urban, water (stagnant), water (river), water-logged area, and fallow. No significant overlap of rice class was observed with urban, homesteads/villages and forest classes (>5 per cent). Major misclassification of rice was observed with water bodies like rivers, streams and flooded fallow fields. The classification accuracy increased to more than 90 per cent for both irrigated and rainfed crop using data of 24 August and 28 September. This was due mainly to increased separability of rice from fallow fields, ponds and waterlogged areas. However, misclassification with water from river and streams did not show any improvement in any combination of temporal data.

Use of the two-date data acquired on 24 August and 6 October resulted in almost

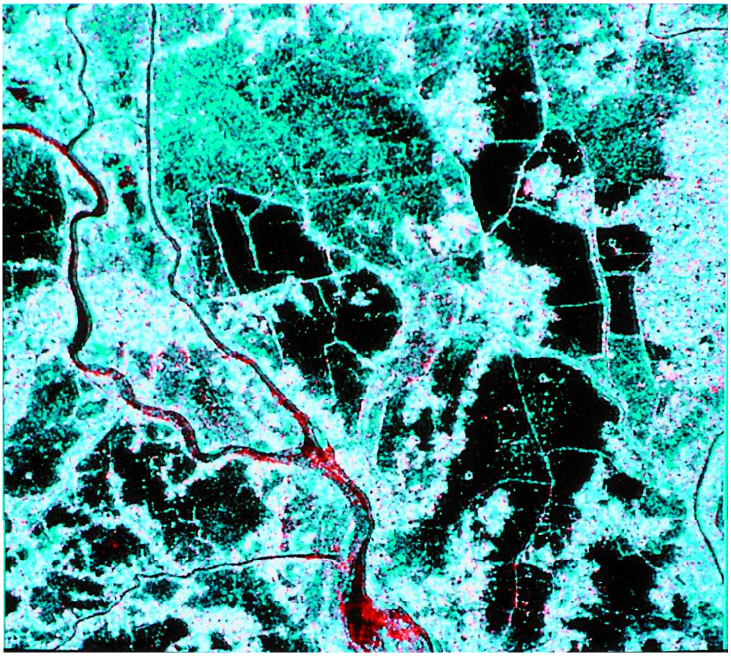

Figure 1. Colour composite of 2 date ERS-1 SAR data of 24 August (red) and 1 September (green and blue) over a site in Howrah district, West Bengal. Rice fields with early vegetative stage appear very dark, field ridges appear bright.

similar accuracy as that of 24 August and 28 September. Using three-date data, the classification accuracy increased marginally but the overall accuracy was best as observed in the kappa value. Table 1 shows the classification accuracy obtained in different date of data combinations. Figure 2 shows the classified SAR image of Howrah district using two-date data (24 August and 1 September). Note that a portion in the Rupnarayan river was classified as rice. This misclassification was consistently observed in all the data combinations. While generating crop statistics, this was masked out manually.

Use of 70 m spatial resolution data had little effect on recognizing the ground truth sites and the acreage estimates. This may be due to the prevailing large synthetic

Table 1. Classification accuracy of rice crop in different combinations of SAR data.

District	Percentage accuracy in data sets			
	D1 + D2	D1 + D3	D1 + D4	D1 + D2 + D3
Howrah	88·0	90·5	91·0	91·5
Hughli	85·8	90·0	90·6	91·0

D1: 24 August, D2: 1 September, D3: 28 September and D4: 6 October

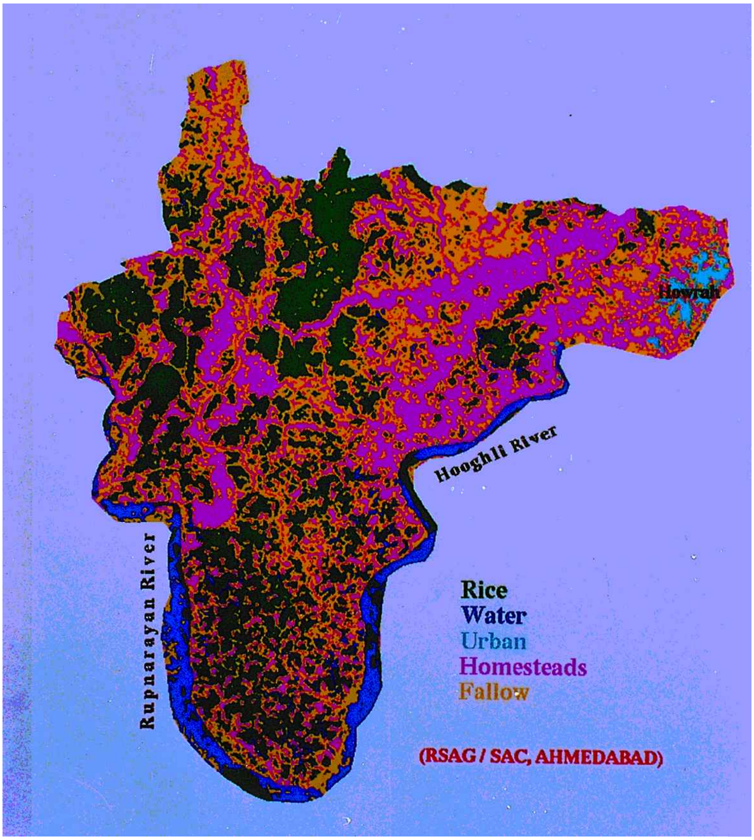

Figure 2. Classified two date ERS-1 SAR image with district mask showing rice area in green and other land covers in Howrah district, West Bengal.

Table 2. Estimated rice acreage (000 hectares) using 30 and 70 m. Resolution two date SAR data (24 August and 28 September).

District	Estimated rice area (30 m)	*Reported area (70 m)	
Howrah	83·7	84·20	82·8
Hughly	206·5	204·8	204·2

(* Reported estimate from State Department of Agriculture, W. Bengal.)

fields of rice and the dominance of rice crop in agricultural area in these two districts. Though the average field size in the area is less than 0·2 ha., the synthetic field size was more than 50 ha due to the contiguous fields cultivated under rice crop. Similar results have been reported by other workers Diorio *et al.* using simulated Radarsat SAR data (Diorio *et al.* 1995). Data of 70 m resolution were examined to assess its utility for state and region level estimates, which will require a large amount of data. Though the results were encouraging, one needs to validate further using field level data base for absolute accuracy, before reaching to any conclusion.

Table 2 shows the rice area estimates obtained using two date ERS-1 SAR data acquired on 24 August and 28 September 1995 for original SAR and 70 m spatial resolution data. The acreage reported by the State Department of Agriculture, West Bengal were found to be very close to this estimate. The Department uses a complete enumeration approach using village cadastral maps as the starting point and aggregates to the district and state level. But the final estimates were available only after December.

Using ERS-1 SAR data, the first estimates were made by the first week of September, that is, almost two months before the harvest. The estimates were revised by the first week of October using optimum two-date data. It can be noted that, generally it is very difficult to obtain data from optical sensors during this period due to cloud cover problem for this region.

3. Conclusion

The system of growing rice under flooded conditions gives a distinct temporal signature to radar beam. This study indicates that multi-temporal ERS SAR data can be used in an operational or semi-operational manner for acreage estimation of rice crop grown under rain-fed as well as irrigated condition. Data acquired during the early vegetative stages of flooded fields was found essential for accurate map to image registration, and to obtain high classification accuracy. This was also found useful to be used as a base map for collecting field level information for subsequent passes. Two-date data: one acquired around 30 days of transplantation and another after 30 days was found optimum for early estimation of rice acreage. It is worth using two-date data acquired with 7–8 days difference after 30–40 days of transplantation to increase separability of rice crop from a water/water logged area and to obtain a very early acreage estimate. This is the first time that ERS SAR data were operationally used to forecast rice acreage in India and the results were promising. Similar results can be expected for other rice growing areas of Asia, as the growing conditions are similar. The classification accuracy may be increased further using classification techniques more suitable for SAR data, which needs further investigation.

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