Rice crop assessment and monitoring using SAR data: Indian experience and its extendibility to Asian region

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Abstract

Asia region harbours the highest population density as well as large fraction of global population where rice is the principal food grain. The increasing population and dependence of rice mostly on the rains poses problem in ensuring the food security. The planning and management of food supply chain requires regional and timely information of expected harvest. Traditional methods of collecting such information are often found wanting in fulfilling the timeliness of information. Remote sensing has emerged a very potential tool for overcoming above problem. However, the persistence of cloud cover limits the use of optical remote sensing. SAR has been found useful in addressing the diverse range of rice culture types.

C-band SAR data with HH polarization and acquired with incidence angle ranging 32-36^0 has been found very effective in detecting the rice crop just after the transplanting. The temporal data of about three weeks repeat cycle has been found useful in capturing the growth pattern of rice, till it reaches high vegetative biomass of about 6 tons/ha. It is found to be effective in detecting the flood/drought as well. The analysis of temporal backscattering has also shown the possibility of mapping the rice culture types. It has shown the capability to map the major rice culture types found in Asia. Yield forecast is an important issue in crop assessment and production forecasting. SAR has been found effective in assessment of crop biomass and its relationship with crop yield.

All the major culture types of rice are found in India. It has been seen that there is good extendibility of SAR signature over large regions, even outside the country. This, has opened the possibility of easy assessment of rice crop grown in vast Asian region, with first establishing the signature of rice crop using SAR data. With suitable sampling strategy, it would be possible to cover large geographic regions. Such a system will be ideally suited for programme like Asia-Rice crop assessment and monitoring as a part of GEOGLAM. Salient findings and its implication for assessing Asian rice are presented in the paper.

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1. Introduction

Agriculture as a system is most dynamic and this dynamism comes from interaction of a large number of factors such as weather, soil, water, fertilizer, seed etc. The complexity in agriculture and socio-economic scenario in the rice growing Asia calls for development of a robust system for crop monitoring. The system has to address subsistence of farming, rained agriculture, diverse crop calendar, management practice, land types, frequent flood, drought, cyclone and storm surge etc. Information on agricultural statistics is essential for developing stable economic environment, reducing the risk in production, marketing and distribution operations and making decisions for exports and imports. Due to use of conventional techniques there have been delays in the crop forecasts and flaws in the decisions made. This information gap must be minimized by use of modern technology such as remote sensing data, agrometeorology and advanced information technology. Remote sensing (RS) technology has potential in estimating crop acreage and production at district and regional level due to its multispectral, large area and repetitive coverage. Geospatial technique with an integrated approach combining diverse sources of data is the answer to this challenging situation. Information from field observations, weather parameters, and space based observation need to be integrated into the procedure. Such a concept has been realized in monitoring the rice crop in India under the project “National Rice Crop Monitoring”, The concept has been developed, tested and operationalised under the aegis of Department of Agriculture & Cooperation, Ministry of Agriculture (MOA) for more than a decade under ‘Forecasting Agricultural output using Space, Agrometeorology and Land-based observations’(FASAL) programme (Parihar and Oza, 2006). The FASAL programme is built under the concept of multidate-multi sensor data integration with groundtruth and meteorological data assimilation to provide periodical preharvest area and production estimation and has nation wide network of institutional framework for data collection, analysis and dissemination. India has largest rice area in the world (~44 Mha) and about 90% of this is grown during the monsoonal wet season (locally called kharif, June-October). Since this season coincides with cloudy conditions, the SAR (all weather capability) data based technique of rice area was intensively studied; methodology was developed and was incorporated into the FASAL programme (Parihar and Oza; 2006).

Exploring the use of remote sensing for agricultural application In India started with the use of multi band and colour infra red (CIR) aerial photographs as early as 1974-75. Further knowledge on crop signature was gathered through scientifically designed field experiments using multi band radiometer. Since then a large number of experiments have been carried out for developing techniques for extracting agriculture-related information from airborne and space borne data. Many of these studies have led to the operationalisation of the methodology and conduct of national-level projects (Panigrahy et al., 1992, Panigrahy and Parihar, 1992, Manjunath et al, 2000).

Crop Acreage and Production Estimation (CAPE) is the successful outcome of the above efforts. Use of high resolution digital data (LISS-II/III) for crop production forecast at district/state level for important crops in their major growing regions is being carried out under CAPE project (SAC, 1990). Remote sensing data forms basic input to crop production forecasting under CAPE project. While acreage is estimated using data acquired during peak crop growth stage, yield is estimated through optimal yield model concept that combines the information of spectral vegetation index, agro-meteorology and technology trend. As remote sensing, weather and field observations provide complementary and supplementary information for making crop forecasts, FASAL is built on an approach which integrates inputs from the three types of observations to make forecasts of desired coverage, accuracy and timeliness. The concept of FASAL thus strengthens the capabilities of early season crop estimation from econometric and weather-based techniques followed by use of remote sensing data at appropriate stage. FASAL enables multiple forecasts of acreage as well as yield besides tracking the crop growth as the season progresses. The rice crop monitoring within the FASAL project is primarily based on SAR data. The specific advantage of SAR data in rice crop monitoring is highlighted in Fig. 1.

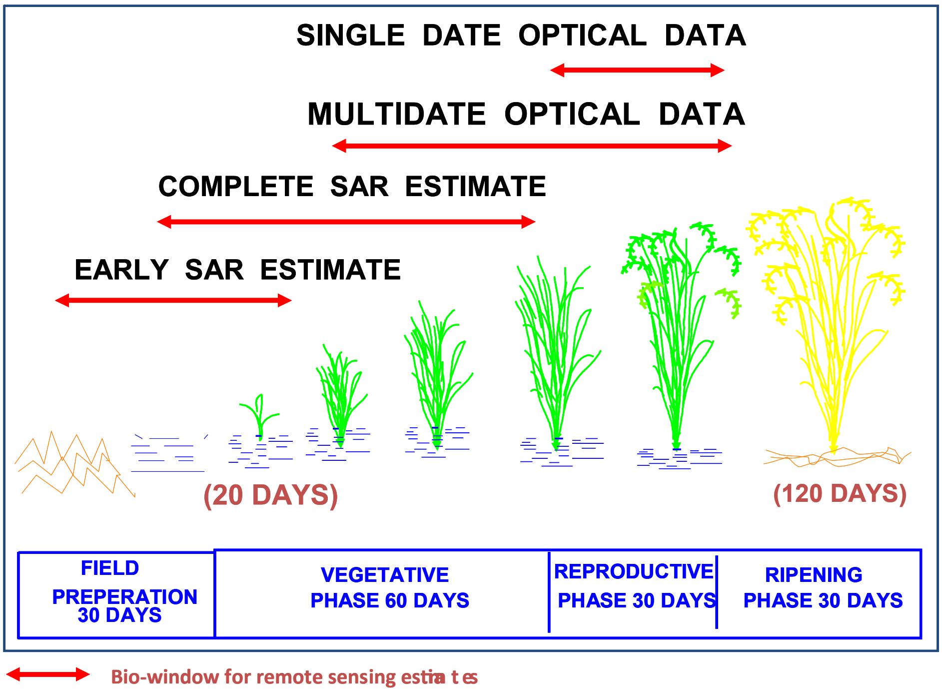

Fig. 1: The advantage of rice crop assessment using SAR data

The current paper highlights the efforts made on methodological aspects and salient findings on rice crop monitoring using SAR in India and its implication to Asian rice crop monitoring. India has one of the most diverse rice cultivation practices in the world from dryland to lowland and deep water ones (De Dutta, 1981). The current synthesis is built up the fact that the diversity of Indian rice crop monitoring techniques captures the Asian rice crop diversity and is extendable with minor modifications.

2 Data used and Methodology

Satellite remote sensing data is used to obtain actual extent of area. In view of persistent cloud cover problem in the rice region (Currey et al., 1987), SAR data has been found sustainable source of EO data. Temporal C band SAR data has been found useful for detection of onset of agricultural activities, early crop area estimation, and progress in planting as the season advances. Due to the sensitivity of SAR to moisture and canopy geometry, temporal SAR data also provide additional information to model damage due to flood, moisture stress, etc. Thus, SAR data forms the backbone of rice monitoring system (ESA, 1995, Kurosu, 1995, Ribbes 1999, Liew, 1998, Panigrahy et al., 1997,1999, 2000, and Le Toan, 1997, Chakraborty and Panigrahy, 1997). Feasibility of estimating in-season district level rice crop area using two and three-date ERS SAR data has been demonstrated (Panigrahy et al., 1997). In view of the large geographic area and crop distribution RADARSAT ScanSAR Narrow Beam B (SN2) having a shallow incidence angle and swath width of 300 km was found optimum for country level monitoring. Three and four-date data acquired at 24 day repeat cycle were used in the study. Data are acquired with respect to rice crop calendar of each state (Panigrahy et al, 1999). The first-date data is acquired during transplanting operation. Total number of ScanSAR scenes covering the rice area in India is around 34 for wet season while it is about 15 scenes for second season crop. The area of wet and dry seasons contributes about 93 and 86 percent of rice production, respectively. The total area of the country is then computed by extrapolating to the normal rice growing proportion. The study districts(Fig. 2).

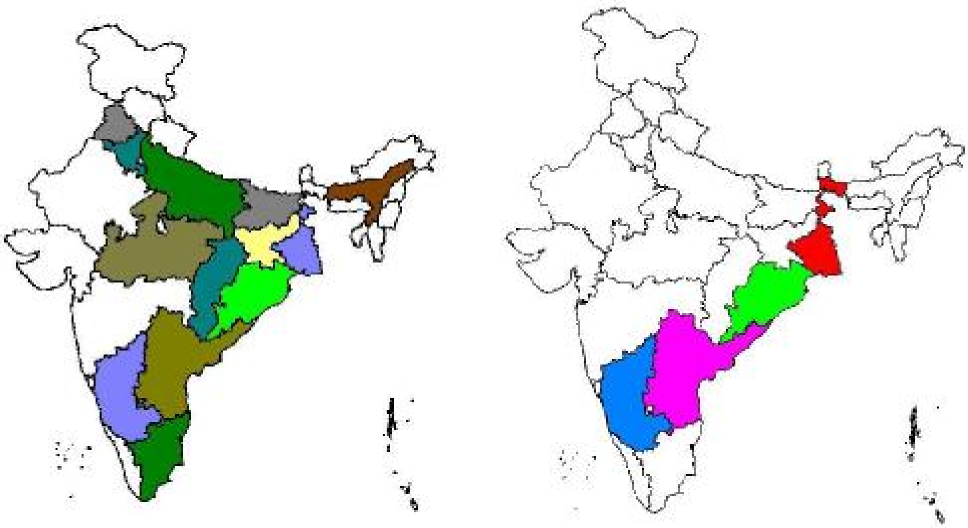

Fig. 2: The rice assessment states of India during wet (left) and dry (right) season.

2.1 Rice crop classification

A Multiple Scattering Radiative Transfer (RT) model has been calibrated and validated using a large number of samples of *in situ* data of rice crop signature covering a wide spectrum of growing environment and crop variety (Fig. 3).

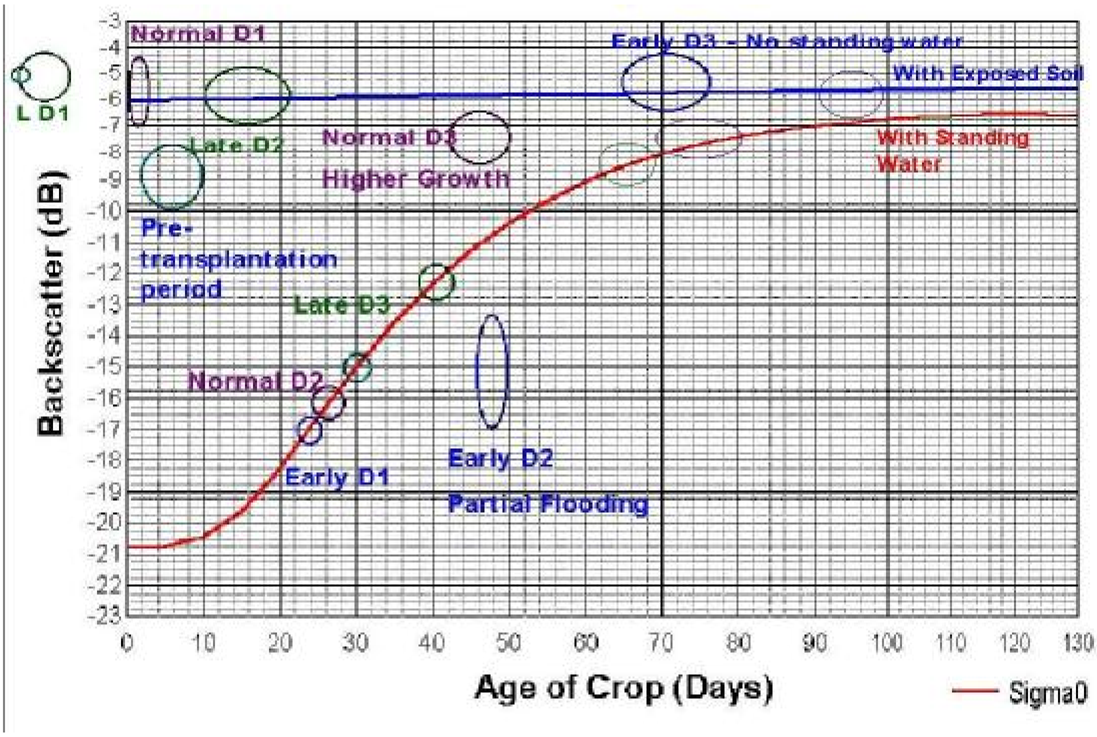

Fig. 3: The temporal backscatter pattern of rice crop under various growing environments (Chakraborty, 2002)

Based on this model, decision rules have been developed to classify the temporal SAR data (Chakraborty and Panigrahy, 1997). This classifier essentially uses the temporal backscatter to model the rice growth in three and four date data. Working in the calibrated domain is essential for this. The model also is able to detect the anomaly like moisture deficiency or flooding. Automated software packages are one of the essential requirements for operational crop survey methods not only to meet timeliness targets but also to maintain uniformity of approach where a number of interdisciplinary users are involved. The steps are packaged together keeping view minimum interaction and ease of use by the user. The package named 'SARCROPS' is built around EASI/PACE image processing software (Chakraborty et al, 2000). The generalized procedure of multidate image analysis is shown in fig. 4.

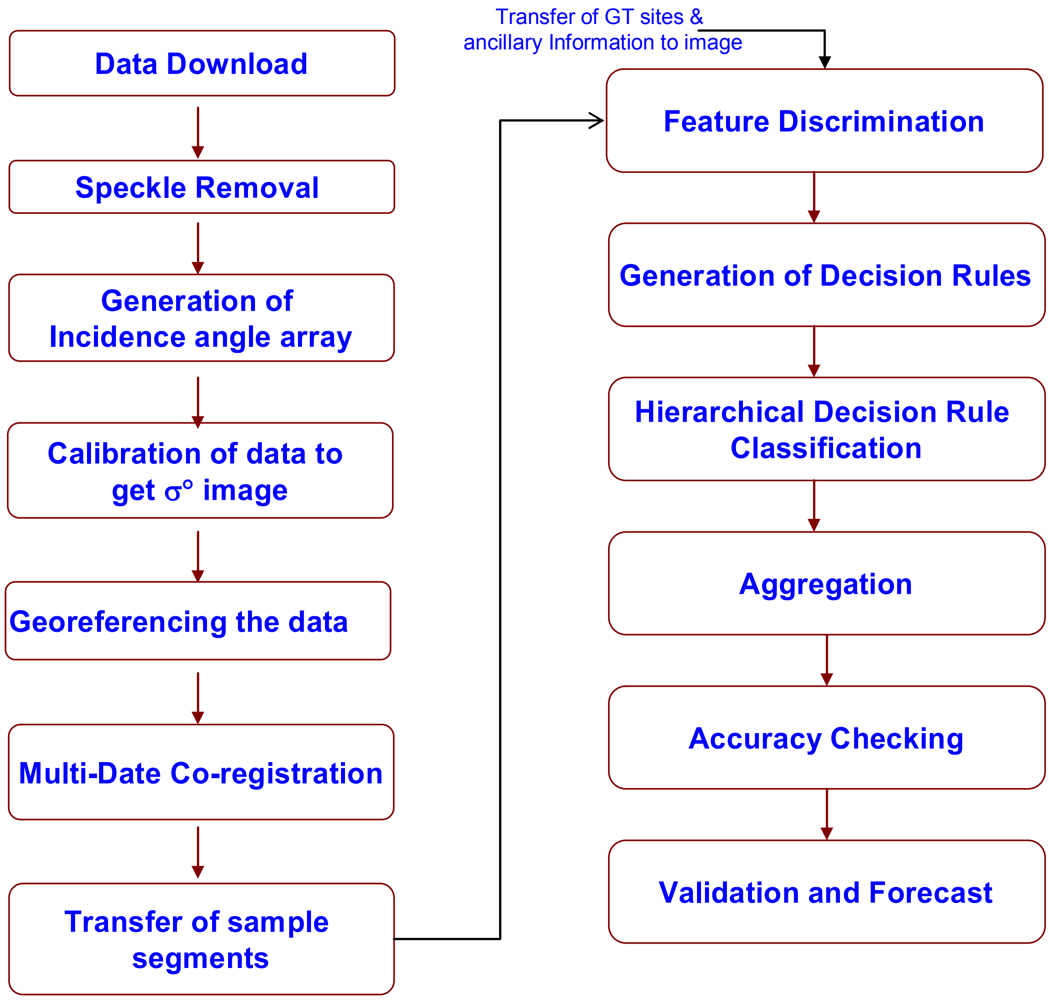

Fig. 4: The flow diagram showing multi-date SAR data analysis procedure for rice area estimation

2.2 Area estimation

To gather crop statistics at country level will require a sampling approach. Most area sampling frames are stratified taking into account the priorities of the survey. Sampling error is generally expressed through standard errors or coefficient of variation of the estimates. The classical sampling theory provides a wide range of formulas for this purpose, including regression, calibration or small area estimators. The salient features of stratified random sampling are formation of strata and allocation of sample segments within strata (Cochran 1977; Des Raj and Chandhok 1999). Satellite images derived thematic maps can be used as main source of information for stratification. Country level sampling grid of 5*5 km labeled as agriculture or non-agriculture based on the Landuse/cover map forms the basic sampling frame, with any grid having =>5 per cent of the total area under agriculture is tagged as the agriculture grid (Fig. 5).

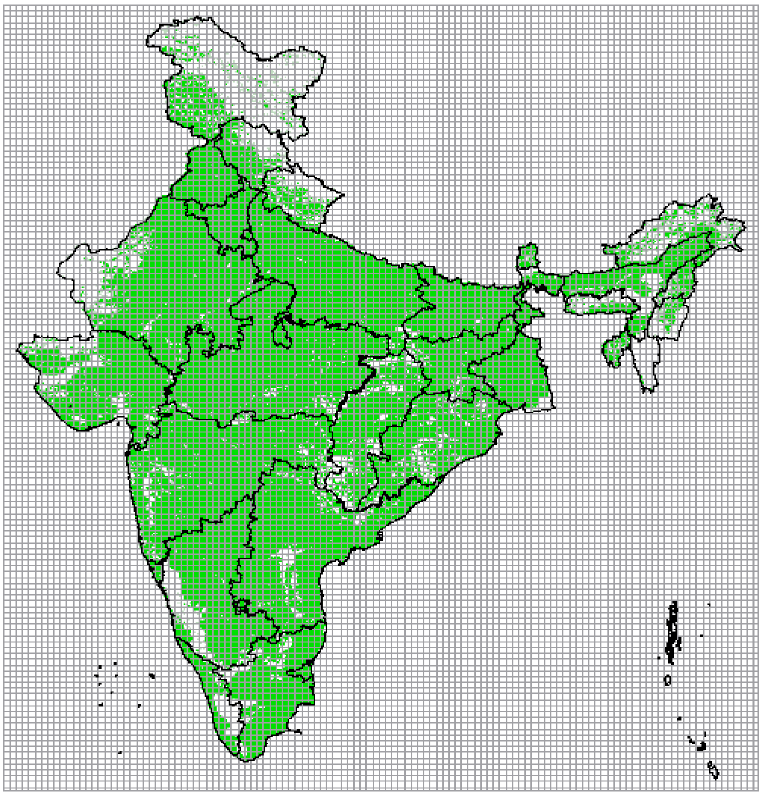

Fig. 5: The 5X5 km grids and agricultural area (Green) of India (Sharma et al, 2011)

All these grids form the agriculture population. Further stratification is done based on actual crop area map derived using remote sensing data. Rice crop is grown as a major crop during monsoon season (July-October) which account for around 90 per cent of total rice area. The rest is grown as irrigated crop during summer season (January-April). Fig. 6 shows the rice cropping pattern map of India (Manjunath et al, 2009). Frequency distribution method, also known as cumulative square root of frequency method (Dalenius and Hodges 1959; Bhagia et al. 2011) has been found suitable for stratification to allot each grid as A, B, C, D etc. based on crop proportion. Around 15 % of samples are randomly drawn from each stratum, which are analysed using remote sensing data for crop area estimation.

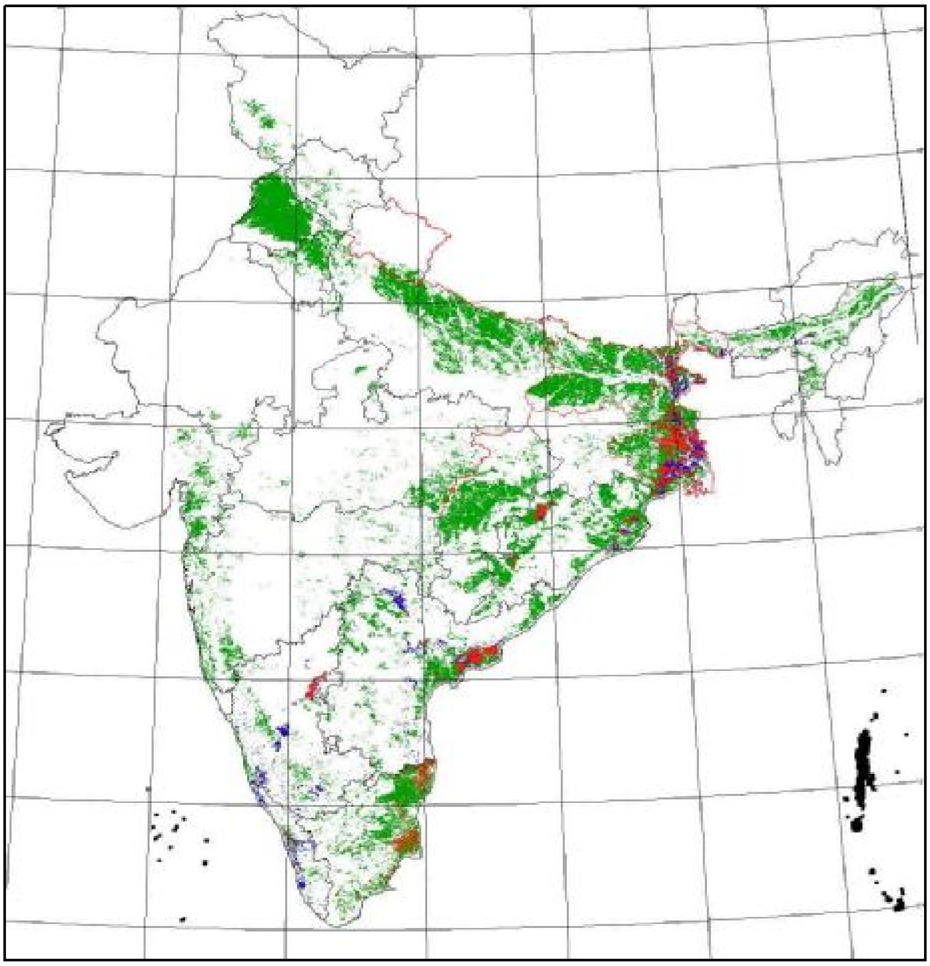

Fig. 6: Rice cropping pattern in India (Green-wet season rice, Red-both season rice, Blue-only dry season rice) (Manjunath and Panigrahy, 2009)

Detailed studies using microwave data analysis for crops has shown that rice crop can be discriminated at better than 95 per cent accuracy and early detection with multiple forecasts is possible (Chakraborty et al., 1997).

2.3 Crop yield and condition assessment

Empirical agro-meteorological models are being used for crop yield forecasting in the beginning of season, while process based models are used later in the season. A statistical model has been developed for rice biomass estimation using HH polarization data. A Least-square fitting of the backscatter curves with observed biomass (wet) data has been used to generate the calibration curve, which is used for predicting fresh peak biomass. This is used to estimate grain yield using tabulated dry/fresh biomass, harvest index and grain/chaff ratios.

2.4 Crop Calendar

The procedure enables to compute the progress of planting and obtain the crop calendar spectrum in each state (Fig. 7). The polynomial relationships were found to be the most appropriate to link age with backscatter.

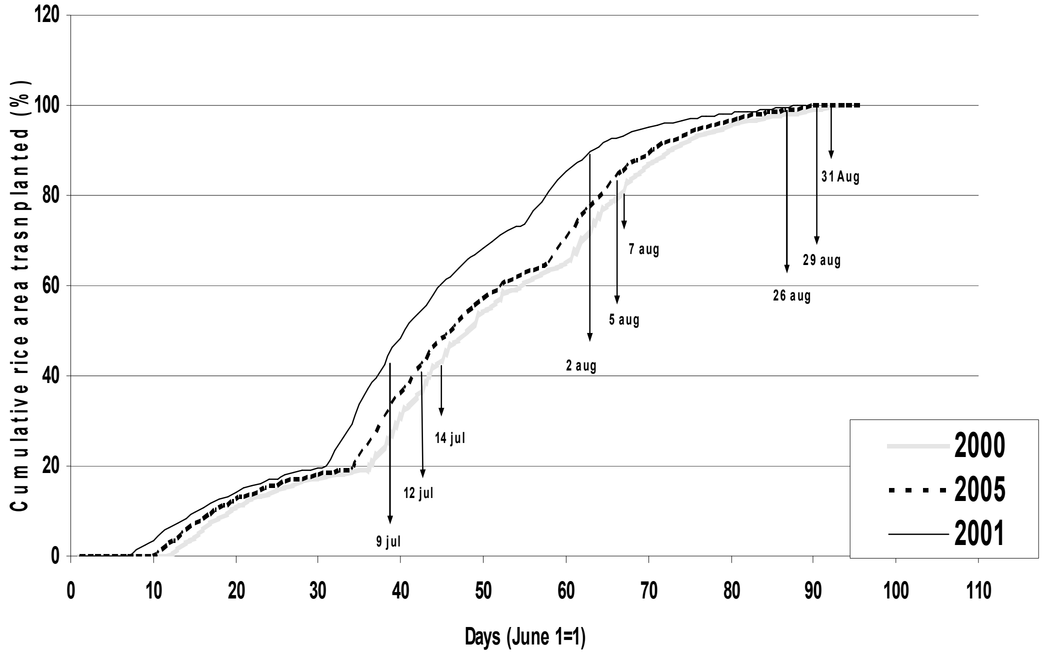

Fig. 7: Cumulative rice transplanting curve derived using multi-date SAR data for West Bengal state in India during 2000, 2001 and 2005 (Choudhury and Chakraborty, 2002).

3.0 Implications to Asia rice assessment

Assessment of rice crop in Asia needs appropriate sampling strategy at the country level. Preliminary work carried out on sampling size for agriculture area monitoring of the world had shown the adequacy of 5' grid for country level study (Sharma et al, 2011). Analysis has been carried out for the Asian rice growing countries using MERIS derived agriculture area map and 5' grid size. Results showed that adequate samples could be obtained for most of the countries (table 1, 'n' is the total population).

Table-1: Selected Sample size based stratified random sampling with 10% of population

Country	>75% (A)	50-75% (B)	30-50% (C)	10-30% (D)	Total 'n'
China	3020	1881	1458	1819	8177
India	2826	347	220	249	3642
Indonesia	425	399	380	546	1750
Thailand	376	76	51	71	574
Pakistan	315	68	59	121	563
Myanmar	199	62	76	162	499
Vietnam	123	93	74	66	357
Japan	44	60	88	155	347
Philippines	127	93	59	52	330
Malaysia	54	82	72	107	315
Nepal	33	36	44	44	158
Cambodia	79	27	20	30	156
Bangladesh	113	16	7	9	145
Lao PDR	12	18	29	74	133
Republic of Korea	2	7	10	16	34
Sri Lanka	0	1	4	10	16

The calibrated SAR data has enabled development of Radiative Transfer based rice detection algorithms in backscatter domain and create a signature bank. India harbors almost all the cultural types of rice found in Asia, the algorithms developed for rice crop identification using SAR data has the potential to be extended to other Asian regions. Implementing of this programme for more than a decade has enabled to test the procedure under diverse situations. This concept has been validated for the neighboring countries like Bangladesh (Fig. 8).

Conclusions

Asia accounts for about 90 percent of global rice production and studies carried out in India and elsewhere shows the feasibility of SAR data for monitoring rice crop. India has diverse rice growing conditions and cultural types. The studies carried out in India on rice crop monitoring during the last fifteen years has resulted in development of techniques/tools for national/regional assessment and is now extendable to other regions. A stratified sampling at 5' grid size with two stage stratification and three date (Shallow beam SAR) decision rule is ideal for rice crop discrimination at acceptable accuracy of around ninety-five percent.

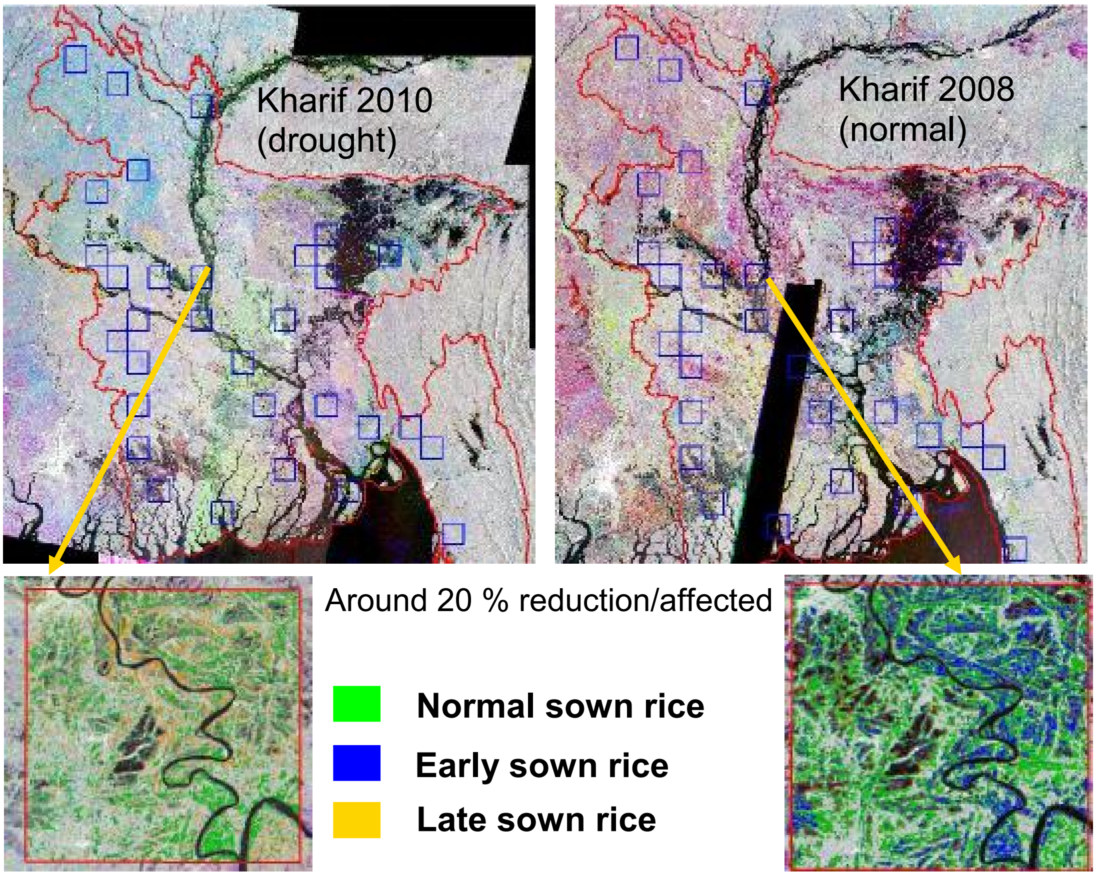

Fig. 8: Three date Radarsat ScanSAR (SN2) FCC and classified image (inset) showing rice crop (Panigrahy et al, 2011).

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