Evaluation of RADARSAT Standard Beam data for identification of potato and rice crops in India

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Received 25 October 1997; accepted 2 June 1999

Abstract

The Canadian satellite RADARSAT launched in November 1995 acquires C-band HH polarisation Synthetic Aperture Radar (SAR) data in various incident angles and spatial resolutions. In this study, the Standard Beam S7 SAR data with 45°–49° incidence angle has been used to discriminate rice and potato crops grown in the Gangetic plains of West Bengal state. Four-date data acquired in the 24-day repeat cycle between January 2 and March 15, 1997 was used to study the temporal backscatter characteristics of these crops in relation to the growth stages. Two, three and four-date data were used to classify the crops. The results show that the backscatter was the lowest during puddling of rice fields and increased as the crop growth progressed. The backscatter during this period changed from −18 dB to −8 dB. This temporal behaviour was similar to that observed in case of ERS-SAR data. The classification accuracy of rice areas was 94% using four-date data. Two-date data, one corresponding to pre-field preparation and the other corresponding to transplantation stage, resulted in 92% accuracy. The last observation is of particular interest as one may estimate the crop area as early as within 20–30 days of transplantation. Such an early estimate is not feasible using optical remote sensing data or ERS-SAR data. The backscatter of potato crop varied from −9 dB to −6 dB during the growth phase and showed large variations during early vegetative stage. Two-date data, one acquired during 40–45 days of planting and another at maturing stage, resulted in 93% classification accuracy for potato. All other combinations of two-date data resulted in less than 90% classification accuracy for potato. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: RADARSAT; SAR; rice; potato; backscatter; classification accuracy

1. Introduction

Utility of radar backscatter for crop type classification has been demonstrated by many studies carried out using airborne Synthetic Aperture Radar (SAR) data (Bush and Ulaby, 1978; Brown et al., 1984; Foody et al., 1989). The possibility of using spaceborne radar data for large-area applications was realised with the successful launch of ERS-1 SAR followed by ERS-2. Though the C-band 23° incidence angle of ERS-SAR was not considered optimum for agricultural studies, promising results for identification and classification of rice crop have been reported using temporal ERS-SAR data (Kuroso et al., 1993; Patel et al., 1995; ESA, 1995; Chakraborty et al., 1997). This was attributed to the wetland management practice of rice crop, which results in a characteristic temporal backscatter signa-

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ture. The feasibility of estimating district level in-
season rice crop area using two and three-date ERS-
SAR data has been demonstrated (Panigrahy et al.,
1997). However, the results obtained for tuber crops 1
(including potato) were not very encouraging (ESA,
1995).

The scope of possible utilisation of SAR data for
large-area crop survey has widened with the launch
of the Canadian satellite, RADARSAT in November
1995. RADARSAT is designed specifically to pro-
vide advanced SAR imaging capability. It operates at
a C-band frequency of 5.3 GHz, with horizontal
polarisation for both transmission and reception of
the signals and can be steered to image a swath from
50 to 500 km using a number of imaging modes.
There are seven beams with 25 beam positions pro-
viding data with a range of incidence angles from 10
to 59 degrees and spatial resolutions from 10 to 100
m. The Standard beam data have seven beam posi-
tions with incidence angle varying from 20°–49°
(Anon, 1996). Shallow angle data of more than 40°
incidence angle is of particular interest, as it is
considered better suited for identification of agricul-
tural crops.

SAR data has a significant role in the remote
sensing based crop survey programme in India due
to the cloud cover problem during monsoon (July to
October), the main crop season. This paper describes
the results of the investigations carried out using
RADARSAT Standard Beam 7 data for rice and
potato crops in their predominant growing environ-
ments in West Bengal, India. The work has been
carried out under the project entitled “RADARSAT
data evaluation for crop identification and characteri-
zation”, under the Application Development and
Research Opportunity (ADRO) programme (ADRO
project ID 349) of RADARSAT, sponsored by
RADARSAT International (RSI) and the Canada
Centre of Remote Sensing (CCRS), Canada.

2. Study area

The study area lies in the Bardhaman and Hooghli
districts of West Bengal state in Eastern India lo-
cated between 23°00' to 23°30’N latitude and 87°40' to
88°20’E longitude. Potato crops, grown during the
rabi season (December–March), and rice crop, grown
during the summer season (February–May), are ad-
ressed in this study. Around 70% of potato fields
were sown in the first week of December and har-
vested by end of February. The rest were sown at the
end of December and harvested in March. These two
categories were designated as early and late potato,
respectively. Rice was grown totally under wetland
irrigated practice in summer. Seedlings were trans-
planted in puddled fields filled with water during end
of January to middle of February. The crop was
harvested in May.

3. Data used

RADARSAT S7 data have been used in this study.
The incidence angle of beam S7 data ranges from
45°–49°, covering a nominal area of 100 × 100
km². The data product used belonged to the “Path
Image Plus”, which is 16-bit data having a pixel size
of 8 m². Four-date descending-node data (equa-
torial pass time 0630 h) acquired on January 2 and
26, February 19 and March 15, 1997 were used. The
crop growth stages of rice and potato in relation to
the SAR data acquisition are given in Table 1.

Optical remote sensing data from the Indian Remote
Sensing satellite (IRS) 1C, i.e., LISS-III data ac-
cquired on January 26, 1996, October 1996 and PAN
data acquired on February 12, 1996, were used to
generate base maps for ground truth (GT) data col-
lection. LISS-III multispectral data (green, red and
near infrared bands) have a spatial resolution of

<table>
<thead>
<tr>
<th>Date</th>
<th>Potato (early/late)</th>
<th>Rice</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1.97</td>
<td>Vegetative</td>
<td>Fallow fields</td>
</tr>
<tr>
<td>26.1.97</td>
<td>Tubering/vegetative</td>
<td>Fallow/pudding</td>
</tr>
<tr>
<td>19.2.97</td>
<td>Mature/tubering</td>
<td>Puddling/early tilleringa</td>
</tr>
<tr>
<td>15.3.97</td>
<td>Fallow/mature</td>
<td>Peak tillering/panicle</td>
</tr>
</tbody>
</table>

1 Tuber crops: crops with a tuber, an enlarged, fleshy, under-
ground stem with buds capable of producing new plants.

aTilling: growth stage for cereal crops, when additional shoots
are developing from the crown.
23 m and the panchromatic data has a spatial resolution of 5.8 m.

4. Methodology

Five sites, of 10 km × 10 km each, were selected within the RADARSAT scene for analysis. Detailed GT data were collected within these sites. These sites are predominantly agricultural. The crop proportion in these sites varied from 20 to 50%. This selection of sites was carried out using LISS-III data of 1996. Since 1992, the area has been surveyed using remote sensing data under the on-going ‘Crop Acreage and Production Estimation’ project for rice, mustard and potato crops (SAC, 1995). The selected sites cover villages that grow rice and potato crop year after year. The base maps of these sites for GT data collection were generated using LISS-III multispectral data and PAN. PAN data was georeferenced with Survey of India topographic maps of 1:50,000 scale using an image-to-map affine transformation. The LISS-III data were registered with the PAN data using an image-to-image transformation. A merged image was generated, whereby green, red and NIR bands of LISS-III were transformed to intensity, hue and saturation components. The intensity component was replaced by PAN data and the components were transformed back to red, green and blue channels to generate the merged false colour composite with 5 m pixel size. The output maps were generated at 1:15,000 scale. These base maps were used during field visits in January to select crop fields and mark the training sites. These sites were digitised and stored as vectors.

RADARSAT data acquired on January 2 was registered with the georeferenced merged data using image-to-image transformation. All subsequent RADARSAT data were likewise registered to this georeferenced dataset. The GT-site polygons (stored in vector form) marked in the merged image were transferred to the RADARSAT data. The training site pixels were used to analyse the backscatter characteristics, classify the data and evaluate the classification accuracy.

The backscatter was computed using the calibration coefficients supplied by CCRS in the leader file. The calibration coefficients depend on the location of the pixel in the scan line. This calibration process gives radar brightness $\beta^0$ for each pixel. In order to compute the backscatter coefficient $\sigma^0$, the incidence angle for each pixel has also to be used. The steps in the conversion process are given below.

The digital numbers were converted first to $\beta^0$ using the following equation

$$\beta^0_j = 10\log_{10}\left(\frac{\text{DN}_j^2 + A3}{A2}\right) \text{ (in dB)}$$

where: $\text{DN}_j$ the digital number (amplitude of the backscattered signal), $A2$, the calibration coefficient (scaling gain value) of the $j$th pixel (in the range direction) in the scan line, and $A3$ a constant offset (normally equal to zero).

$\beta^0$ was then converted to $\sigma^0$ as follows:

$$\sigma^0_j = \beta^0_j + 10\log_{10}\left[\sin(I_j)\right] \text{ (in dB)}$$

where $I_j$ the incidence angle at the $j$th range pixel.

In this study, for the purpose of simplicity, a mean incidence angle of 47°, corresponding to the centre of the study area, was used. The incident angle varied from 46° to 48° (the $10 \log_{10} (\sin(x))$ function varies by $\pm 0.07$ dB within this range, much less than the calibration error).

Image speckle in SAR data hampers the application of standard pixel-based classification techniques normally used for optical data. Thus, it is necessary to apply some form of adaptive filtering to reduce image speckle, in order to use per-pixel classification techniques (ESA, 1995). In this study, the enhanced Lee filter with $5 \times 5$ pixel window size was used for speckle suppression, before carrying out classification and other analysis (Lee, 1986). In many investigations, this filter has been preferred for agricultural applications (ESA, 1995). The set of speckle filtered, co-registered temporal SAR data was used as multi-channels in the classification process. The amplitude values (DN) from each image were used as elements in a feature vector to classify multi-date data. Various combinations of dates were used.

The data were classified using a per-pixel Artificial Neural Network (ANN) classifier (Benediktsson et al., 1990). Since this ANN classifier is non-parametric, it needs no assumption on the distribution statistics of the image data and is reported to be better suited for classification of SAR data than the widely used Maximum Likelihood classifier.
5. Results and discussion

5.1. Landcover and SAR response

High backscatter of $-6$ to $-5$ dB characterised the villages/homesteads and appeared bright in all images. Low backscatter of less than $-19$ dB characterised open water bodies like rivers, ponds and lakes and these appeared dark in all images (Fig. 1). A very small variation in the backscatter from water bodies was observed on different dates. This is in sharp contrast to ERS-SAR data, where the backscatter from water bodies varies significantly from date to date (due to wind speed variation) (ESA, 1995; Chakraborty et al., 1997). For this reason, high classification accuracy was obtained for water bodies, as there was no signature overlap with rice and other crop classes. This has a direct effect on the accuracy of classification of rice, as signature mixing is significant between water and rice classes in ERS-SAR data. 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. Backscatter of the fallow fields varied, depending upon the presence of grasses, crop residue and moisture status.

The backscatter from crop fields varied, depending on the crop type and their growth stage. The backscatter of potato crop during the study period varied from $-6$ dB to $-9$ dB. High backscatter of $-6$ to $-7$ dB was observed in the January 2 data. At this stage, the fields were not fully covered by the crop canopy (for both early and late sown varieties). The radar response was a combined effect of the soil ridges, soil moisture and plant canopy. In most fields, the furrows were in east–west direction and had a height of 25 to 30 cm. However, critical analysis of the furrow orientation was not carried out in this study. In the January 26 data, most of the early sown crops were in tubering stage and the soil was completely covered by plant cover. The backscatter declined by 2 to 3 dB around $-9$ dB. In the February 19 data, the potato crop was either in mature stage or being harvested; the backscatter increased to $-6$ to $-7$ dB. In case of late sown crop, the backscatter in the second date (January 26) did not vary much with respect to the first date (January 2). The temporal signature (in DN) of four potato sub-classes, three

![Fig. 1. Temporal variation for dates 1, 2, 3 and 4 of backscatter of RADARSAT S7 SAR data for different landcover classes found in the study area. Note that very little change was observed in case of water and villages.](image)
Fig. 2. Temporal variation of potato classes from January 2 to February 19, 1997 shown in digital numbers. Potato 1, 2 and 3 sub-classes belong to early varieties and Potato 4 is a late variety. The vertical bars indicate ±1 standard deviation from the mean backscatter of the classes.

belonging to the early sown and one to the late sown varieties, are shown in Fig. 2. It is observed that the temporal change was not very large. The standard deviations of the crop fields for the early varieties were high during the early growth stage. A similar temporal behaviour has been reported for potato crop grown in European countries using ERS-SAR data (ESA, 1995). In this work, large variations in the

Fig. 3. Temporal variation of RADARSAT mean backscatter of water bodies and rice fields from fallow fields to maximum tillering period. The first point (−3 weeks) corresponds to fallow fields in Jan. 26 data. Points 2, 3 and 4 are rice fields of 8-, 22- and 32-day-old rice crops in Feb. 19 data. The last three points are the same rice fields observed in March 15 data.
signature during the early period of the crop growth were reported, which was attributed to variability in above-ground vegetation cover and the orientation of soil ridges.

Fig. 4. RADARSAT S7 data acquired on January 2 (A) and February 19, 1997 (B). The puddled rice fields with and without crop appear dark in the data acquired in February 19.
Table 2
(a) Confusion matrix of training-class pixels of a site using two-date (Jan. 26 and Feb. 19) classification judged optimum for potato crop

<table>
<thead>
<tr>
<th>Class</th>
<th>Potato</th>
<th>Pumpkin</th>
<th>Fallow 1</th>
<th>Fallow 2</th>
<th>Water</th>
<th>Village</th>
<th>Total pixels</th>
<th>Class. accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato</td>
<td>2036</td>
<td>51</td>
<td>6</td>
<td>21</td>
<td>0</td>
<td>111</td>
<td>2225</td>
<td>91.5</td>
</tr>
<tr>
<td>Pumpkin</td>
<td>140</td>
<td>108</td>
<td>33</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>302</td>
<td>35.8</td>
</tr>
<tr>
<td>Fallow 1</td>
<td>49</td>
<td>99</td>
<td>3503</td>
<td>250</td>
<td>33</td>
<td>0</td>
<td>3934</td>
<td>89.0</td>
</tr>
<tr>
<td>Fallow 2</td>
<td>891</td>
<td>622</td>
<td>682</td>
<td>1146</td>
<td>14</td>
<td>77</td>
<td>3432</td>
<td>33.4</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
<td>0</td>
<td>46</td>
<td>13</td>
<td>3220</td>
<td>0</td>
<td>3279</td>
<td>98.2</td>
</tr>
<tr>
<td>Village</td>
<td>52</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1044</td>
<td>0</td>
<td>1096</td>
<td>95.3</td>
</tr>
</tbody>
</table>

Kappa coefficient = 0.718, Overall accuracy = 77.5%.

(b) Classification accuracy of potato using SAR data of different dates for the same site

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Class. accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 + 2 + 3</td>
<td>92.5</td>
</tr>
<tr>
<td>2 + 3</td>
<td>91.5</td>
</tr>
<tr>
<td>1 + 2</td>
<td>87.5</td>
</tr>
<tr>
<td>1 + 3</td>
<td>66.6</td>
</tr>
</tbody>
</table>

*1 = January 2, 2 = January 26 and 3 = February 19, 1997.

During the study period, the rice crop showed the largest dynamic range of backscatter: \(-18\) to \(-8\) dB. The change of backscatter in relation to the rice growth stage was analysed using the training site fields having different stages of rice growth. The temporal backscatter of rice from transplanting to panicle \(^2\) initiation stage is shown in Fig. 3. The backscatter showed a decline of 6 to 7 dB with the puddling of fields and came very close to that of water bodies. Fig. 4a and b show SAR data acquired on January 2 and February 19 for one of the sites. The puddled rice fields with/without crop appear dark in February. Individual fields in this area were less than 0.5 ha. However, the crop is grown in contiguous fields forming rice field clusters of 10 ha or more. Since the area is predominantly shallow and irrigated with small field bunds, their effect was not seen in the images, contrary to reports for lowland rain-fed rice areas (Panigrahy et al., 1997). The backscatter increased by 5 to 6 dB in March. The rice crop exhibited a similar temporal signature and dynamic range in ERS-SAR data as reported in earlier studies (Kuroso et al., 1993; Chakraborty et al., 1997).

5.2. Classification accuracy

5.2.1. Potato

SAR data acquired on January 2 and 26, and February 19 were considered more suitable for the potato crop study, as most of the fields were harvested by March. Two-date data acquired on January 26 and February 19 resulted in around 90 to 92% classification accuracy for potato. Inclusion of the third date data of January 2 did not improve the results significantly. Table 2a shows the confusion matrix of training site pixels for potato and other

\(^2\) Panicle: a branching cluster of flowers held on a stem, such as the flowering parts of most grasses.
Table 4
Confusion matrix of training class pixels for the same site as in Table 3 in two-date (Jan. 2 and Feb. 19, 1997) classification for early detection of rice fields

<table>
<thead>
<tr>
<th>Class</th>
<th>Rice</th>
<th>Fallow</th>
<th>Potato</th>
<th>Pumpkin</th>
<th>Water</th>
<th>Village</th>
<th>Total pixels</th>
<th>Class accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>3675</td>
<td>171</td>
<td>1</td>
<td>38</td>
<td>37</td>
<td>0</td>
<td>3922</td>
<td>93.7</td>
</tr>
<tr>
<td>Fallow</td>
<td>1315</td>
<td>1199</td>
<td>309</td>
<td>533</td>
<td>16</td>
<td>46</td>
<td>3418</td>
<td>35.1</td>
</tr>
<tr>
<td>Potato</td>
<td>5</td>
<td>62</td>
<td>1482</td>
<td>335</td>
<td>0</td>
<td>342</td>
<td>2226</td>
<td>66.6</td>
</tr>
<tr>
<td>Pumpkin</td>
<td>35</td>
<td>45</td>
<td>56</td>
<td>166</td>
<td>0</td>
<td>0</td>
<td>302</td>
<td>55.0</td>
</tr>
<tr>
<td>Water</td>
<td>102</td>
<td>49</td>
<td>81</td>
<td>18</td>
<td>3126</td>
<td>0</td>
<td>3277</td>
<td>95.4</td>
</tr>
<tr>
<td>Village</td>
<td>0</td>
<td>0</td>
<td>81</td>
<td>18</td>
<td>0</td>
<td>997</td>
<td>1096</td>
<td>91.0</td>
</tr>
</tbody>
</table>

Overall Accuracy = 74.7%, Kappa coefficient = 0.682.

classes using these two-date data for one of the sites. Four to five sub-classes of potato were used in the classification (these were the early and late varieties). The other landcover classes included in the classification were fallow, other vegetable crop fields, homesteads/villages and water bodies. Potato classes overlapped mainly with fallow fields and other vegetable crops. All other combinations of two-date data resulted in less than 90% classification accuracy (Table 2b). A successful use of ERS-SAR data for potato crop classification has not been reported yet. The classification accuracy of potato crop in this area, using single-date high-resolution optical remote sensing data, was 94 to 96%. Data acquired during late January was considered optimum for classification of potato crop in this region (Panigrahy et al., 1995).

5.2.2. Rice
The four-date data was used in various combinations to classify rice crop. Combinations of two, three and four-date data resulted in more than 90% classification accuracy for rice crop (Table 3). The highest classification accuracy (more than 94%) was obtained using the four-date data. However, two-date data acquired on January 2 and February 19 was of particular interest for early detection of rice crop. This combination resulted in more than 92% classification accuracy for all the sites, which is generally not feasible using optical or ERS-SAR 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% in two-date RADARSAT data due to the small temporal variation in the backscatter. This can be attributed to the large incidence angle and HH polarisation of RADARSAT data used, which is expected to be less sensitive to wind-induced roughness (in contrast to the ERS-SAR data). The confusion matrix of the training class pixels for one site using January 2 and February 19 two-date data is shown in Table 4. Using data from optical sensors, one can estimate rice acreage using late March data corresponding to the peak vegetation stage for correctly classifying rice areas. Single-date IRS LISS-II data acquired during late March generally result in 94% classification accuracy (Panigrahy et al., 1995).

6. Conclusions
The investigations using RADARSAT Standard Beam 7 data have shown promising results for rice and potato crop classification. Since the agronomic and morphological characteristics of the two crops were very different, the results indicate the suitability of RADARSAT S7 data for crop identification. Rice crop showed a characteristic temporal behaviour and a large dynamic range of backscatter during its growth period, which was similar to that observed in case of ERS-SAR data. This enabled achievement of more than 90% classification accuracy for rice using different combinations of datasets. It was feasible to detect rice fields early in the season using two-date data, one corresponding to fallow fields and another within 30 days of transplanting. Early season rice
area estimation using such combination of two-date data was not feasible using ERS-SAR data, due to misclassification of rice fields with water bodies. The classification accuracy of water was more than 95% in S7 data due to the small temporal variation, which can be attributed to the large incidence angle and HH polarisation of the RADARSAT data used. The results indicate that RADARSAT data can play a crucial role in monitoring of rice areas, where the availability of optical remote sensing data is very scarce due to persistent cloud cover (Currey et al., 1987). Two-date data acquired during peak vegetative cover and mature stages was found optimum for classification of potato crop. Early and late potato varieties exhibited different temporal backscatter signatures, indicating the possibility of deriving agronomic parameters, which are under further investigation. The present 24-day temporal resolution seems inadequate for potato crop, as only one combination of two-date data resulted in > 90% accuracy. This study has been carried out for the irrigated wetland rice grown during the summer season, where variability in terms of wetland management practice is limited. Investigations for the rainy or monsoon season rice are being carried out to address the large variability of rice cultivation generally prevailing in India and Asia. The temporal profile of backscatter shows the possibility of inclusion of this information in modelling for biomass and yield estimation.

Acknowledgements

The authors are grateful to Dr. K. Kasturirangan, Chairman, Indian Space Research Organisation, for his kind approval to carry out this investigation. We are thankful to CCRS and RSI for providing this opportunity to carry out the study and providing RADARSAT data and other relevant information. Encouragement, guidance and support provided by Dr. George Joseph, Distinguished Professor, SAC, Dr. A.K.S. Gopalan, Director, SAC and Dr. R.R. Navalgund, Deputy Director, RESA, SAC, Ahmedabad, have made this study possible.

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