AN OPERATIONAL RICE FIELD MAPPING TOOL USING SPACEBORNE SAR DATA

F. Holecz [1], E. Dwyer [1], S. Monaco [1], B. Schmid [2], U. Frei [3], and R. Fischer [3]

[1] sarmap, Cascine di Barico, 6989 Purasca, Switzerland
francesco.holecz@sarmap.ch, tel +41 91 600 9366, fax +41 91 600 9369

[2] geoconcept, Dammstrasse 54, 8037 Zurich, Switzerland
barbla.schmid@geoconcept.ch, tel +41 1 440 77 33, fax +41 1 440 47

[3] Remote Sensing Laboratories, Winterthurerstrasse 190, 8057 Zurich, Switzerland
frei@rsl.geo.unizh.ch, tel +41 1 635 6522, fax +41 1 635 6842

ABSTRACT

Rice is of significant importance for many tropical countries, both as a staple food and as an agricultural product for international trading. Crucial parameters for yield forecasting are the area of the rice fields and the rice growth status. Spaceborne microwave remote sensing is a technology that permits mapping and monitoring of the rice growth over large areas at regular intervals.

This paper presents the main achievements of a project that was carried out in the framework of ESA's Data User Programme, and which was dedicated to rice field mapping in tropical areas. The major result of the project is *SARscape*®, a tailor-made software for land applications, which can be used for rice mapping and rice growth monitoring. It utilises ERS and Radarsat-1 Synthetic Aperture Radar data (and in the near future, ENVISAT ASAR data) as input. The modular SAR processing chain is embedded in the commonly used *ArcView*® (Environmental Systems Research Institute, Inc.) Geographic Information System environment and allows novice users, even if they are not at all familiar with SAR technology, to generate thematic products such as rice maps and to monitor the rice growth in an automatic way. Expert users may interactively change the processing chain as they wish. This user friendly tool and the GIS environment allows rapid access to up to date rice information and the direct combination with already available spatial data. This is relevant for natural resource management and monitoring as well as entrepreneurial decision making in the field of rice trade.

The performance of this system and the resulting products are shown for two sites located in Sri Lanka and Vietnam.

INTRODUCTION

Rice is cultivated in about 110 countries on five continents. There are 50 countries with an annual production of at least 100,000 tons of rice per year. Global paddy output in 1999 was a record 590 million tons (395 million tons milled). Asia accounts for 90% of the world's production and consumption of rice because of its favourable hot and humid climate. Two countries, China and India, produce 55% of the total crop.

Less than 5% of the world rice production is traded internationally. For most rice-growing countries where annual production exceeds one million tons, rice is the staple food. In Bangladesh, Cambodia, Indonesia, Laos, Myanmar, Thailand and Vietnam rice provides 55-80% of total calories consumed.

A major source of increase in rice yield in the past was public and private sector investment, flood control and drainage that converted rainfed into irrigated ecosystems to facilitate the adoption of modern rice varieties, and improved farming practices. Theoretically, the potential for further increase in rice yield is still large, as only 55% of Asian riceland is irrigated. The scope for further conversion of rainfed into irrigated ecosystems is, however, becoming limited. Water is becoming a scarse resource with increasing demand for human consumption, industrial use, and for the generation of power. The cost of irrigation has increased substantially, as easy options for irrigation development have already been exploited. Also, environmental concerns regarding adverse effects of irrigation and flood control projects on waterlogging, salinity, fish production, and the quality of groundwater have been growing [1]. This situation leads to the need of an efficient monitoring system for areas under rice cultivation for economical use of resources and early forecasting of rice yield. The relevant organisations, mostly government institutions, require an easily applicable tool supporting decision making.

Conventional methods for rice monitoring are based on ground collected statistics, which have proved time consuming, inaccurate and expensive. Spaceborne remote sensing offers an effective alternative to these traditional methods through operational, weather independent systems utilizing Synthetic Aperture Radar technology. These techniques allow an efficient mapping and monitoring of rice crops over large areas at regular and frequent intervals.

To address the lack of commercial software systems sarmap has developed *SARscape*®, a complete end-to-end processing system, embedded in the widely used GIS software package *ArcView*®. It guides even novice SAR users through the whole SAR processing chain: focusing, interferometric processing, speckle filtering, extraction of features, geocoding and radiometric correction, mosaicing, and classification of SAR data from a number of spaceborne SAR sensors. Advanced users are also accommodated by building in the possibility to change key parameters in the processing chain. The use of the GIS environment allows for direct combination of *SARscape*®'s output with other spatial data without any additional format conversions. Apart from entrepreneurial decision making, this is relevant for resource management and monitoring where easily accessible and up to date information on natural resources is an imperative requirement.

The use of *SARscape*® is illustrated for two study areas. One is located in Polonnaruwa (eastern Sri Lanka), where multi-temporal ERS SAR acquisitions combined with Radarsat-1 SAR data were used. The Mekong River Delta (Vietnam) served as a second demonstration site, where a multi-temporal ERS-2 data set was processed and classified.

TEST SITES AND DATA

Sri Lanka test site Polonnaruwa

Test site

The test area of Polonnaruwa has a size of about 30 by 40 km and is located in the flat lowlands of eastern Sri Lanka. Agricultural activities are mainly paddy cultivation and homesteads. Also some sparsely used cropland and scrubland can be found. The cultivated land is irrigated with water from tanks and rainfall during the monsoon from November to March. The area is flat and thinly populated.

There are normally two paddy seasons: the Maha season from November to March, and the Yala season from May to September. Within this project phase, the rice growing during the Maha season 1999/2000 was monitored. The cultivation cycle starts with the release of water from the reservoirs (tanks) at a particular date. The farmers then allow the fields, now covered with grass and stubble from the last season, to soak for about two weeks. Depending on the availability of labour, they gradually start ploughing the fields and restore the small embankments. After levelling the fields, excess water is let off, and the pre-germinated seeds are sown directly onto the muddy soil. Nursing and transplanting of paddy is practised almost exclusively for infilling poorly covered parts, if at all. Depending on the variety, water is brought back immediately after sowing or only once the first leaves are visible. About two weeks after sowing, the important tillering phase starts and lasts for about one month. In this phase the plants build additional stems, each capable of developing panicles. The ground gets covered gradually in this phase. Next is the reproductive phase, lasting another month. Here the panicles are formed and the plants flower. Vertical growth stops and the leaves become more horizontal. Finally, the ripening phase takes another month. The moisture content of the plants decreases and they change colour from full green to yellowish green. The supply of water is stopped about two weeks before harvest to dry the land and to ease harvesting ([2], [3]).

SAR data

An ERS SAR time-series was acquired in order to monitor a complete paddy growing cycle (Figure 1). Thanks to the short check-out phases carried out on a regular basis to verify all systems and instruments on-board the ERS-1 spacecraft, it was possible to acquire two Tandem pairs in November and December 1999.

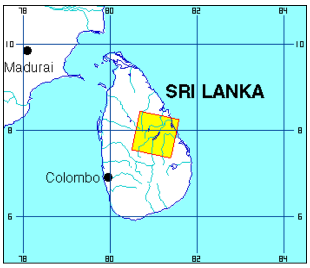

Figure 1: Acquired area for the test site Polonnaruwa

Radarsat-1 SAR data were also used to evaluate ENVISAT ASAR characteristics with respect to temporal resolution, variable incidence angle, and alternate polarization mode [4]. An overview of all acquisitions is given in Table 1.

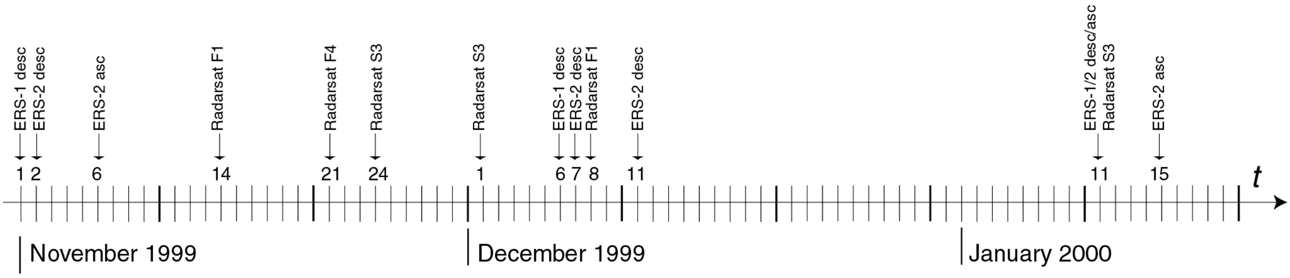

Table 1: ERS and Radarsat-1 data acquired for test site Polonnaruwa

DEM data

For the SAR data geocoding, the appropriate part of the GTOPO30, which is a global Digital Elevation Model with a grid spacing of 30 arc seconds (roughly corresponds to 1 km), was used. The area covered by the ERS and Radarsat-1 SAR scenes was transformed to the Sri Lankan map projection, and resampled to a pixel size of 25 by 25 m and 10 by 10 m (for Fine Beam mode), respectively. The quality of the GTOPO30 is certainly insufficient for a precise terrain geocoding, however, it is the only available DEM of Sri Lanka, and using it leads to far better results than ellipsoidal geocoding.

Ground truth

Field work was undertaken in November and December 1999. Since the most perceivable changes in paddy growth stage occur in the first part of the paddy cultivation cycle, five field campaigns were carried out during this period. The actual campaigns were organised to be temporally as close as possible to the corresponding satellite overpasses. A detailed description of the field work is given in [4].

Vietnam test site Mekong River Delta

Test site

The main rice seasons in the Mekong River Delta are during the Winter-Spring, Summer-Autumn, and rainy season (May to November). These three rice seasons, in various combinations governed by hydrology, rainfall pattern, and availability of irrigation, constitute the variety of rice-based cropping systems practised in the Mekong River Delta. The rice cropping systems vary from the single rainfed rice crop in the coastal fringes to the double rainfed rice, double and triple irrigated rice crops, and even more intense and more diverse cropping systems involving rice with shrimp culture and with upland crops [5].

SAR data

Seven descending ERS-2 SAR scenes at the 35-day repeat interval were acquired (Figure 2). The acquisition dates are between May 5 1996 and December 1 1996.

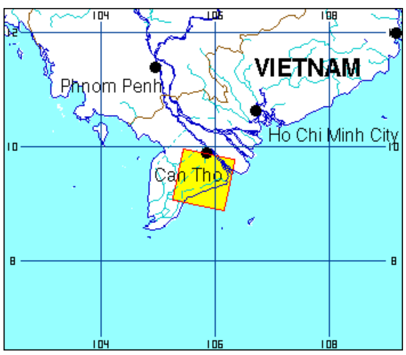

Figure 2: Acquired area for the test site Mekong River Delta

DATA PROCESSING

Method

The basic idea behind the generation of rice maps using remote sensing SAR techniques is the analysis of changes in the acquired data over time. Measurement of temporal changes in reflectivity of the plants relates to the phenological status of the rice: an increase in the radar backscatter corresponds to a growth in the rice plants and therefore to the rice crop's biomass. In fact, the radar response to rice fields at different growing stages during the crop cycle can be distinguished in three main growing stages, namely sowing-transplanting (surface scattering), growing (surface-volume scattering) and flowering (volume scattering) [3].

Another piece of useful information for thematic purposes is the degree of correlation of interferometric SAR data: rice covered areas tend to have a high coherence, while forested regions and water covered areas have a low interferometric correlation.

Processing Chain

Figure 3 illustrates the complete processing chain available in *SARscape*®. A detailed description of each function is given in [10]. Since the main goal of this project was the generation of rice maps by means of backscattering coefficients and interferometric correlation, only the functions depicted in light blue and dark green (coherence calculation) were considered.

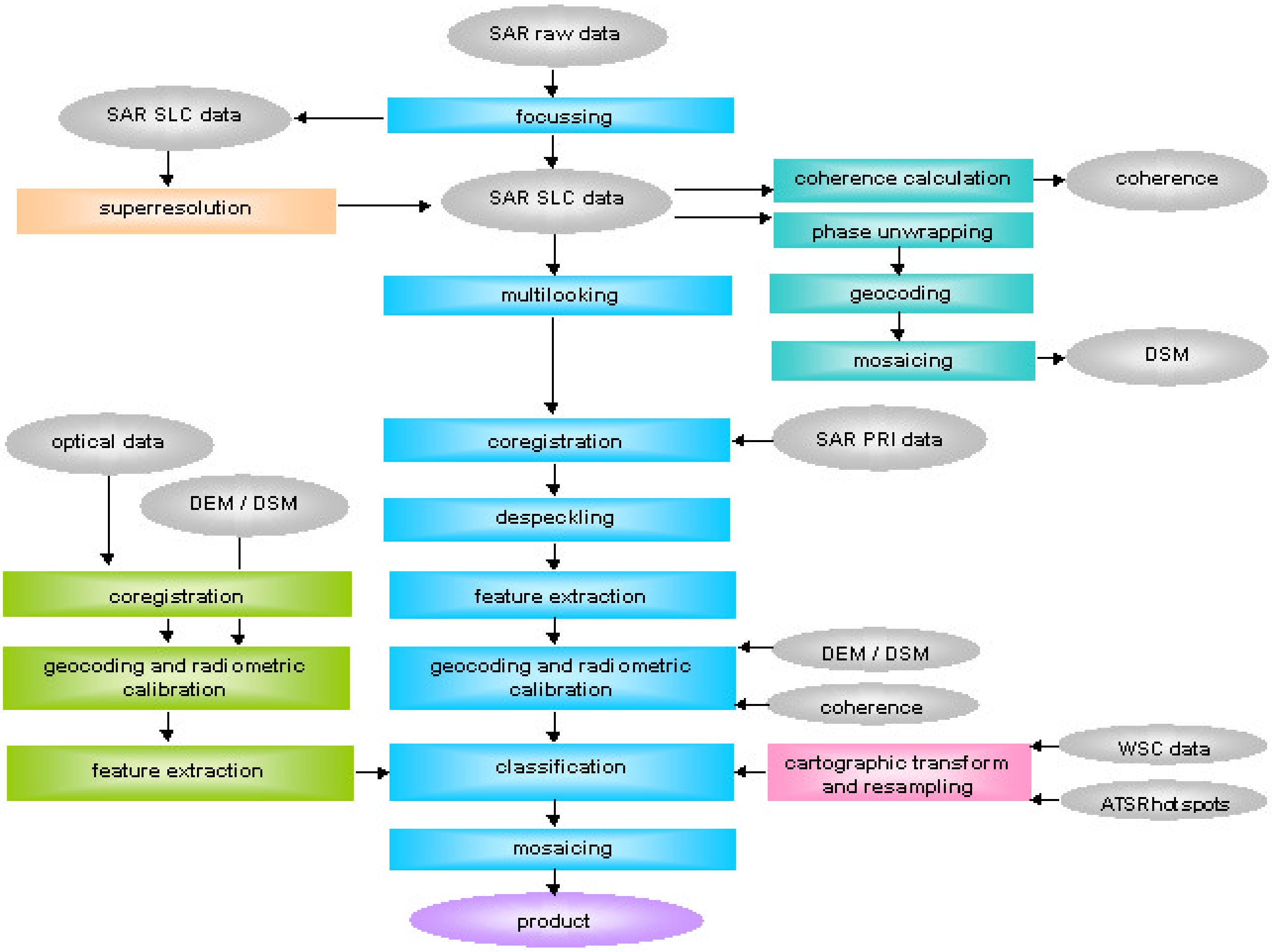

Figure 3: Processing modules available within *SARscape*®

SAR raw data were focused using the omega-k processor [6] and subsequently multi-looked to amplitude data. Images having the same orbit and frame were automatically coregistered by maximising the correlation in a number of subwindows in the image. Speckle reduction was carried out using a recently developed method for multi-temporal images which involves a combination of a modified version of Lee's spatial filter with an averaging in time. The full spatial resolution of all the imagery is retained while there is a significant increase in the signal-to-noise ratio [7]. This method gives superior results compared to other methods, in particular if more than four images are used.

Since in the Sri Lankan case various data sets were acquired from different orbits and systems, the SAR data were terrain geocoded into the local cartographic reference system and radiometrically calibrated [8]. Only in this way is it possible to combine and compare σ^o data. Supervised classification based on the maximum likelihood approach was considered for the rice map generation in Polonnaruwa, while a classification based on the thresholding of σ^o-ratio for each consecutive pair [5] was applied to the Mekong River time-series data.

Interferometric processing, which permits the generation of both coherence (interferometric correlation) maps and Digital Elevation Model data [9], was considered for the Polonnaruwa site only, where coherence maps were calculated - using ERS-Tandem acquisitions - and subsequently terrain geocoded into the local cartographic reference system.

RESULTS

Crop calendar, plant varieties, rice field dimensions are for each country/area different. Temporal and spatial resolution of the SAR data must be therefore selected accordingly as well as the methodology to be applied. In the following a selection of intermediate products based on multi-temporal data sets and sensors are presented and discussed, followed by the final products consisting of rice maps integrated with hydrological and rice fields boundaries.

Sri Lanka test site Polonnaruwa

Multitemporal data sets

Backscattering coefficients from ERS-2 SAR data show changes, of the order of +8 dB, during the rice cultivation. This increase in the radar backscatter is visualised in Figure 4 – left, where SAR data have been acquired during the descending orbits of November 2 1999 (red), December 7 1999 (green), and January 11 2000 (blue). Paddy fields can be clearly distinguished as red areas, while forest and other agricultural extents, whose variations over time are constant or different, appear in green. The SAR data have been speckle filtered using the multi-temporal approach and subsequently terrain geocoded and radiometrically calibrated, using ground control points and the resampled DEM data (see *test site and data*), into the local cartographic reference system.

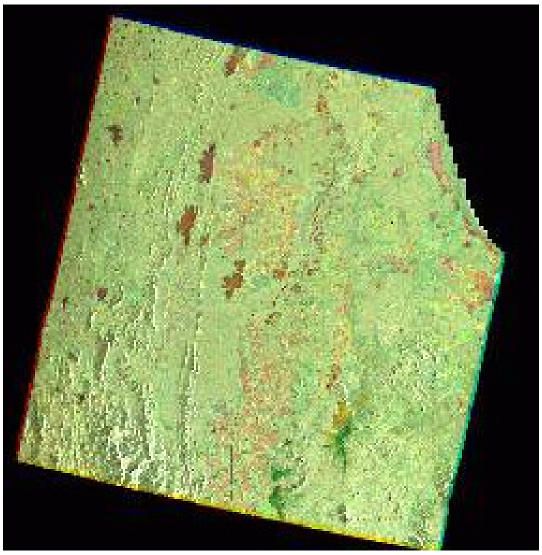
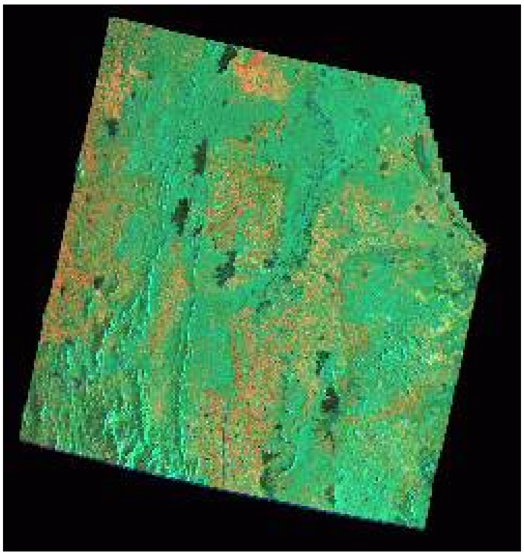

Figure 4: Terrain geocoded ERS-2 (descending) multi-temporal backscattering coefficients (left) and terrain geocoded ERS-2 backscattering coefficient combined with coherence (right)

Due to the coarse resolution of the GTOPO30 the structure of the relief is rough, especially in areas where topography is highly varying. The height inaccuracy of those areas has an impact on the location of the pixel and on the scattering area correction, where its effect on the SAR data can be only partially compensated (see bottom left in Figure 4). Nevertheless, the use of GTOPO30 leads to far better results, in regions where relief variations are present, than an ellipsoidal geocoding.

On the right side in Figure 4, the backscattering coefficient and the interferometric correlation were combined (red: coherence, green: mean amplitude, blue: amplitude difference). These ERS-Tandem data have been acquired during the descending orbits of December 6 and 7 1999. Since rice covered areas (red) have a higher coherence (in this case around 0.25 higher) than forested regions (green) and water (blue), paddy fields can be identified.

A comparison of the two colour composites, obtained using different methodologies, exhibits a high similarity. However, in the interferometric image (Figure 4 – right) there is a larger rice area than in the σ^o time-series image. In the interferometric images, with data acquired on two dates only, other crops are confused with rice. On the other hand, the σ^o time-series imagery allows more precise identification of rice due to its unique temporal signature.

The possibility to combine data acquired from different orbits and SAR systems is important for rice mapping purposes, mainly because of time synchronisation problems between rice growth (in particular at sowing-transplanting stage) and orbit repeat cycle. A failure of the system or delay of the acquisition at the earliest stages (due to windy conditions, etc.) can compromise the mapping accuracy of the final product. This is illustrated in Figure 5 – left, where ERS data have been acquired during the ascending orbit of December 11 1999 (red), and descending orbits of November 1 1999 (green) and January 11 2000 (blue). In order to achieve a geometric accuracy within one pixel, the SAR data have been terrain geocoded to 25 meters using ground control points and the resampled DEM. On the right side in Figure 5, processed in the same way, ERS-2 data from descending orbit of November 1 1999 (red), and the ascending orbit December 11 1999 (green) and Radarsat-1 S3 data from the descending orbit of December 1 1999 (blue) have been combined. Note, the high similarity between the two images: paddy fields can be clearly identified in red while forest appears in grey-green.

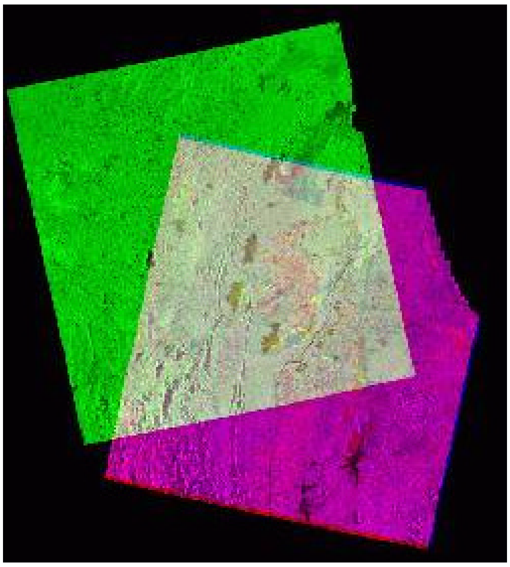
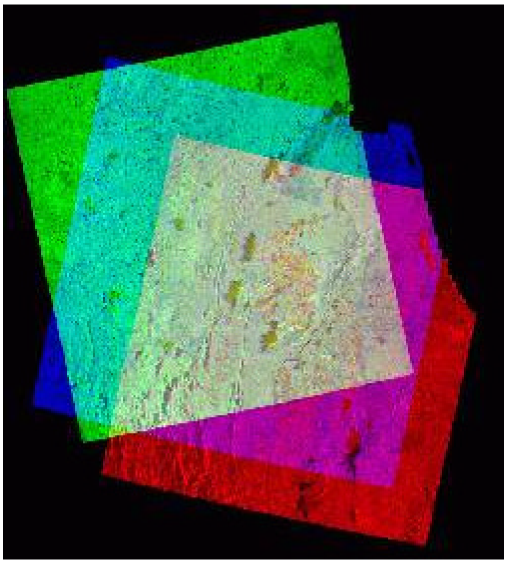

Figure 5: Terrain geocoded ERS backscattering coefficients from descending and ascending orbits (left) and terrain geocoded backscattering coefficients of ERS backscattering coefficients from descending and ascending orbits combined with Radarsat-1 S3 backscattering coefficients from descending orbit (right)

The spatial resolution of the SAR system plays an important role for precise rice mapping, especially in those regions like Polonnaruwa, where the dimensions of rice parcels are often under half a hectare. Furthermore, the possibility of merging SAR data from different acquisition modes improves the data availability. For this reason, backscattering coefficients from three Radarsat-1 Fine Beam mode acquisitions were acquired and combined as shown in Figure 6. Note, that due to its higher spatial resolution, paddy fields (green-yellow) are more easy to recognise than in Figure 4 - left. The SAR data, collected on November 14 (red) and 21 1999 (green), and December 8 1999 (blue), have been speckle filtered using a conventional filter (the multi-temporal approach could not be applied, because the data have different orbits) and subsequently terrain geocoded into the local cartographic reference system to 10 meters grid size. Here, as in the previous case, an accurate calibration procedure (in terms of geometry and radiometry) is a fundamental prerequisite, in order to obtain a correct pixel location on the ground. Furthermore, due to the large inaccuracies of the Radarsat-1 orbit, ground control points have been used for the orbit correction.

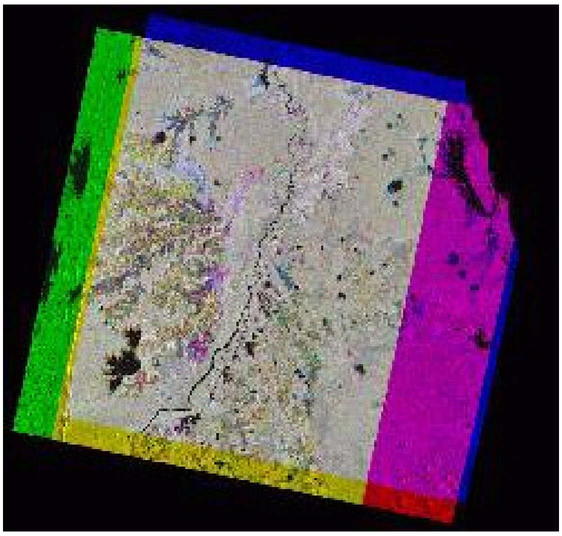

Figure 6: Terrain geocoded backscattering coefficients of three Radarsat-1 Fine Beam acquisitions

Classification results
Semi-automated supervised classification techniques allow quantification of rice (yellow) and non-rice areas. Forested regions are depicted in green, while water covered areas are marked in blue.

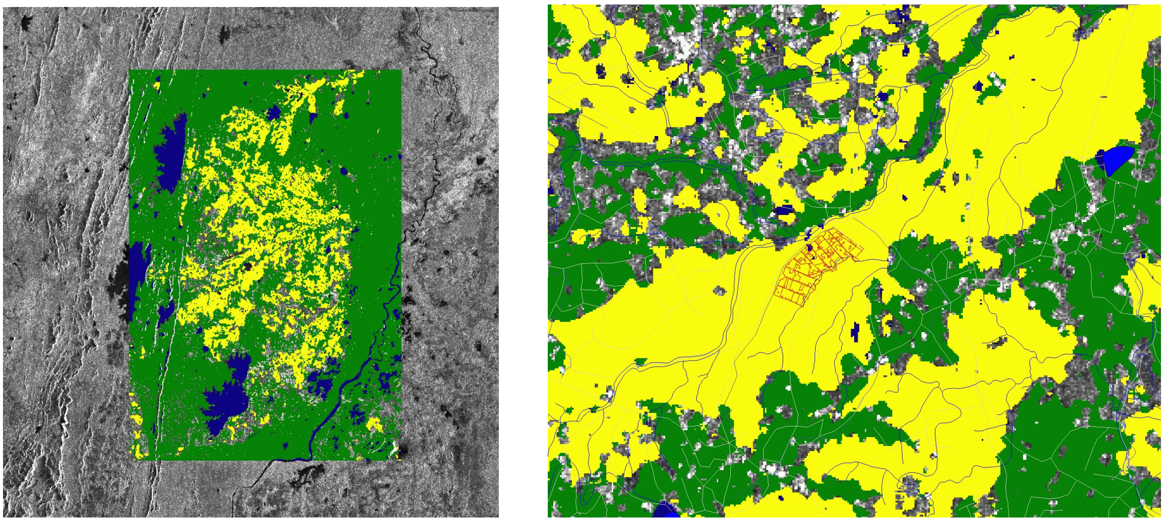

Figure 7: Rice map derived from multi-temporal ERS-2 backscattering coefficients (left) and enlarged area overlaid with available GIS data (right)

The classification, based on the maximum likelihood approach, was carried out considering the backscattering coefficients from ERS-2 descending orbits over the whole rice season (Figure 4 – left). Since *SARscape*® products are already in a GIS environment, they can be easily integrated with other data for further kinds of analysis and/or planning tasks. In this case the generated rice map was overlaid with the ERS backscattering coefficient, hydrological data (light blue), road transport data (grey), and some rice field boundaries (red). As a comparison, Figure 8 shows rice maps derived from Radarsat-1 Fine Beam mode data (Figure 6) and ERS-Tandem data (Figure 4 – right). Forested regions are depicted in dark green, while sparse vegetation and water covered areas are marked in light green and blue, respectively.

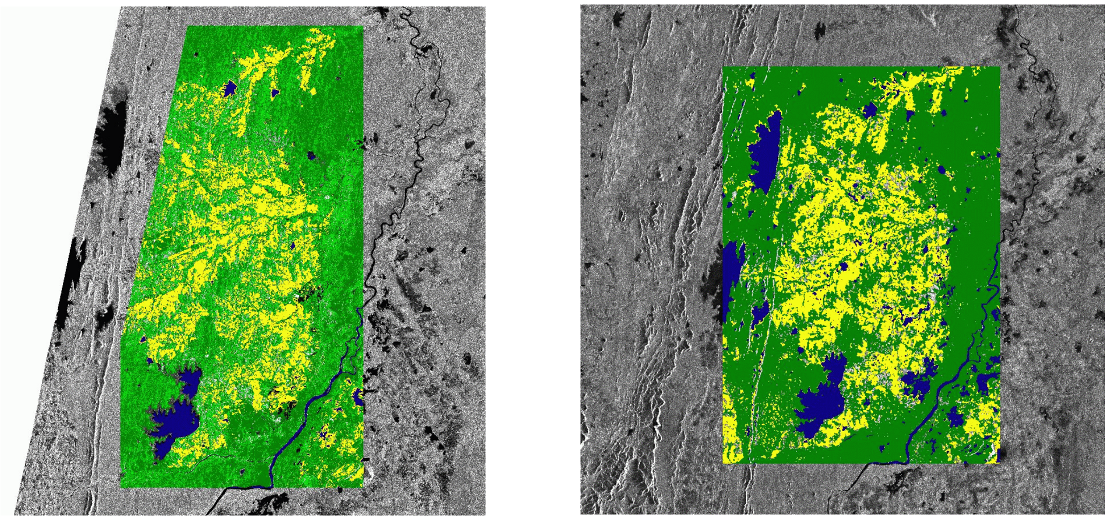

Figure 8: Rice maps using multi-temporal Radarsat-1 fine beam mode backscattering coefficients (left) and ERS-Tandem data (right)

Vietnam test site Mekong River Delta

Backscattering coefficients from ERS-2 SAR data acquired on May 5 1996 (red), June 9 1996 (green), and July 14 1996 (blue) are shown in Figure 9 - left. The data have been speckle filtered using a multi-temporal approach and subsequently ellipsoidal geocoded to the Universal Transverse Mercator (zone 48) cartographic reference system.

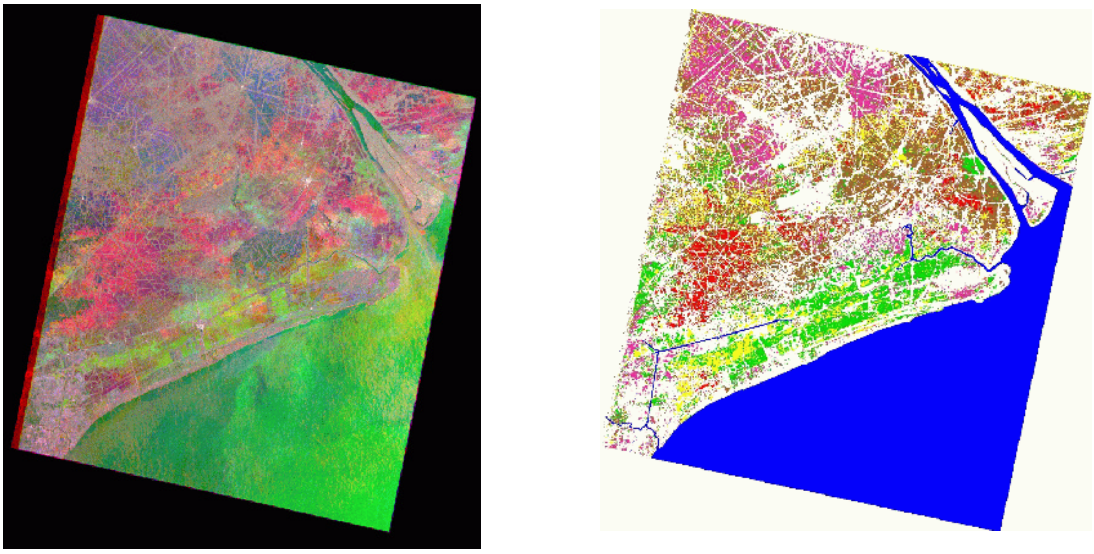

Figure 9: Ellipsoidal geocoded multi-temporal ERS-2 backscattering coefficients (left) and derived rice map (right)

The classification was carried out in this case by ratioing all consecutive backscattering coefficient pairs and by thresholding the resulting clusters. The classes in the derived rice map depicted in Figure 9 – right, corresponds to Single Crop Rice (green), Double Crop Rice Irrigated (purple), Mixed Double Crop Rice (brown), Double Crop Rice 1 (red), Double Crop Rice 2 (yellow), Water (blue), Urban areas, roads and uncultivated (white). This classification corresponds very well to that of Liew et al. [5], from whom the class names were obtained.

CONCLUSIONS

From the experience that we have gained during this ESA project, we have learned that it is feasible to map and monitor rice in an operational way but that no standard procedures can be applied. Each area has to be considered individually with respect to crop calendar, plant varieties, rice field dimensions, and data availability (topographic maps, DEM data, etc.). The temporal and spatial resolution of the SAR data to be used must be selected accordingly.

A tailor-made software package for land applications which handles different SAR systems and provides a range of processing options was developed. This was successfully used for rice mapping and rice growth monitoring. The software is a modular SAR processing chain embedded in the commonly used *ArcView®* GIS environment, which allows novice users to generate thematic products in an automatic way. Expert users may interactively change the processing chain as they wish.

Finally, we have also learned that it is feasible to produce rice maps over large areas for operational monitoring within a few days of satellite data acquisition. However, satellite overpass and flooding of the paddy fields should coincide temporally, and the weather and surface conditions at the beginning of the rice growing cycle should be favourable, i.e. without wind. In addition expert knowledge with respect to rice is required to generate properly the desired products.

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