

MAPPING AND MONITORING RICE AREAS IN CENTRAL LUZON, PHILIPPINES USING X AND C-BAND SAR IMAGERY

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ABSTRACT: This study aims to assess the use of X- and C-band Synthetic Aperture Radar (SAR) for mapping rice areas. Specifically, we used TerraSAR-X (TSX, X-band, HH polarization) and Sentinel-1A (S1A, C-band, VV and VH polarizations) data from two cropping seasons: 2015 wet season (WS, June to October) and 2016 dry season (DS, October to February) in Central Luzon, Philippines. A total of 130 TSX and 80 S1A images were used to map rice areas in these two seasons. We used the image processing software MAPscape-RICE® to process SAR images and to generate the rice maps. The procedure involved three main steps: (1) basic processing, (2) rice area mapping, and (3) validation. In basic processing (step 1), original SAR data were converted to terrain-geocoded images (backscatter δ° values). The multi-temporal SAR signature from step 1 were then analysed to set the appropriate thresholds following a rule-based rice detection algorithm (step 2). The rules for rice detection were based on a well-studied temporal signature of rice gathered from monitored sites and its relationship with SAR backscatter. Although the same procedure was followed, different thresholds were applied to the SAR data. Accuracies were compared using ground observations collected towards the end of each growing season (step 3). Based on 126 ground observations gathered in the study area in 2015 WS, the overall accuracies of the rice maps generated were 86% ($\kappa=0.71$) for TSX, 80% ($\kappa=0.60$) for S1A-VV, and 76% ($\kappa=0.52$) for S1A-VH. In 2016 DS, the overall accuracies based on 132 ground observations were 86% for TSX, 82% for S1A-VV and 70% for S1A-VH. From this study, TSX consistently provided the highest accuracies and S1A-VH the lowest. S1A-VH may not be useful for mapping rice areas. S1A-VV, on the other hand, still provided high accuracies. Better thresholds will be explored to improve accuracies.

1. INTRODUCTION

Rice is a key crop for food security and is grown to 3.2 million hectares of land in the Philippines. Filipinos greatly depend on rice; it is the basic staple for the majority of the population and it accounts for nearly half of their caloric intake (DA, 2012). Rice is grown in nearly all of the 16 administrative regions in the country. It is mainly grown throughout the country during the wet season (WS, May to October), and also in some areas with irrigation facilities in the dry season (DS, November to April).

Synthetic aperture radar (SAR) has been used in rice mapping and monitoring in the Philippines since 2013 through the Remote Sensing-based Information and Insurance for Crops in Emerging economies (RIICE) and the Philippine Rice Information System (PRISM) projects. SAR is based on active sensors that emit microwave radiation that can penetrate clouds. This is essential for reliable mapping and monitoring in conditions where cloud cover is pervasive such as during the monsoon season (Le Toan et al., 1997; Bouvet et al., 2009; Nelson et al., 2014).

In 2013 WS, RIICE mapped and monitored rice areas in three geographic areas in the country characterized by different cropping practices: Nueva Ecija (Luzon), Leyte (Visayas) and Agusan del Norte (Mindanao) using X-band HH polarization COSMO-SkyMed (CSK) from the Italian Space Agency (ASI/e-GEOS) and TerraSAR-X (TSX) from Airbus Defence and Space. CSK images were used in Leyte and Agusan del Norte while TSX was used in Nueva Ecija. The overall accuracies of the maps generated ranged from 86 to 89% (Nelson et al., 2014).

In 2014 WS, PRISM mapped and monitored sites in seven administrative regions namely: Cordillera Administrative Region (CAR), Regions III (Central Luzon), IVB (MIMAROPA), V (Bicol), VI (Western Visayas), VII (Central Visayas), and VIII (Eastern Visayas). CSK was used for Region VIII and TSX was used for the other six regions to map rice areas during the 2014 WS with an overall accuracy of 86% (Laborte et al., 2015).

Starting in the 2015 WS, PRISM expanded its coverage to include all the 16 rice growing regions of the country. The main source of SAR data for all 16 regions was still TSX acquired every 11 days. In one crop season, 8 to 10 images were acquired per footprint to map rice areas. However, this source of X-band SAR data is costly and careful planning is needed to make sure that the acquisitions cover the land preparation stage which is crucial for detecting rice areas and crop growth. Moreover, because of the cost of the images, not all regions were completely covered by TSX images.

The launch of the Sentinel-1A (S1A) satellite by the European Space Agency in April 2014 provided a new and free source of SAR imagery, allowing full country coverage which makes this ideal for regular rice mapping and monitoring (Nelson et al., 2015). PRISM tested the first images from S1A, C-band and VV polarization images to map the 2015 DS rice areas in Mindanao, Philippines. The overall accuracy was 89% (Raviz et al., 2015).

This paper aims to compare rice maps generated using the following SAR data: (1) TSX (X-band, HH polarization), (2) S1A (C-band, VV), and (3) S1A (C-band, VH) polarizations.

2. DATA AND METHODS

2.1 The study area

Central Luzon is an administrative region in the island of Luzon, Philippines. The region is composed of seven provinces, namely, Aurora, Bataan, Bulacan, Nueva Ecija, Pampanga, Tarlac and Zambales. Climate varies within the region. Central Luzon is visited by approximately 4 typhoons every year. The typhoon season is usually from the month of July to November and mostly coincides with the WS rice cropping. Some of these typhoons cause significant damages to rice crops. Central Luzon, home to 11.2 million people, ranked 3rd among regions with the biggest populations in 2015 (POPCEN, 2015).

Central Luzon has the largest plains and is the top rice producing region in the country. Almost 90% of rice areas in the region are irrigated and the remaining 10% are rainfed (PSA 2015). The Upper Pampanga River Integrated Irrigation System (NIA-UPRIIS) and communal irrigation systems supply water for irrigation. Most rainfed areas are in the province of Zambales. In 2015 WS, 376,241 ha were planted to rice and contributing to 15% of the WS rice production in the country. The region also contributed 24% of the total rice production in 2016 DS.

Among the provinces in the region, Nueva Ecija was the top producer both in terms of share in the region's total area (44%) and production (48%) in 2015 (PSA, 2015). In addition to rice, Central Luzon also produces onion, corn, sugarcane, and fruit bearing vegetables, coconut, banana and mango. Different provinces have different top crops – in Aurora, the top crop is coconut, mango in Zambales, Tarlac and Pampanga, and banana in Bataan and Bulacan (PSA, 2015).

2.2 Data

2.2.1. Satellite data: We used multi-temporal TerraSAR-X (TSX, X-band, HH polarization) and Sentinel-1A (S1A, C-band, VV and VH polarizations) data from two cropping seasons: 2015 WS (June to October) and 2016 DS (October to February). A total of 130 TSX and 80 S1A images were used to map rice areas (Figure 1, Table 1).

2.2.2. Field data: Field observations were performed throughout the two rice cropping seasons. A total of 80 monitoring fields in four provinces in the region were monitored in 2015 WS. In 2016 DS only 76 monitoring fields (MFs) were monitored because some of these were planted to corn. A total of 1,246 field visits (WS=640 and DS=606) were conducted (Figure 1, Table2). These MFs were selected prior to the start of cropping season and SAR acquisition schedule. Rice fields monitored were at least 200 m² in size and at least 1 km away from each other. Monitoring was carried starting land preparation and field visits were conducted on or as close as possible to the SAR image acquisition dates. Monitoring was conducted to determine the crop status throughout the season. Farmers were interviewed to get the actual dates of flooding and crop establishment.

Open Data Kit (ODK) forms were developed and installed on smartphones used to collect ground data such as location (latitude/longitude), field status, crop growth stage, plant height, water depth, weather condition, and leaf area index (LAI). LAI measurements were gathered using the PocketLAI app installed on the phones (Confalonieri et al., 2013). At the end of each cropping season, information on rice variety, water source and management practices were also collected. These field data were sent to a centralized database and used in the analyses.

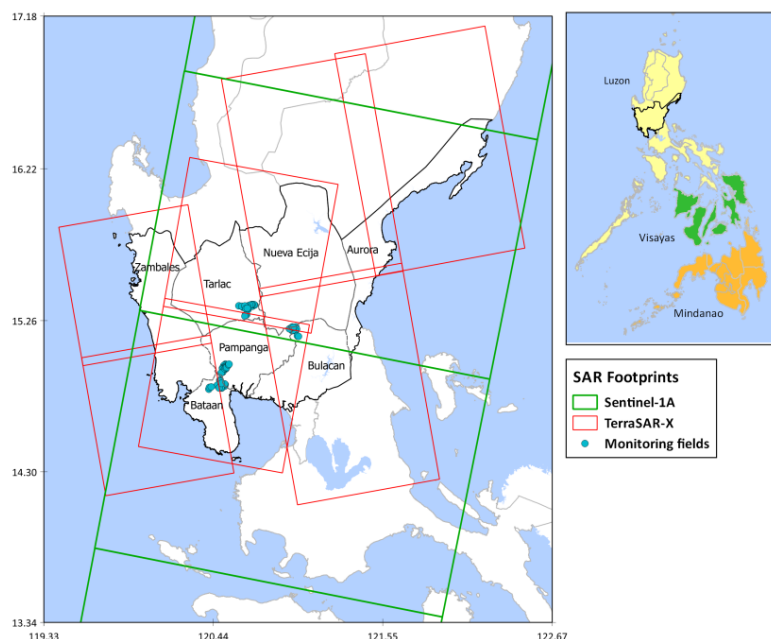


Figure 1. Location of study site showing the different footprints of SAR images acquired in Central Luzon during 2015 WS and 2016 DS. The map also shows the location of monitoring fields. The inset map shows the location of Central Luzon in the Philippines.

Table 1. Characteristics of SAR data used in mapping.

Satellite, band	TerraSAR-X (TSX), X	Sentinel-1A (S1A), C
Polarization, angle	HH, 45	VV, VH, 40
Mode, resolution (m)	ScanSAR, 20	Interferometric wide swath, 20
Pass	Ascending, descending	Descending
Repeat frequency (days)	11	12
Footprint area (km)	100 x 150	250 x 200
Number of footprints used	7	4
Area of combined footprints, km ²	105,000	120,000
Study site covered by combined footprints (%)	100	98
Total number of images used	130 (WS=62 , DS=68)	80 (WS=44 , DS=36)
Start and end dates, 2015 WS	7-Jun-15, 30-Sep-15	4-Jun-15, 2-Oct-15
Start and end dates, 2016 DS	22-Oct-15, 9-Feb-16	26-Oct-15, 11-Feb-16
Image availability	Commercial	Free
Image source	Airbus Defence and Space	European Space Agency (ESA)

Towards the end of each growing season, at least 120 validation points were collected within the region for use in the accuracy assessment of the rice maps. These validation points were split 50/50 between rice and non-rice. In areas with resources and time limitations, collection of validation points was focused for land cover where SAR signature changes over time such as rice and other annual crops. Other land covers where SAR signature was more or less stable such as forest, plantations, permanent water bodies and urban areas were gathered using geo-wiki – a free online service where registered users perform land cover validation using Google Earth imagery (<http://www.geo-wiki.org/>).

Table 2. Summary of field visits and observations conducted in the study area during the monitored seasons.

Year, Season	Monitoring sites	Period monitored	No of fields and visits	Start and end of planting	
2015 WS	Bataan	Jun 23 - Sep 11	20, 8	23-Jun-15	19-Aug-15
	Bulacan	Jun 23 - Sep 11	20, 8	20-Jun-15	08-Sep-15
	Pampanga	Jun 23 - Sep 11	20, 8	05-Jul-15	27-Aug-15
	Tarlac	Jun 23 - Sep 11	20, 8	19-Jun-15	17-Aug-15
All			80, 640		
2016 DS	Bataan	Nov 13 - Feb 9	20, 8	12-Oct-15	9-Jan-16
	Bulacan	Nov 13 - Feb 9	20, 8	3-Nov-15	30-Dec-15
	Pampanga	Nov 13 - Feb 9	19 ^a , 7	18-Nov-15	17-Dec-15
	Tarlac	Oct 22 - Jan 18	17 ^b , 9	22-Oct-15	22-Dec-15
All			76, 606		

^a One MF was planted to corn. No observations in Dec 16 due to Typhoon Melor.

^b Three MF's were planted to corn. No observations in Dec 16 due to Typhoon Melor.

2.3 Methods

2.3.1. Rice mapping: We used the image processing software MAPscape-RICE® developed by sarmap to process SAR images and to generate the rice maps. Rice mapping involved these main steps: (1) basic processing, (2) rice area mapping, and (3) product validation. In basic processing (step 1), original SAR data were converted to terrain-geocoded images (backscatter δ^0 values) following these steps fully automated in MAPscape-RICE® (Holecz et al., 2013): (a) strip mosaicking and multilooking, (b) data separation and grouping based on the SAR viewing geometry, (c) co-registration in the original SAR viewing geometry, (d) De-Grandi time series speckle filtering, (e) terrain geocoding, calibration and normalization, (f) anisotropic non-linear diffusion filtering, (g) SAR signature temporal smoothing and (h) removal of cloud related effects from intense weather events (only when needed). The multi-temporal SAR signature from step 1 were then analysed to set the appropriate thresholds following a rule-based rice detection algorithm (step 2). The rules for rice detection were based on a well-studied temporal signature of rice gathered from monitored sites and its relationship with SAR backscatter. Although the same algorithm was followed, different thresholds were used to the different bands and polarizations. The procedure in our rice classification is discussed in detail in Nelson et al. (2014). Accuracies were compared using the same set of rice and non-rice validation points collected towards the end of each growing season (step 3).

2.3.2. Accuracy assessment: A total of 126 ground observations in 2015 WS and 132 in 2016 DS distributed within the region were collected for use in accuracy assessment. The validation points were classified into two types: rice and non-rice. Land cover types other than rice were grouped into one single non-rice class. A one hectare area buffer around each validation point was created and zonal majority statistic for this region was compared with the actual land use/cover following the procedure described in Laborte et al., 2015 and Raviz et al, 2015. The overall accuracy by season was calculated using a standard confusion matrix table and the kappa statistic was estimated.

To further assess the quality of the rice maps derived from SAR imagery, we calculated the rice area at provincial level and compared the estimates against the official statistics released by the Philippine Statistics Authority (PSA).

3. RESULTS AND DISCUSSION

Figure 2 shows the temporal backscatter signatures for different land covers extracted from TSX and S1A SAR data for two seasons. From the graphs, rice has a very distinct temporal signature that differentiates it from other land covers in TSX and S1A (VV and VH) and in both seasons. The signature of other crops in 2016 DS is due to a typhoon which affected the area. A comparison of temporal radar backscatter of rice using the three SAR sources is given in Figure 3. All three exhibit the low radar backscatter values during land preparation. Both TSX and S1A-VV show a steep increase whereas S1A-VH shows a more moderate increase. The peak of TSX is observed on August 28, more than a week earlier than S1A with peak on September 8. Based on the ground information, this monitoring field was planted on July 30, and the crop was at maximum tillering stage during the August 29 observation. The ground observations correspond well to the information derived from SAR data. The lowest radar backscatter value was detected on July 26 (TSX) and July 22 (S1A VV and VH). The peak of radar backscatter was observed on August 28 (TSX), September 8 (S1A VV) and October 2 (S1A VH).

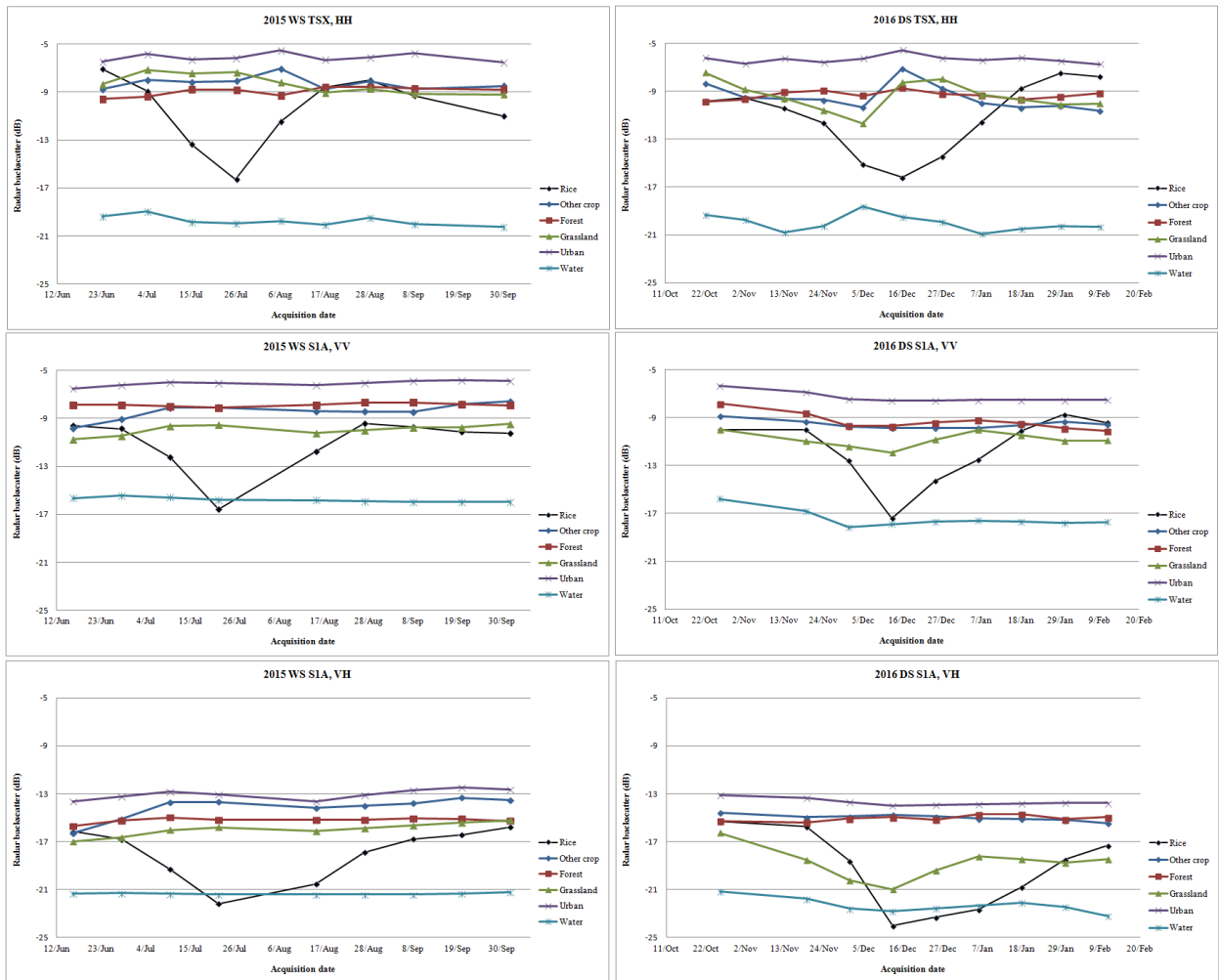


Figure 2. Example temporal signatures extracted from the study site showing the detection of rice and other land covers from TSX, X-band, HH polarization and S1A, C-band, VV and VH polarizations in 2015 WS and 2016 DS.

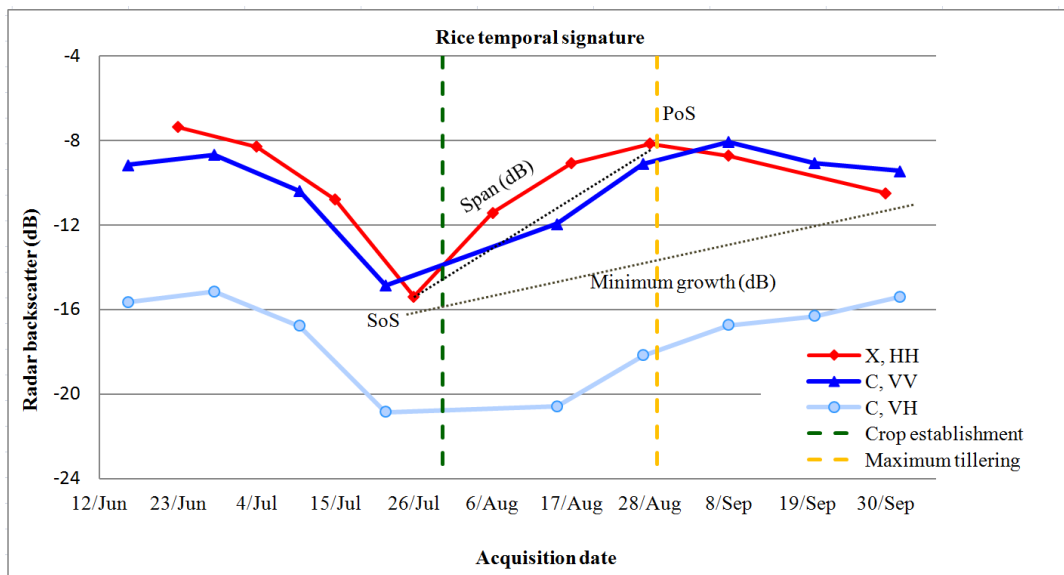


Figure 3. Example rice temporal signature extracted from the different bands and polarizations showing the backscatter values and the relevant parameters used in rice classification. Crop establishment corresponds to the start of season (SoS) and maximum tillering in X-band corresponds to the peak of SAR (PoS). In C-band PoS is observed during reproductive phase, close to panicle initiation stage.

Figure 4 shows validated rice area maps derived from multi-temporal X- and C-band SAR imagery for Central Luzon in 2015 WS and 2016 DS. Rice was cultivated in all provinces in the region with majority found in the province of Nueva Ecija. Rice maps derived from X-band (TSX) for both seasons have the highest accuracies (Table 3). The thresholds used for this sensor have been tested and established for the different cropping seasons and rice environments since 2013 which may partly explain these high accuracies. In addition, the software that we used in the classification was initially designed for processing X-band data. Rice maps derived from C-band (S1A-VV) also provided high accuracy however further testing is required to improve the classification. S1A-VH on the other hand provided the lowest accuracy for both seasons. S1A-VH may not be useful for mapping rice areas; however, the potential application of using the ratio of S1A VV/VH polarizations in rice mapping and monitoring can be explored (Chen et al., 2016). The software has been calibrated for use in C-band data since 2015, but in case of the Philippines, we are still fine tuning the parameters for mapping.

Although the classifier can detect most rice areas, some land covers can cause misclassifications, either omission or commission. In X-band, many of the omission errors were rice areas near the roads and other built up areas. During 2016 DS, the higher commission error could be associated with the flooding event in Dec (that coincided with agronomic flooding); some areas planted with other annual crops such as corn and sugarcane and grasslands/pasture were flooded (Appendix Table 1). In S1A both VV and VH, most of the commission errors were grasslands. Rice area maps derived from S1A-VH has the highest omission error.

Table 3. Accuracy of the SAR-derived rice maps over the study area, 2015 WS and 2016 DS.

Year, Season	Parameter	TSX, C-band, HH	S1A, X-band, VV	S1A, X-band, VH
2015 WS 126 ground observations	Overall Accuracy (%)	86	80	76
	kappa	0.71	0.60	0.52
2016 DS 132 ground observations	Overall Accuracy (%)	86	82	70
	kappa	0.73	0.64	0.39

Rice area estimates derived from TSX was the closest to the PSA reported harvested area. In 2015 WS, there was a 15% difference in the area estimated across the provinces. In 2016 DS, the difference in the estimates was very small (0.04% or 1,140 ha only) (Table 4 and Figure 5). Based on the SAR estimates, more than 50% the rice areas in Central Luzon were planted in the province of Nueva Ecija, consistent with the PSA report where nearly half of harvested areas were in Nueva Ecija. SAR estimates were based on area planted while PSA reports were based on area harvested (Appendix Table 3). The difference in the percent share may be due to the damaged area caused by flooding and typhoons – Mujigae and Koppu in October and Melor in December – that struck the study area in 2015. The lower rice area estimates from maps derived from S1A may be due to cancellations that coincided with the start of planting in some provinces (Figure 5). In 2015 WS, August 3, 2015 acquisition was cancelled. Based on the monitoring observations the transplanting period ranged from June 20 to September 8 in the provinces of Bataan, Bulacan, Pampanga and Tarlac. We might have missed the areas that planted in the first week of August. In 2016 DS, the November 7, 2015 acquisition was also cancelled. Crop establishment period ranged from October 12, 2015 to January 9, 2016. In addition, rice areas that have been flooded before the start of SAR acquisition were not detected. SAR image acquisition during agronomic flooding (land preparation) is essential because the change in backscatter from very low during agronomic flooding to the rapid increase as the rice crop grows is critical in our rice detection algorithm. In contrast, there was no cancellation in TSX acquisitions. In addition, Zambales was not completely covered by S1A footprint; this was another source of area underestimation in the province.

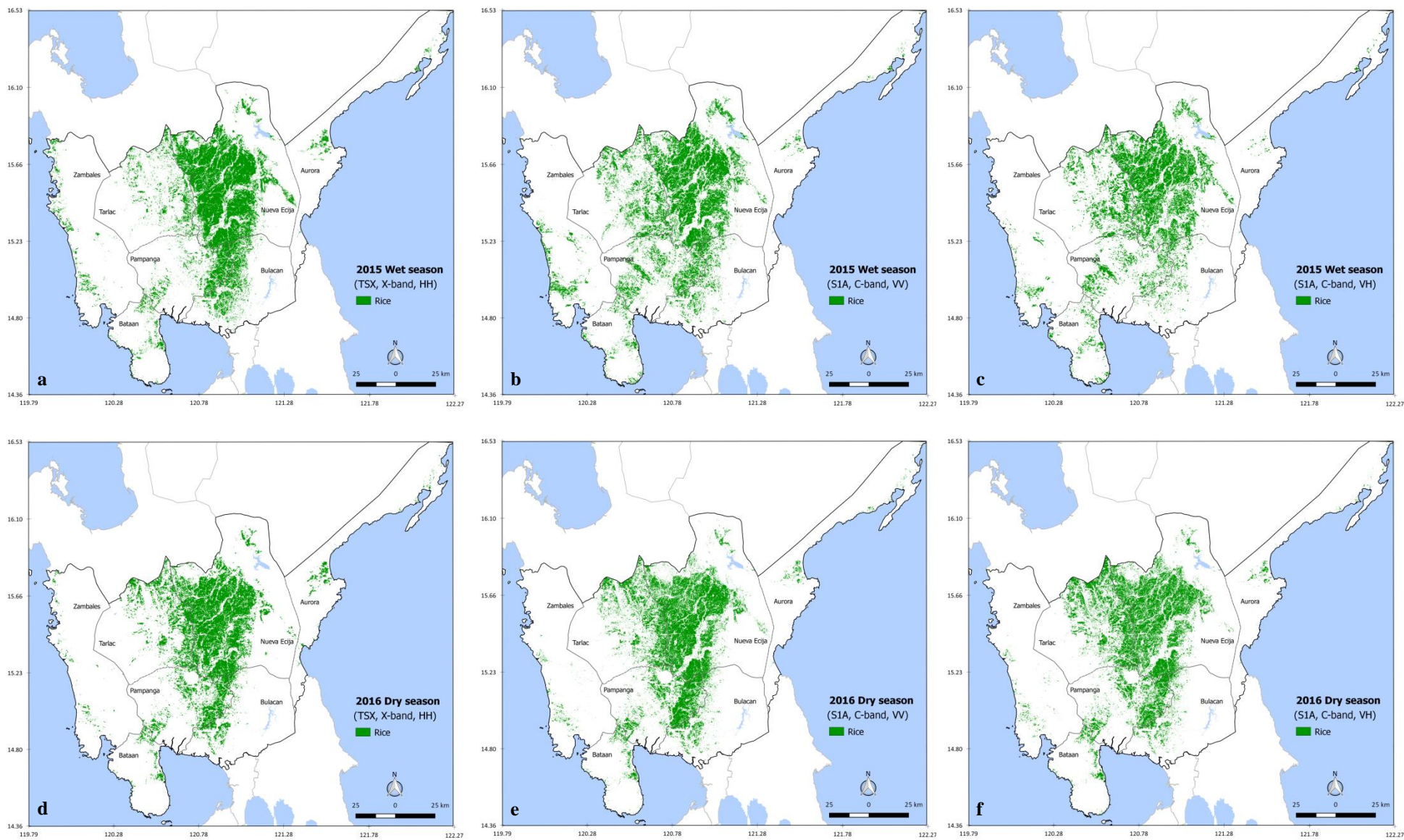


Figure 4. Map of rice areas and validation points, Central Luzon, Philippines during 2015 WS (a) TSX, HH; (b) S1A, VV; (c) S1A, VH and 2016 DS (d) TSX, HH; (e) S1A, VV; and (f) S1A, VH. SAR imagery from Airbus Defence and Space and ESA: Sentinel-1A Copernicus data (2015-2016). Rice area maps processed using MAPscape-RICE®.

Table 4. Comparison of rice area estimates between SAR-derived rice maps and PSA estimates in Central Luzon in 2015 WS and 2016 DS.

Year, Season	Estimates	Source			
		TSX, C-band, HH	S1A, X-band, VV	S1A, X-band, VH	PSA
2015 WS	Rice area (ha)	319,293	318,943	270,918	376,241
	Difference (%)	-15.1	-15.2	-28.0	
2016 DS	Rice area (ha)	318,489	300,758	297,011	319,629
	Difference (%)	-0.4	-5.9	-7.1	

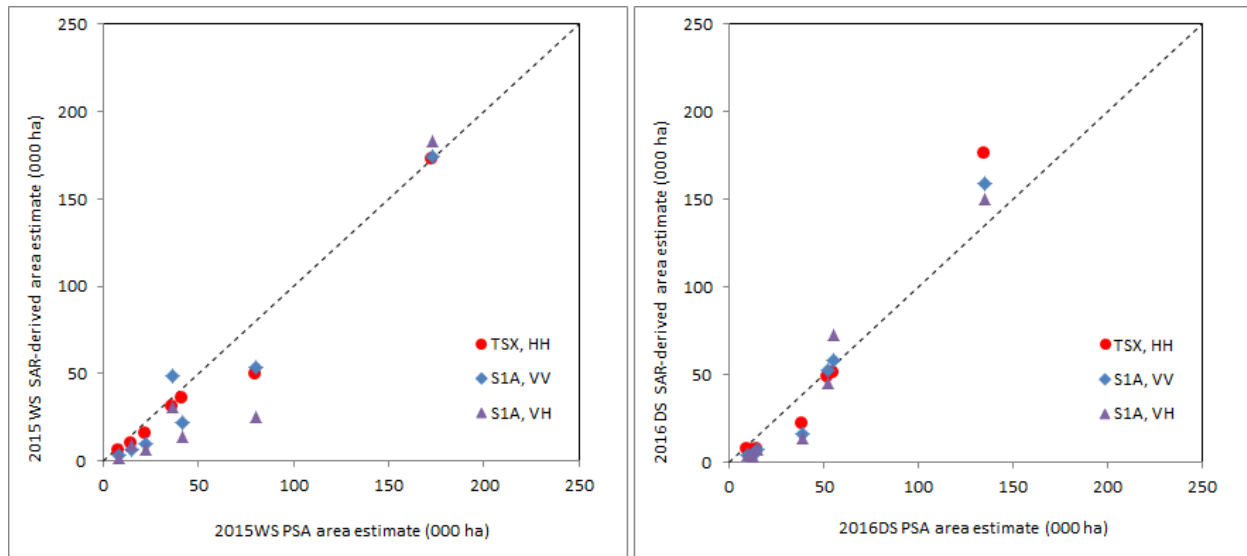


Figure 5. Comparison of area estimates between SAR-derived rice maps and PSA estimates in Central Luzon, 2015 WS and 2016 DS. One dot in the graph is one province.

4. CONCLUSIONS

Using remote sensing to map rice growing areas can provide accurate and timely information to planners and decision makers as these can help them in formulating policies and targeting interventions. Based on two seasons of analysis, TSX consistently provided the highest accuracies and S1A-VH the lowest. S1A-VH may not be useful for mapping rice areas. S1A-VV, on the other hand, still provided high accuracies and better thresholds will be explored to improve accuracies.

The ESA Sentinel program is essential in the future of remote sensing-based applications for rice (Nelson et al., 2015). The continuous acquisition of images and their availability at no cost makes this ideal for rice crop monitoring in developing countries. From 2017 onwards, Sentinel-1A will subsequently be the main source of SAR imagery for the PRISM project.

The involvement of regional partners is crucial to sustain the country level operation. PRISM partners from the DA Regional Field Offices (DA-RFOs) lead in the field monitoring and validation activities where local knowledge on rice environment is essential.

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SAR imagery from ESA: Sentinel-1A © Copernicus data (2015 and 2016).

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APPENDIX

Table 1. Errors in rice classification using different sensors, bands, and polarizations, Central Luzon, 2015-16.

Year, Season	Source	Misclassification (%)	Omission error (%)	Commission error (%)
2015 WS	TSX, C-band, HH	14	10	5
(n = 126)	S1A, X-band, VV	20	13	7
	S1A, X-band, VH	24	20	4
2016 DS	TSX, C-band, HH	14	5	8
(n = 132)	S1A, X-band, VV	18	15	3
	S1A, X-band, VH	30	26	5

Table 2. Rice area estimates from SAR-derived rice maps and official statistics (PSA), Central Luzon, by province and by season (ha).

Province/ Region	2015 WS				2016 DS			
	TSX, HH	S1A, VV	S1A, VH	PSA	TSX, HH	S1A, VV	S1A, VH	PSA
Aurora	5,519	3,730	1,785	8,342	6,896	3,953	3,339	12,917
Bataan	10,218	6,968	9,224	14,957	7,065	7,495	7,589	15,269
Bulacan	35,712	21,800	13,634	41,603	21,777	16,050	14,129	38,729
Nueva Ecija	172,350	174,050	183,421	172,771	175,952	159,074	149,985	135,119
Pampanga	31,128	48,437	31,124	36,659	48,181	52,480	45,637	52,529
Tarlac	49,202	53,720	25,028	79,936	50,924	57,850	72,387	55,357
Zambales	15,164	10,237	6,703	21,973	7,694	3,857	3,945	9,709
Central Luzon	319,293	318,943	270,918	376,241	318,489	300,758	297,011	319,629

Table 3. Share of provincial rice area to the region's based on estimates derived from SAR and official statistics, Central Luzon, 2015-DS.

Province	2015 WS				2016 DS			
	TSX, HH	S1A, VV	S1A, VH	PSA	TSX, HH	S1A, VV	S1A, VH	PSA
Aurora	2	1	1	2	2	1	1	4
Bataan	3	2	3	4	2	2	3	5
Bulacan	11	7	5	11	7	5	5	12
Nueva Ecija	54	55	68	46	55	53	50	42
Pampanga	10	15	11	10	15	17	15	16
Tarlac	15	17	9	21	16	19	24	17
Zambales	5	3	2	6	2	1	1	3