MONITORING RICE CROP YIELD USING SENTINEL-1A SAR DATA

Emma Quicho[1], Tri Setiyono[1], Gene Christopher Romuga[1], Aileen Maunahan[1], Cornelia Garcia[1], Jeny Raviz[1], Arnel Rala[1], Francesco Holecz[2], Francesco Collivignarelli[2], Luca Gatti[2]

[1]International Rice Research Institute (IRRI), DAPO Box 7777, Metro Manila 1301, Philippines
Email: *e.quicho@irri.org*
[2] sarmap, Cascine di Barico 10, Purasca 6989, Switzerland
Email: lgatti@sarmap.ch

KEY WORDS: remote sensing, ORYZA, yield forecast and estimates, LAI

ABSTRACT: Rice remains to be the most important crop among Asian countries. As such, the ability to generate yield forecast and estimates at an accurate and timely manner would help the policymakers and other stakeholders in their import and export decisions. Compared to the conventional method of crop monitoring which is very costly and time consuming, assimilation of the remote sensing data into crop growth models have been increasingly used to monitor crop growth and other field conditions. This study aims to showcase the use of multi-temporal Synthetic Aperture Radar (SAR) data specifically Sentinel-1A from the European Space Agency and crop growth simulation model to generate yield information. Radar-based information is seen to be the most suitable for monitoring lowland rice as it eliminates the effects of clouds. Remote sensing information particularly the start of season and leaf area index are combined with crop growth model inputs to generate yield. Cloud vegetation model was used to convert the SAR backscatter into LAI values that will then be translated into relative growth rate of leaves (RGRL) parameter for ORYZA crop growth simulation model. In 2015, yield estimates were generated for 168 districts in 6 different cropping seasons across 4 countries in Southeast (Vietnam, Cambodia and Thailand) and South Asia (India). Yield estimation results from this integrated Remote-Sensing and Crop Modeling System were within 81% to 94% of the official yield. With such reasonable agreement level, this remote sensing-based rice yield monitoring system offers comparative advantage of providing: (1) timely yield information soon after the end of season and even before the season completed as yield forecast, (2) with high level of details (high resolution yield maps), and (3) process-based yield information to allow further investigation and various driving factors of yield determinants including genotype, agronomic, and environments.

1. INTRODUCTION

Out of the 25 major rice-producing countries in the world, 17 are located in Asia which together produce 92%, and consume 90%, of the world's total rice production (Matthews et al., 1995). This implies that rice produced in Asia is also consumed domestically. Given this scenario, fluctuation in production needs an immediate decision from the policy makers. Timely information on yield would help policy makers and other stakeholders in their decision whether it is necessary to import (in case of shortfall) or export (in case of surplus).

Synthetic Aperture Radar (SAR) can be used effectively to monitor rice area and addressed the problem with cloud obstruction especially during the monsoon period of where most rice is grown in the tropics (Nelson, et.al., 2014). In 2013, the Remote sensing-based Information and Insurance for Crops in Emerging economies (RIICE) project started operating in Southeast Asia and South Asia. RIICE is a public-private partnership that aims to reduce vulnerability of rice smallholder farmers in low-income Asian countries. Under this project, yield estimation activities were conducted in pilot sites using multi-temporal COSMO-Skymed (CSK, X-band, HH polarization) from the Italian Space Agency (ASI/e-GEOS) and TerraSAR-X (TSX, X-band, HH polarization) images from AirBUS Defense and Space. In addition, Sentinel-1A satellite (developed and operated by the European Space Agency) was launch in April 2014, this provides new source of SAR imagery that is freely available and allows regional coverage which makes it ideal for regularly monitoring rice growth stages. Hence in 2015, RIICE project started using Sentinel-1A SAR data in its rice monitoring activities. This paper aims to showcase the use multi-temporal Sentinel-1A SAR data and presents the initial results of the yield estimation.

2. DATA AND METHODS

2.1. Data

2.1.1 Study area: In 2015, initial yield estimation using Sentinel-1A satellite images was generated in four different locations in Asia. In Vietnam, 2 provinces (An Giang, Dong Thap) were covered in Mekong River Delta (MRD), 8 provinces (Bac Ninh, Ha Nam, Hai Duong, Hai Phong, Hanoi, Hung Yen, Nam Dinh,Thai Binh) in Red River Delta (RRD), 4 provinces (Kandal, Prey Veng, Takeo, Svay Rieng) in Cambodia, 3 provinces (Suphanburi, Chiang Rai, Nakhon Sawan) in Thailand, and 5 districts (Thanjavur, Tiruvarur, Nagapattinam, Tiruchipalli, Sivaganga) Tamil Nadu, India. These provinces were chosen as the area of interest considering the large area planted to rice as well as the high temporal resolution of Sentine-1A satellite images in 2015.

2.2.2 Satellite Images: Multi-temporal Synthetic Aperture Radar (SAR) data from Sentinel-1A (C-band, VV polarization, 20 meter resolution) was used in this study. These images have a 12-day regular repeat cycle (except for the images over Thailand which was at 24-day repeat cycle). The number of satellite images used during the 2015 rice cropping season differs in each monitoring locations. In Cambodia a total of 8 images was used from April to July covering the early wet season; Mekong River used 11 images from October to February (winter-spring season); Red River Delta used 7 images (summer season) while Thailand used 7 images from May to September (wet season); Tamil Nadu used 10 images from August to December (samba season).

2.2.3 Crop Model Input Data: Aside from the SAR images, daily weather information was also used in generating yield forecast and estimates. The weather data (solar radiation, wind speed, and vapor pressure) comes from NASA POWER dataset (a publicly available global weather data produced by NASA Langley Research Center Power Project) while minimum and maximum temperature and rainfall comes from local weather stations of the monitoring locations. The NASA POWER weather data were downscaled to 15 arc-minute resolutions and corrected using reported data from local stations (Sparks, et al., unpublished) before it can be use in the crop model. Also, soil information from the World Inventory of Soil Emission potential (WISE) dataset and Harmonized World Soil Database (HWSD) were used in the model. Similarly, field information particularly crop management practices (nitrogen fertilizer application, irrigation management, and crop establishment) were also used in the model. Together with management practices, other information collected in the field are field locations (lat/lon), crop status, rice variety, plant height, leaf area index (LAI), water depth, etc., these ground information were collected using an Open Data Kit (ODK) forms installed in smartphones. The ground information is collected by each country partners.

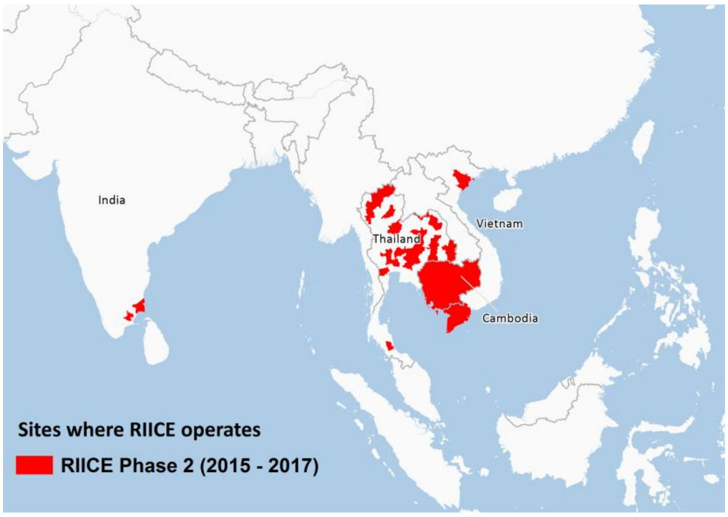

Figure 1. Map showing the monitoring locations.

2.2 Methods

The operational diagram illustrates the processes of the remote sensing-based yield estimation system starting from the satellite acquisitions to integration of SAR data into ORYZA model until the generation of yield forecast or estimates and final yield map (Figure 2). MAPscape-Rice® was used to process the SAR data into terrain-geocoded images (backscatter δ^o values) to produce the rice area estimates, start of season (SoS), phenological field status, and LAI. The system assimilates SAR products, particularly LAI and SoS into ORYZA model in order to generate yield estimates. Combined with rice area product, the estimated yield then can be converted into production estimates for the selected geographical area. SAR processing was done for each of the track covering the monitoring locations stated above. Given that the SAR images were acquired on a regular basis this gives us a better picture of the whole cropping season from flooding until harvesting. LAI is defined as the one sided green leaf area per unit ground area. For rice the values ranges from close to zero for seedling stage to a maximum of 10-12 at flowering (possible for hybrid rice varieties), although maximum values closer to 6 or 7 are the typical. In this rice yield estimation system, LAI is inferred from the backscattering coefficient using the vegetation water cloud model (Attema and Ulaby, 1978).

ORYZA crop model was developed through the collaboration work of International Rice Research Institute (IRRI) and Wageningen University and Research Center (WUR) (Bouman, et al., 2001). It is a process-based rice growth and yield estimation model that captures complex and dynamic interactions among weather, agronomic management, crop characteristics, and soil properties. LAI values at approximately 33% maturity of the rice variety together with the SoS product are inferred from radar backscatter using cloud vegetation model (Attema and Ulaby, 1978) with parameters calibrated with in situ LAI measurements. Inferred LAI are finally used to calibrate the relative leaf growth rates parameters (RGRLmax and RGRLmin) in ORYZA.

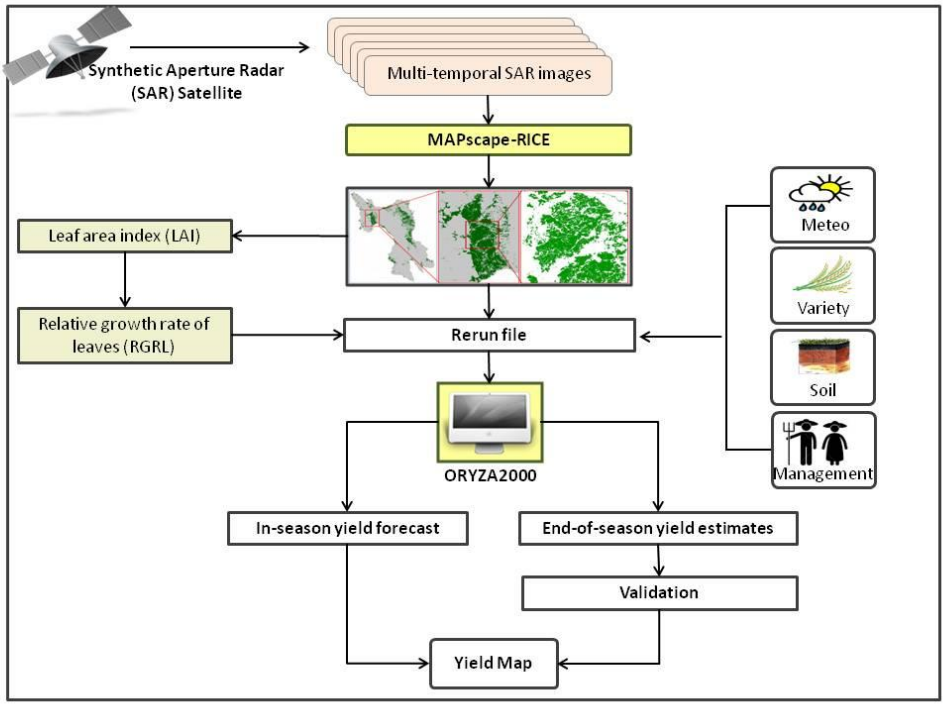

Figure 2. Operational diagram of yield estimation system showing the integration of SAR data using MAPscape-Rice® into ORYZA model.

3. RESULTS AND DISCUSSION

In 2015, using Sentinel-1A data processed in MAPscape-RICE® and assimilated into ORYZA model, yield estimates were generated for RIICE monitoring locations. Figure 3 shows the wide ranges of start of seasons for the 2015 rice cropping seasons in the study areas. In Mekong River Delta, the majority of the winter-spring season started on October to November while in Red River Delta summer season, majority of fields planted in June to July. Farmers in these areas planted rice varieties with maturity of 90-100 days duration in summer season while around 110 days duration in winter-spring season. There was an overlap in the two seasons in Cambodia because the early wet and main wet seasons were not well aggregated. For early wet season majority of SoS was detected in April while for main wet season it was detected in June to September. During main wet season, farmers are using photoperiod sensitive rice varieties hence, the season is very long. On the other hand, because there are some cancellations in the initial acquisitions of Sentinel-1A for some locations in Thailand, the study only covered Suphan Buri province given continuous satellite images every 24 days. In Suphan Buri's wet season, majority of SoS was detected in June to July. Lastly in Tamil Nadu, India, majority of SoS for Samba season was in September to October.

In 2015, yield estimates were generated for 168 districts in 6 different cropping seasons. across 4 countries in Southeast (Vietnam, Cambodia and Thailand) and South Asian (India) countries Table 1 provides the validation of the estimated yield against the official yield at the provincial level as provided by the country partners. In Red River Delta in which there were 8 monitoring provinces, compared with the official yield, the agreement was 89% with Root Mean Error (RMSE) of 630 kg ha^{-1}. In Cambodia, the yield estimates agreement against official yield data was 84% with RMSE of 560 kg ha^{-1}. Overall yield estimates agreement against official yield data at district level ranged from 81% to 94% while the RMSE ranged from 340 kg ha^{-1} to 1,110 kg ha^{-1}. Samba season and main wet season of Tamil Nadu and Cambodia respectively, were not included in the table analysis due to lack of official yield data.

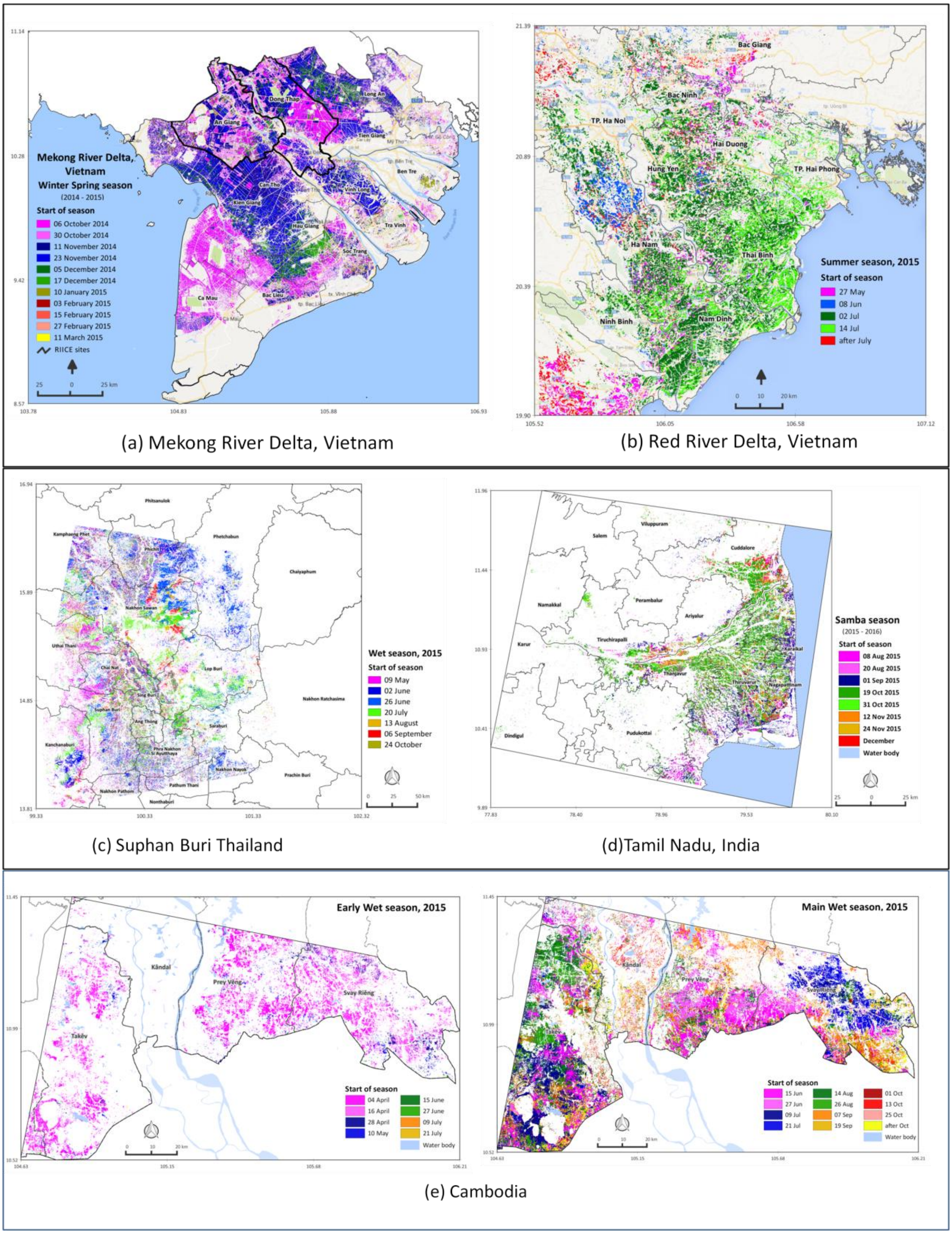

Figure 3. Map showing the start of seasons in RIICE monitoring locations during the 2015 rice cropping season.

Table 1. Comparison of yield estimates and official statistics, 2015 cropping seasons.

Country/Province	Season	Number of Districts covered	Yield (t/ha)		RMSE (kg ha^{-1})	Agreement (%)
			Estimated	Official		
Vietnam						
Hanoi	Summer	19	5.57	5.34	540	90
Hai Duong	Summer	12	5.04	5.61	690	88
Hai Phong	Summer	11	4.96	5.20	540	90
Hung Yen	Summer	10	5.12	5.95	910	85
Nam Dinh	Summer	10	5.07	5.04	580	88
Thai Binh	Summer	8	5.16	6.00	870	86
Bac Ninh	Summer	8	5.73	5.74	580	90
Ha Nam	Summer	6	5.53	5.25	340	94
An Giang	Winter-spring	11	6.71	7.53	910	88
Dong Thap	Winter-spring	11	6.33	7.24	1,110	85
Thailand						
Suphan Buri	Wet	10	5.39	5.12	750	85
Cambodia						
Kandal	Early wet	3	3.90	4.01	770	81
Prey Veng	Early wet	4	3.29	3.73	480	87
Svay Rieng	Early wet	6	3.13	3.04	350	88
Takeo	Early wet	6	3.26	3.44	630	82

Figure 4 shows the yield estimate map (by pixel) for each monitoring location, where it allows the assessment of spatial yield distribution across the area of interest and where interventions maybe provided if needed. As shown in the map, yield varies across locations and from season to season. In Red River Delta, the end of season yield estimates during the 2015 summer season ranges from 4.2 to 6.1 t/ha while in Mekong River Delta, yield ranges from 5.5 to 7.2 t/ha during the winter-spring season. In Vietnam, the yield aggregation was also done at the commune level but in this paper district level yield result was presented. In Cambodia, early wet season have slightly higher yield that ranges from 2.6 to 4.8 t/ha while main wet season have yield that ranges from 2.2 to 4.4 t/ha. Farmers in these areas usually plant short duration varieties during the early wet while photoperiod sensitive varieties are common during main wet season. For Suphan Buri, the average yield at the district level is 5.3 t/ha covering the period of May to October (wet season). In the case of Tamil Nadu, the level of aggregation was made at the Block level where the average is 3.4 t/ha.

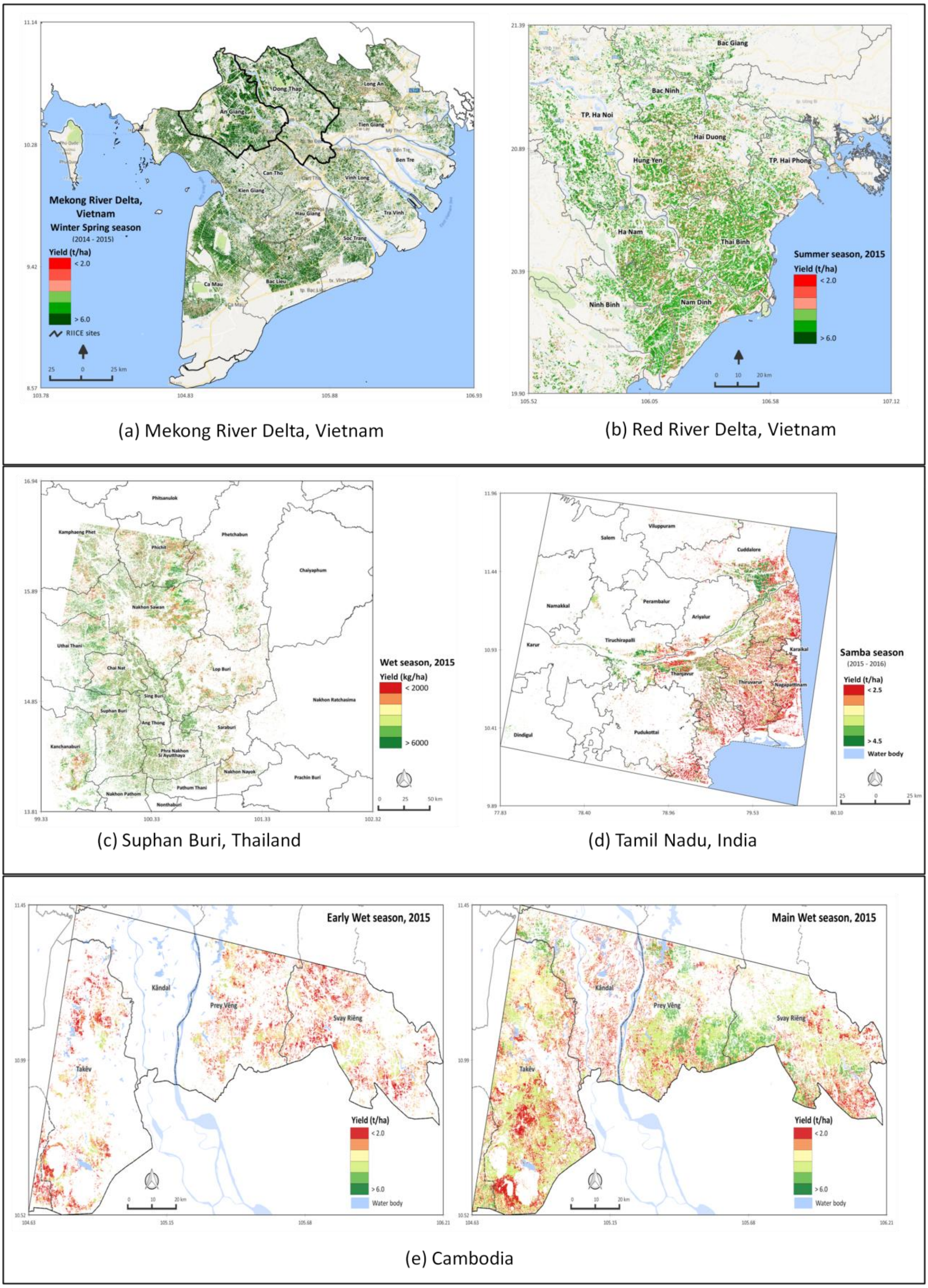

Figure 4. Map showing the yield estimates in RIICE monitoring locations during the 2015 cropping seasons.

4. CONCLUSIONS

The study demonstrates that with regular SAR data acquisitions, rice crop monitoring is possible across Asian region where rice is commonly grown. The results presented in this study is from the first year of availability of SAR imagery from Sentinel-1A. This case study demonstrated promising results and methodology of rice yield estimation using a combine use of SAR remote sensing data and Crop Growth Simulation Model.
The availability of SAR data from Sentine-1A at no-cost at all will enable country-wide provision of rice monitoring particularly in Asian region where majority of rice is grown.

ACKNOWLEDGEMENTS

This work was undertaken within the framework of the Remote sensing-based Information and Insurance for Crops in Emerging economies (RIICE) project, financially supported by the Swiss Agency for Development and Cooperation (SDC). SAR data were provided by ESA: Sentinel-1A © Copernicus data (2015). We also thanked all the National Partners working under the RIICE project.

REFERENCES

Anup K. Prasad, Lim Chai, Ramesh P. Singh, Menas Kafatos (2006). Crop yield estimation model for Iowa using remote sensing and surface parameters. International Journal of Applied Earth Observation and Geoinformation 8 (2006) 26-33

Attema E.P.W. and F.T. Ulaby, Vegetation modeled as a water cloud, *Radio Science*, Vol. 13, 1978.

Bouman BAM, Kropff MJ, Tuong TP, Wopereis MCS, ten Berge HFM, van Laar HH, 2001. ORYZA2000: modeling lowland rice. Los Baños (Philippines): International Rice Research Institute, and Wageningen University and Research Center. 235 p.

Nelson, A., Setiyono, T., Rala, A.B., Quicho, E.D., Raviz, J.V., Abonete, P.J., et al., 2014. Towards an operational SAR-based rice monitoring system in Asia: Examples from 13 demonstration sites across Asia in the RIICE Project. *Remote Sens.*, 6, pp. 10773-10812.

https://sites.google.com/a/irri.org/oryza2000/

http://www.icasa.net/toolkit/wise.htm

http://webarchive.iiasa.ac.at/Research/LUC/External-World-soildatabase/HTML/

http://power.larc.nasa.gov