A new method to estimate rice crop production and outlook using Earth Observation satellite data

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ABSTRACT

From 2011 to 2012, The Rice Crop Workgroup; a collaborative project of the Japan Aerospace Exploration Agency (JAXA), the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand, and the Remote Sensing Technology Center of Japan (RESTEC); developed a method to estimate rice crop area and production using space-based Synthetic Aperture Radar (SAR). RESTEC developed the software (INternational Asian Harvest mOnitoring system for Rice – INAHOR) on behalf of JAXA, under contract to JAXA. INAHOR will be applied to Vietnamese and Indonesian sites under their country's and JAXA's joint Asia Pacific Regional Space Forum (APRSAF) projects and the GEOGLAM Asian rice crop monitoring team activity (Asia-RiCE). Additionally, a satellite-based agricultural weather information system (JASMIN) was implemented to support rice crop outlook information provision to FAO AMIS as part of Asia-RiCE GEOGLAM activities. This was done in cooperation with the ASEAN Food Security Information System (AFSIS) project under contract to JAXA.

Key Terminology Synthetic Aperture Radar (SAR), ScanSAR, AFSIS, GEOGLAM, Asia Rice crop

1. Background

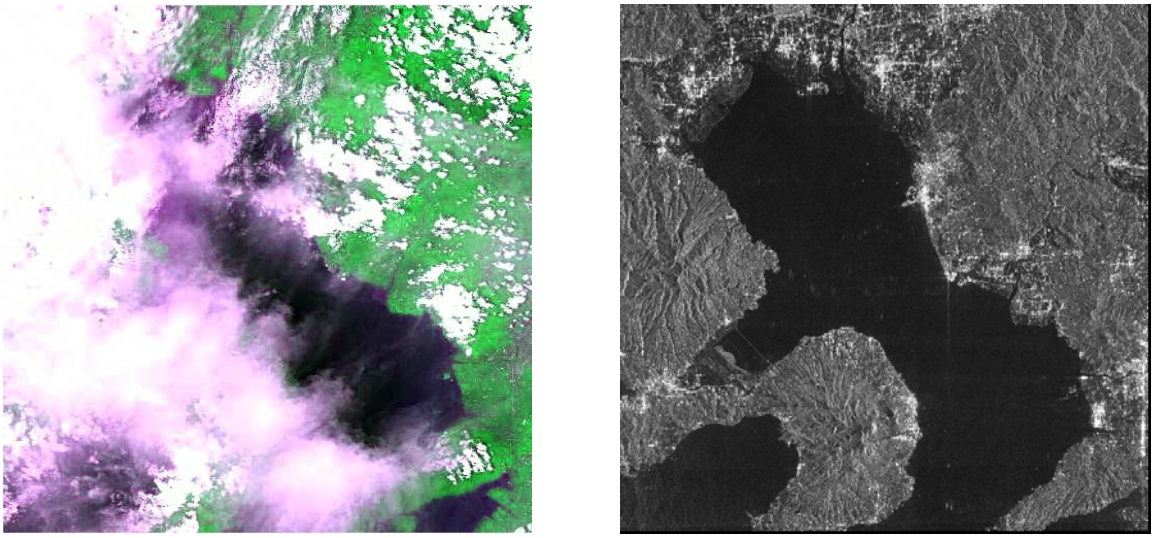
The G20 Agriculture Ministers agreed on an "Action Plan on food price volatility and agriculture" during their first meeting in Paris, from the 22nd to the 23rd of June 2011. The action plan was then submitted to their Leaders at a Summit in November 2011. In order to improve crop production projections and weather forecasting, the use of modern tools was promoted, in particular remote sensing. The Group on Earth Observations (GEO) was directed to develop an international voluntary network for agricultural production monitoring. The GEO Global Agricultural Monitoring initiative (GEOGLAM) serves as a useful input for the FAO's Agricultural Market Information System (AMIS), which aims to the provide more accurate crop forecast data of four type of commodity crops – wheat, maize, rice, and soybeans. Since rice is the main commodity crop in Asia, the Japan Aerospace Exploration Agency (JAXA) proposes and leads the Asian Rice Crop Estimation & Monitoring project (Asia-RiCE), which focuses on leveraging space technology to represent rice crops in GEOGLAM. Asia-RiCE is a collaborative effort between a number of Asian organizations in countries including India, Indonesia, Thailand, and Vietnam.

RESTEC provides the technical and administrative support for JAXA's lead role in Asia-RiCE. In 2009 and 2010, a system was developed for the Ministry of Agriculture, Forestry, and Fisheries (MAFF) to estimate rice crop acreage using GIS and space-based remote sensing data. During 2011and 2012, the JAXA-GISTDA Rice Crop workgroup in collaboration with RESTEC developed software to estimate rice crop acreage and production using space-based Synthetic Aperture Radar (SAR) from the ALOS and THEOS series of satellites. The software, named INAHOR (INternational Asian Harvest mOnitoring system for Rice) will be applied to Vietnam and Indonesia under a Space Application for Environment (SAFE) prototyping project of the Asia Pacific Regional Space Agency Forum (APRSAF). This prototyping result will also be also useful for the GEOGLAM Asia rice crop team activity, Asia-RiCE. Additionally, a satellite-based agricultural weather information system (JASMIN) is implemented to support rice crop outlook information provision to FAO AMIS as part of Asia-RiCE GEOGLAM activities. This was done in cooperation with the ASEAN Food Security Information System (AFSIS) project in 2013.

This paper discusses the development of this space-based remote sensing application for rice crop monitoring in Asia.

2. Proposed Methodology

Because Earth observation satellites can observe large spatial extents at high temporal frequency and in high quality for reasonable cost, they are a very powerful tool for agricultural monitoring at national and provincial levels. For Agricultural monitoring of crops including corn, wheat, and soybean, time series of optical data from missions such as Landsat commonly are used to estimate crop area and production very efficiently and effectively. However, Asian rice crops are generally grown during the rainy season (monsoon season), and cloudy and rainy weather condition causes a problem to estimate paddy area and rice production using optical sensors. Space-based Synthetic Aperture Radar (SAR) is a useful tool for rice crop monitoring, as the microwave frequencies used can penetrate cloud cover/rain to give accurate information of Earth's surface. SAR is used to complement optical sensor data to estimate rice crop area and production in Asia. Fig. 2.1 shows images observed simultaneously by ALOS's optical AVNIR-2 sensor and SAR PALSAR instrument. Although clouds in the AVNIR-2 image obscure the ground, it is clearly captured in the PALSAR image.



ALOS AVNIR-2 (Optical Sensor) ALOS PALSAR (SAR)

Figure 2.1 Images observed simultaneously by ALOS

The basic approach to estimate paddy area using SAR is shown in Fig. 2.2. SAR instruments emit a microwave signal and receive the echo (the microwave back scattered signal) from the ground. When newly planted, rice weakly backscatters the signal to the satellite because of minimal polarisation (specular reflection), and the SAR data image becomes dark (low count value). At a well-grown stage, the microwave backscatter becomes strongly polarised, and the brightness of image increases. Using the well-established relationship between backscatter and crop growth stage, we can estimate rice crop area.

Fig. 2.3 is a flow chart that demonstrates the process of using INAHOR to estimate rice crop area with SAR data. Firstly, the SAR images are opened, selecting one for the planting season and another for the well-growing season. Next, two threshold values are set to differentiate flooding areas and well-grown areas. Finally, following noise reduction, an estimate of the rice crop area is made. Flooding and well-grown areas are classified by image analysis processing. If the result is poor, a change of threshold values is made and the analysis is repeated. The rice crop production is calculated using this rice crop area and values for yield per unit, which is derived from statistic information or field surveys.

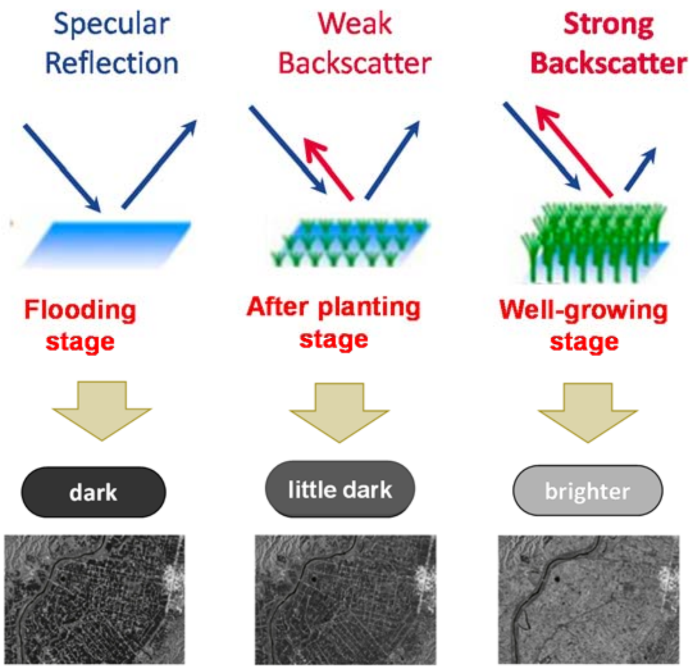


Figure 2.2 Basic approach to estimate paddy area using SAR

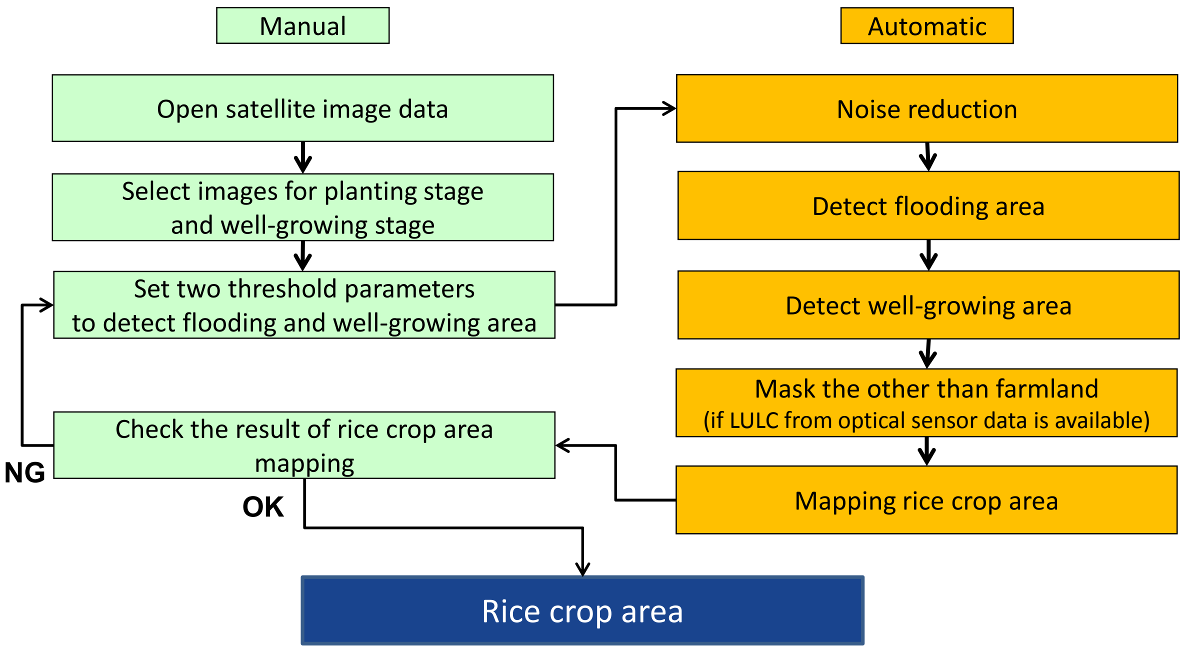


Figure 2.3 Flow chart that demonstrates the process of using INAHOR

3. Results

This methodology was applied during the JAXA-GISTDA cooperative project in 2011 to estimate the acreage and production of rainy-season rice crops at Khon Kaen province in Thailand. Khon Kaen is located in the northeastern part of Thailand, and has the feature that most rice fields are rain fed. About 200 field surveys were conducted for validation purposes. Crop yields (production per area) were measured by harvesting approximately 1 square of the crop at its harvesting stage. The field surveys also revealed, that the local crop calendar is as follows: direct seeding from June to July, transplanting from July to August, and harvesting from November to December. The satellite data used was Canadian RADARSAT-2 data provided by GISTDA. The multi-look fine mode (HH polarization) was used, which offers 8m spatial resolution, and a 50km observation swath width. The result of the analysis is shown in Fig. 3.1. Imaging data from the 20th of June, 14th of July, and 7th of August were used for the planting stage and data observed on the 7th of August and 31st of August were used for the well-grown stage. Urban, water, and forested areas were masked-out using land cover classification maps derived from ALOS AVNIR-2. The validation results using data from the field survey are shown in Table. 3.1. The accuracy of estimated rice crop acreage was more than 90% of the field survey value. Conversely, the accuracy of estimated productions was about 80% of the field survey value. This is because the variation in the yield of direct seeding fields was large at the verification site, and varied substantially from the statistical information which was used to estimate the production.

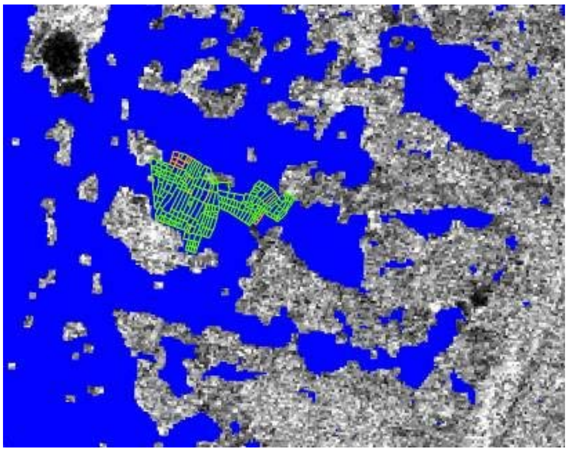


Figure 3.1 Result of the analysis at study site in Khon kane in 2011

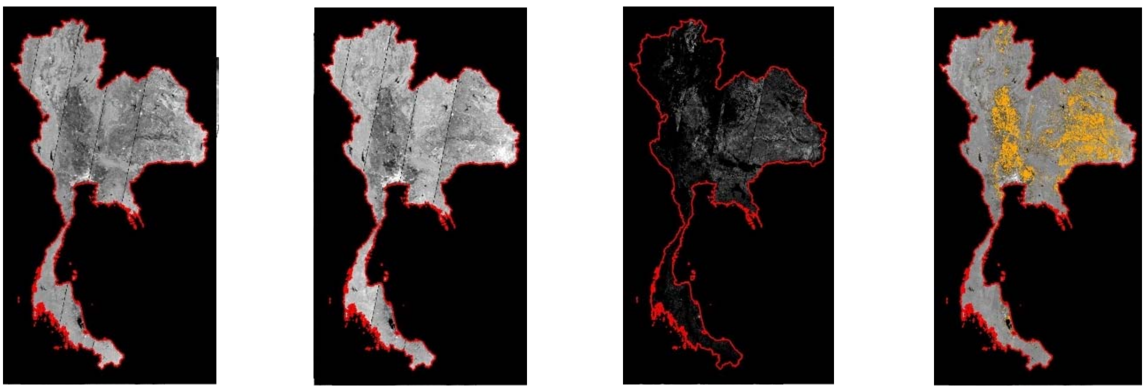
Table 3.1 Validation results using data from the field survey in Khon kaen in 2011

	Acreage [m^2]	Yield [g/m^2]	Production [ton]
Estimation value	164,405.99	(203.96)*1	33.53
Validation value	166,766.39	2.47 – 750.08	40.96
Accuracy of estimation	98.58%	-	81.87%

*1: The statistic information was used to estimate the production.

In the second year of the JAXA-GISTDA collaboration in 2012, the methodology of estimating rainy season rice crop acreage using SAR was updated and applied at the Suphan buri province in Thailand. Suphan buri is located in the central region of Thailand, and features mostly irrigated rice paddy's.

In addition to fine-mode (high-resolution) SAR, wide-mode SAR data (ScanSAR) was used to make wall-to-wall estimates of the acreage and production of Thailand's rainy season rice crops. The satellite data used was from ALOS PALSAR and was provided by JAXA. ScanSAR mode (HH polarization) was used, which provides a 100m spatial resolution, and a 350km observation swath width. Although ScanSAR data is coarser, monthly updates for the entirety of Thailand can be achieved. And, it is useful to estimate rice crop area in provincial level. The results of the analysis using ScanSAR data is shown in Fig. 3.2. Imagery collected in 2009 was used, with the planting stage defined as April to August, and the well-grown stage was taken to be August to November. Non-vegetation area and high altitude land were masked-out using MODIS NDVI and SRTM DSM. By comparing with statistical information provided by Thailand's Office of Agricultural Economics (AOE), an accuracy of more than 70% was confirmed in 37 provinces in 76 provinces. In the future, it is suggested that the methodology be improved by conducting field surveys in other areas that have different local situation than Khon kaen or Suphan buri.



Minimum value image for planting stage

Maximum value image for well-growing stage

Difference image between planting stage and well-growing stage

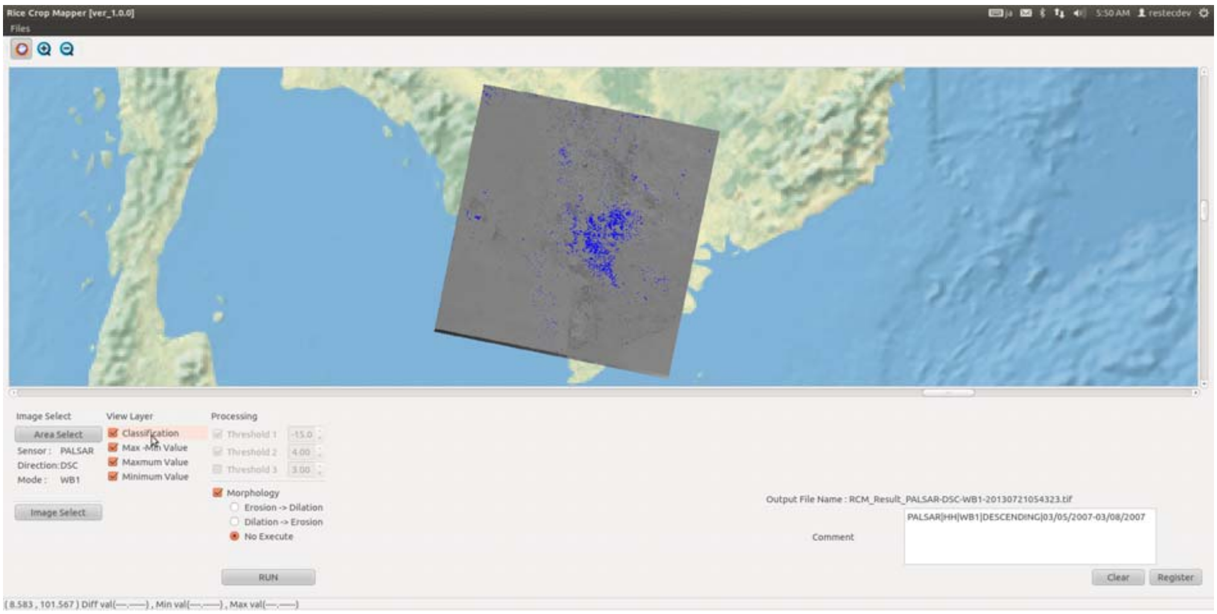
Estimated area of rice crop

Figure 3.2 Results of the analysis using ScanSAR

Finally, the software for estimating rice crop acreage and production called INAHOR was developed using the above methodology. INAHOR will be applied to Vietnamese and Indonesian sites under JAXA and the countries' joint projects as part of the APRSAF SAFE prototyping and the GEOGLAM Asian rice crop team activity (Asia-RiCE).

In the future the aim is to develop the system for use in GEOGLAM/Asia-RiCE. Asia-RiCE was launched by JAXA after the agricultural ministers' 2011 G20 meeting in Paris, France, during which it was decided to launch AMIS and GEOGLAM. The Asia-RiCE team aims to start operational rice crop monitoring in Asia from 2017, and is currently in the Phase 1 stage (proof of concept). In Phase 1, four 100km x 100km technical demonstration sites were selected in Indonesia, Thailand, and Vietnam (North and South). These sites are being used to verify the rice crop monitoring methodology using statistical information, ground (in-situ) observations, computer modelling, SAR, and other space-based observation data. The results of a study on Southern Vietnam's An Giang province Asia-RiCE Technical Demonstration Site (TDS) that used 2007 wet season rice crop ALOS PALSAR data is shown in Fig. 3.3.

Figure 3.3 Example of INAHOR at Southern Vietnam's An Giang province



Asia-RiCE, led by JAXA, has also started to provide rice crop outlooks in Thailand, Vietnam and Indonesia for FAO AMIS. The work-flow for making these rice crop outlooks is shown in Fig. 3.4. JAXA provides satellite weather information to statistical experts in each country in cooperation with AFSIS through the web system called JASMIN. The statistics officers make rice crop outlook report using ground-based observation data, field surveys, statistical information and JASMIN. AFSIS compiles the three countries' outlook text and provides it to the Asia-RiCE team for review. During the review, some additional outlook information derived from monthly satellite data is added. JAXA then posts the outlook to GEOGLAM through The University of Maryland (UMD) GEOGLAM outlook homepage. GEOGLAM also compiles monthly outlook reports for corn, wheat, and soybean.AMIS uses this information to publish their "Market Monitor".

Figure 3.4 Work-flow for making rice crop outlooks

RESTEC developed JASMIN to provide satellite weather information to statistical experts. The JASMIN user interface is shown in Fig. 3.5. Sample information provided by JASMIN is shown in Table 3.2. JASMIN displays information in maps and graphs, and the information includes information on current conditions and anomalies (deviations from past normal years) such as Precipitation, Solar Radiation, Land Surface Temperature, Soil Moisture, Drought Index (KBDI) (developed by The University of Tokyo) and Vegetation Index (NDVI). Data is updated twice a month.

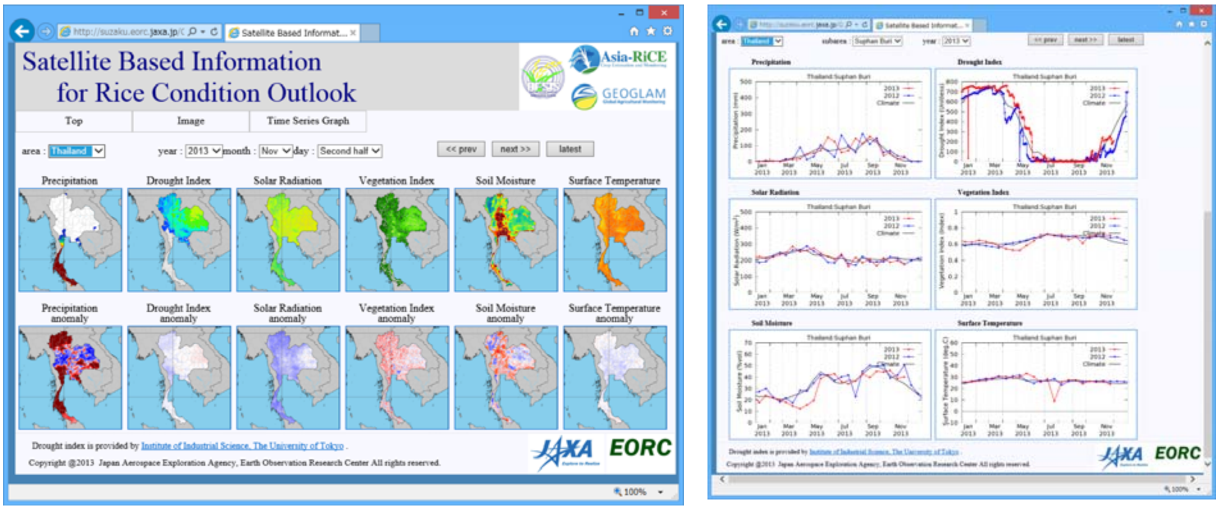


Figure 3.5 JASMIN user interface

Table 3.2 Information provided by JASMIN

Parameters	Interval	Spatial Resolution	Data Period (anomaly calc.)	Satellite Data Source
Precipitation	Cumulative (15-day)	10 km	2002- (2002-2012)	GSMaP (GCOM-W1, TRMM, MTSAT etc.)
Solar Radiation	15-day Average	5 km	2007- (2007-2012)	MODIS
Land Surface Temperature	15-day Average	5 km	2002- (2002-2012)	MODIS
Soil Moisture	15-day Average	50 km	2009- (2002-2012)	AMSR-E, WINDSAT
Drought Index	15th /31[30]th day of month	10 km	2003- (2003-2012)	GSMaP, MTSAT
Vegetation Index	15th /31[30]th day of month	5 km	2002- (2009-2012)	MODIS

4. Conclusions

RESTEC developed INAHOR and JASMIN under contract to JAXA. INAHOR is software that is used to estimate rice crop acreage and production using SAR data. JASMIN is a web-based system that provides satellite agricultural weather information to statistical experts for the purpose of making crop outlooks. JAXA and RESTEC are working to verify their methods of rice crop monitoring using EO satellite data for GEOGLAM/Asia-RiCE.

To improve accuracy of estimation, studies are being undertaken to better distinguish rice from other crops by analysing biomass in the well-grown stage, and analysing the period from planting to harvest, paying attention to the characteristics of cross polarization and analysing complex images with full polarizations. To estimate rice crop production with high accuracy, yield for each field type is require. Studies are underway to get yield from SAR data by using a correlation between biomass and the SAR backscatter. In addition, we also preparing to apply new SAR sources such as ALOS-2 and Sentinel-1. ScanSAR modes will be able to provide national-level statistical information of rice crop area and production in Asia.

Rice crop outlooks using the satellite weather information system JASMIN are not yet mature and it is expected that more knowledge will be accumulated. In the future, JASMIN will be expanded to support FAO AMIS outlook reporting for other ASEAN countries in cooperation with AFSIS.