MONITORING RICE CROP USING TIME SERIES SENTINEL-1 DATA IN GOOGLE EARTH ENGINE PLATFORM

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ABSTRACT: Rice is one of the major crops grown in Asian countries. Information on its temporal changes is very important for crop monitoring and yield estimation which in turn helps for food security and decision making. Synthetic Aperture Radar (SAR) data is highly suitable for monitoring rice crop, especially in tropical and subtropical areas, where pervasive cloud cover during the rainy seasons prevents the use of optical data. The SAR observations are sensitive to growth stages, leaf area index (LAI), biomass, crop height, soil moisture, and inundation frequency and duration. This makes SAR predominantly useful for mapping rice extent and monitoring rice growth. However, monitoring the rice dynamics requires an intensive multi-temporal data. Dense time series Sentinel-1 C-band SAR data at high spatial resolution offers new opportunities for monitoring agriculture. However, in operational level, several practical problems arise in agricultural monitoring using Sentinel-1 data. It requires processing and management of a large amount of satellite imagery that consequently leads to a ‘Big Data’ problem. In this present work, this problem is overcome with the Google Earth Engine which offers a cloud computing platform to access and seamlessly process a large amount of available satellite imagery. In this present research, time series Sentinel-1A Interferometric Wide (IW) Swath images are utilized to monitor rice crops across Bardhaman district of West Bengal, India. Time series phenological analysis of the Sentinel-1 data is then performed to assess rice information across the test site. The results indicate a low backscatter during transplanting stage due to the inundation. As rice crop grows from tillering to heading, the backscatter response increases proportionally with the increase in biomass. After ripening and near harvesting stage, a decline in backscatter is observed. The results show strong ability of Sentinel-1 data to assess and monitor rice crop for better decision making.

1. INTRODUCTION

Asian countries significantly depends on rice crop (*Oryza sativa*) which has a critical role in economy of this region. There are several initiatives viz. Asian Rice Crop Estimation and Monitoring (Asia-RiCE) and Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) (Hamamoto et al., 2016; Whitcraft et al., 2015) which initiates monitoring rice at a larger scale. The primary goals of these initiatives are to estimate production and potential risk information during the cropping season. Satellite remote sensing has played a key role in monitoring rice dynamics and food security initiatives. Remotely sensed data can help to monitor crop growth by providing precise and timely information on the phenological status and development of vegetation. They constitute a valuable tool for tackling those issues at different scales, from local to global extents, especially when combined with agro-hydrological models for studies related to crop yield (Duchemin et al., 2015; Baup et al., 2015), and agro-meteorology (Ferrant et al., 2014). In this context, remote sensing based time series analysis is a powerful tool to reveal rice dynamics and to analyze the magnitude of these dynamics within a defined monitoring time span.

Synthetic Aperture Radar (SAR) data is highly suitable for monitoring rice crop, especially in tropical and subtropical areas, where pervasive cloud cover during the rainy season prevents the use of optical data. Moreover, the SAR observations are sensitive to growth stages, LAI and biomass, crop height, soil moisture, and inundation frequency and duration (McNairn and Shang, 2016; Nelson et al., 2014). This makes SAR predominantly useful for mapping rice extent and monitoring rice growth. However, monitoring the rice dynamics requires an intensive multi-temporal data. Thanks to ESA’s Copernicus programme (European Commission, 2014) which provides operational Sentinel-1 data globally. The Copernicus programme includes simultaneous operation of dual sensors with interleaved 12-day revisit frequency from 2016 onwards for the next 15 years. It can lead to a dramatic scale up of the detail agronomic information (e.g., crop area, biophysical parameters, anomaly detection, etc.).

So far, a few studies have been reported using dense time series Sentinel-1 data for rice monitoring and mapping (Nguyen et al., 2016; Torbick et al., 2017; Chen et al, 2016). However, the presently operational Sentinel-1series satellites (Sentinel-1A, 1B, 2A, 2B, 3A) are generating up to a few petabytes of raw images per year. The increasing volume generates a “Big Data” problem, produces new challenges in handling datasets that necessitate new approaches to extracting relevant information from remote sensing data (Ma et al., 2015). Hence, the paper aims to explore the efficiency of using the Google Earth Engine (GEE) platform for temporal analysis of rice with the potential to apply the platform for a larger scale. The GEE provides a cloud platform to access and seamlessly process a large amount of freely available Sentinel-1 satellite imagery for crop studies (Lemoine and Olivier Léo 2015; Shelestov et al., 2017). Management practices, e.g., date of transplanting (late or early season) and flooding of rice field's response with SAR is also being studied for the test site using GEE platform. This strategy takes advantage of the Sentinel-1 dense temporal series and is particularly suited for monitoring even small farms. The paper focuses on the analysis of the temporal behavior of SAR backscatter coefficients of rice crop during the monsoon season in Bardhaman district of West Bengal, India with different management practices (e.g., transplanting date, inundation practice) and weather conditions (rainfall pattern).

2. STUDY AREA AND DATASET

The study area shown in Figure 1 is located in Bardhaman District of West Bengal, India and covers an area of approximately 7,024 km². The study region is mainly covered by arable lands (approximately 64.7%). The main cultivated crops are kharif rice (monsoon season rice), rabi rice (winter season rice) and potato.

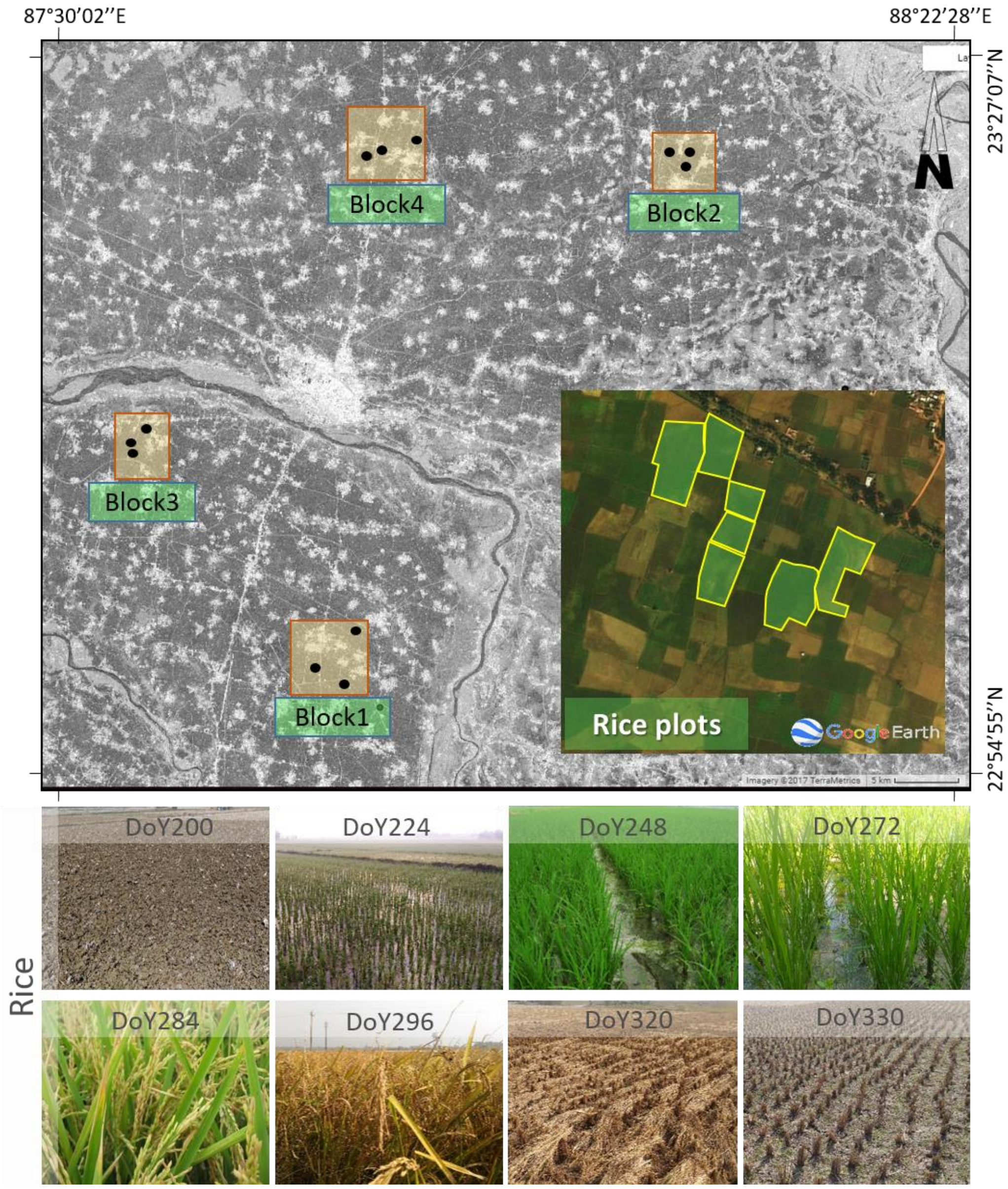

Figure 1: Study area at Bardhaman district of West Bengal, India in HV channel image (DoY224). Red polygons with yellow shade represents the Blocks. The location of each Site within a Block in this study is indicated by black points in the box itself. A zoomed portion of one site of Block1 is presents with field plots in green colour with yellow border. Photographs illustrating the different growth stages of rice fields (Block1) were taken during the in-situ measurements.

The present work is carried out over different rice plots for kharif rice (rainfed + irrigated). The rainfall pattern is different throughout the study area; especially the monsoon rainfall varies (early/late monsoon). Ground data were collected throughout the growing season which includes rice phenological stages as shown in Figure 1 for four Blocks distributed throughout the study area. For each Block 3 sites are considered and 6 sampling fields per site is being monitored during the in-situ measurement.

The satellite data used for this study is C-band dual polarized (VV+VH or HH+HV) Sentinel-1 SAR data. It is fetched from Google Earth Engine Image collection. This collection includes the S1 Ground Range Detected (GRD) scenes, processed using the Sentinel-1 Toolbox to generate a calibrated, ortho-corrected product. Each scene is pre-processed with Sentinel-1 Toolbox using the thermal noise removal, radiometric calibration, and terrain correction. The final terrain corrected values are transformed to decibels (dB) via log scaling and quantized to 16-bits. In this present work, VV+VH polarized data with Interferometric Wide (IW) mode is considered for rice monitoring. The time series data spans from July-December (Monsoon season) with the acquisitions on 18/07/2016, 11/08/2016, 04/09/2016, 28/09/2016, 10/10/2016, 22/10/2016, 03/11/2016, 15/11/2016 and 09/12/2016.

3. RICE GROWING STAGES AND MANAGEMENT PRACTICES

Rice is mainly cultivated in irrigated or lowland rainfed conditions. The total growing period of different rice varieties ranges from 90 to 140 days. During this growing period, the major phenological stages of rice are (1) Leaf development; (2) tillering; (3) stem elongation; (4) heading; and (5) grain development and ripening. The rice phenological stages over different Test Fields of Bardhaman district is shown in Figure 2. Apart from the rice physiology, agronomic management influences SAR backscatter signal. In the transplanted system, rice seedlings are grown in a seedbed for about 20 days, and then, the rice seedlings are transplanted in a hill configuration at about 2-3 plants per hill with a spacing of 20 × 20 cm. Prior to transplanting, the rice field is flooded with water at depths ranging from 2 to 15 cm. After transplanting, the recommended practice is to keep the water level at about 3 cm and gradually increase it to 5–10 cm with increasing plant height. During ripening there is no standing water, but still, soil remains saturated.

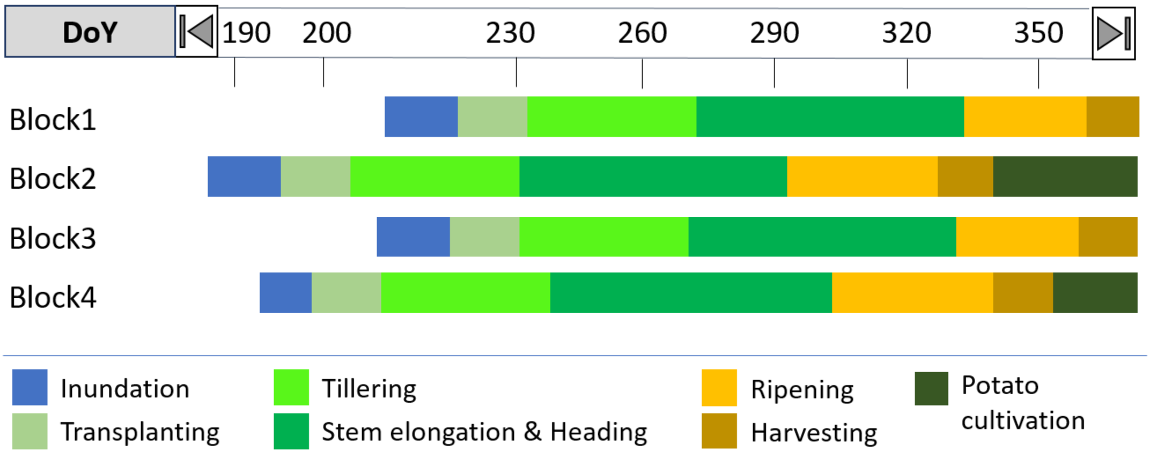

Figure 2: Rice crop calendar for different Blocks of Bardhaman district.

4. METHODOLOGY

The framework is developed under GEE platform which includes preprocessing of Sentinel-1 image collection followed by importing ground data points and temporal analysis of backscatter coefficients. Sentinel-1 data is acquired with several instrument configurations, resolutions, polarization combinations during both ascending and descending pass. Due to this heterogeneity, it requires to filter the data to a homogenous subset before processing. This process is carried out in GEE using the 'Metadata and Filtering' approach followed by a spatial filtering using a boundary of the study area. After this, a temporal filter is applied using '*.filterDate*' for specified scenes followed by a speckle filter (BoxCar 3×3 kernel) in GEE platform. Then speckle filtered images are stacked in two set of images i.e. VV stack and VH stack. After this, backscatter responses are plotted for each ground point locations and analyzed with respect to the rice growth stages. For each site an average over six fields is analyzed in this study.

5. RESULTS AND DISCUSSIONS

An RGB composite is generated with temporal data (R: DoY200VH; G: DoY224; B: DoY248VH) for visualization as shown in Figure 3. A significant variation in colour in different farm plots is observed which is due to variablity in growth stages of the rice and field conditions. Further temporal pattern in VV and VH polarization are shown in following plots for different Blocks.

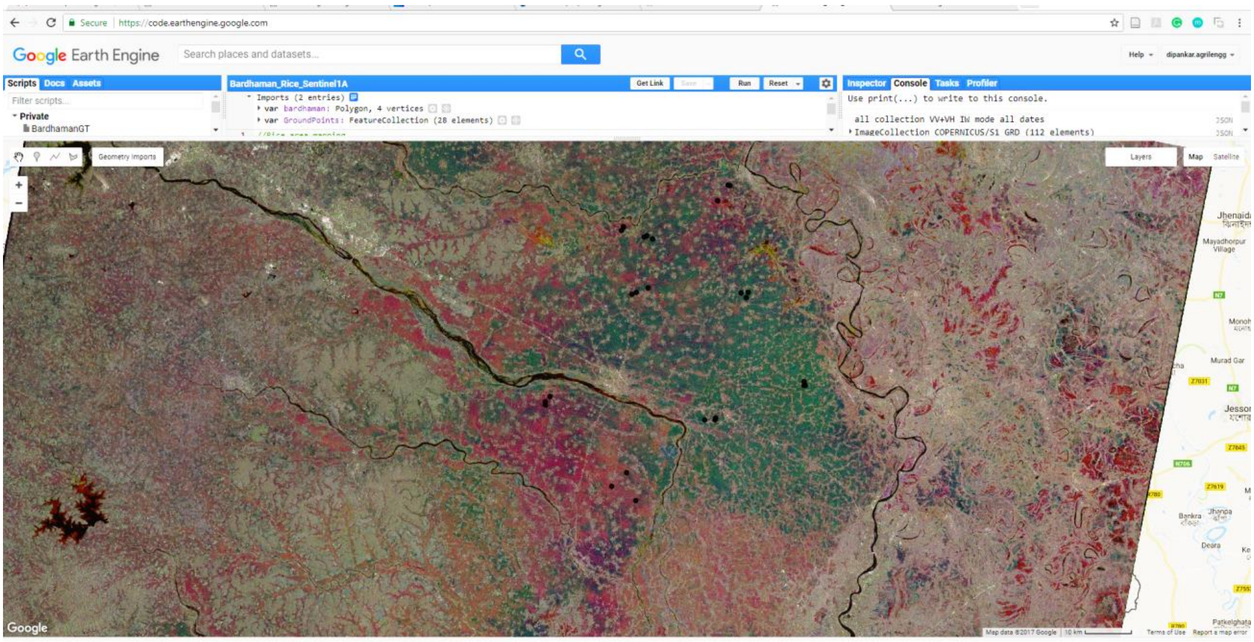

Figure 3: Temporal RGB composite of Sentinel-1 cross-pol channel data over study area (R: DoY200VH; G: DoY224; B: DoY248VH).

SAR backscatter response in linear co-pol (VV) and cross-pol (VH) throughout the growing season are shown in Figure 4 and 5. The backscatter intensities (dB) varies significantly for different blocks on a particular date as well as temporal scale. VV and VH backscatter from rice fields are relatively high on DoY200 for sites of Block 1 and 3. However the VV and VH backscatter coefficients are around -15 and -22.5dB for sites of Block2. It is mainly due to the difference in inundation practice over that fields. In Block 1 and 3, the fields were bare, or tillage was in operation; whereas early transplanting of rice is being practiced in sites of Block2. So, most of the rice fields in Block2 are inundated for transplantation. A significant low backscatter in rice fields may be due to standing water which causes a scattering of signal away from the radar. However, backscatter responses from the Block4 reveal normal rice cultivation practices, with inundation during DoY224.

A significant decrease in backscatter of VV and VH polarization (>10dB) is observed on DoY224 for all the Block except Block2. It is due to start of inundation and transplantation of rice seedling in fields. It is confirmed from in-situ data that in Block4 sites rice transplanting is started during DoY220, whereas Block 1 and 3 sites are inundated and fields are being prepared for transplantation (late transplantation). However, in Block2 sites an increase in backscatter coefficients are obsereved due to the start of vegetative growth (leaf development and tillering) of early transplanted rice.

After DoY224, an increase in VV and VH backscatter is observed for Block2 and 4 sites. This can be explained by increase in wet biomass of rice during tillering and stem development stage. The co-pol and cross-pol backscatter intensities as shown in Figure 4 and 5, increases from DoY224 with the main vegetative growth, e.g., tillering, stem elongation for rice crop. The increasing trend of backscatter intensities are found to be similar as reported by Nelson et al. (2014), which is due to increasing in wet biomass during vegetative growth. Backscatter is positively correlated with the dielectric constant of a target and thus typically, backscatter increases as water content in vegetation increases (McNairn and Shang, 2016). However, in Block1 and 3 sites still the backscatter intensities are low as compared to other Blocks, which is due to just transplanted or early tillering phase rice with low crop density and leaf area index.

Similarly, the backscatter intensity decreases with the decline of wet biomass, which can be observed after DoY320 with ripening stage of rice. However, an increasing trend in VV backscatter is observed for Block2 sites during

DoY344. It is due to cultivation of potato crop after the harvest of rice as shown in Figure 2. The fields were ploughed and partially saturated (no inundation) for bed preparation of potato crops.

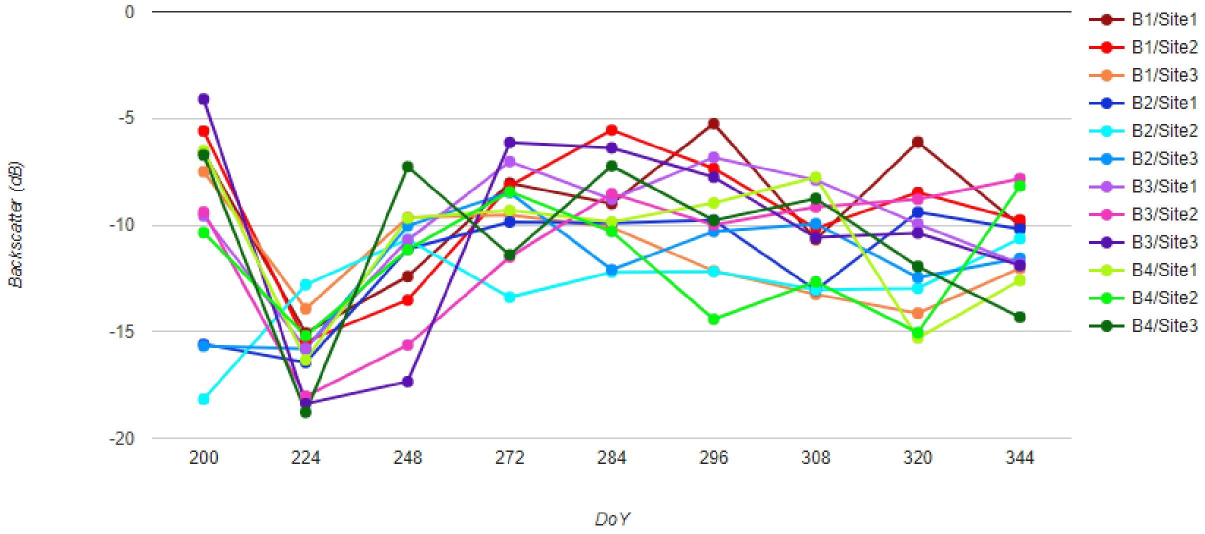

Figure 4: Temporal response of co-pol (VV) backscatter coefficients for different sites of each Block.

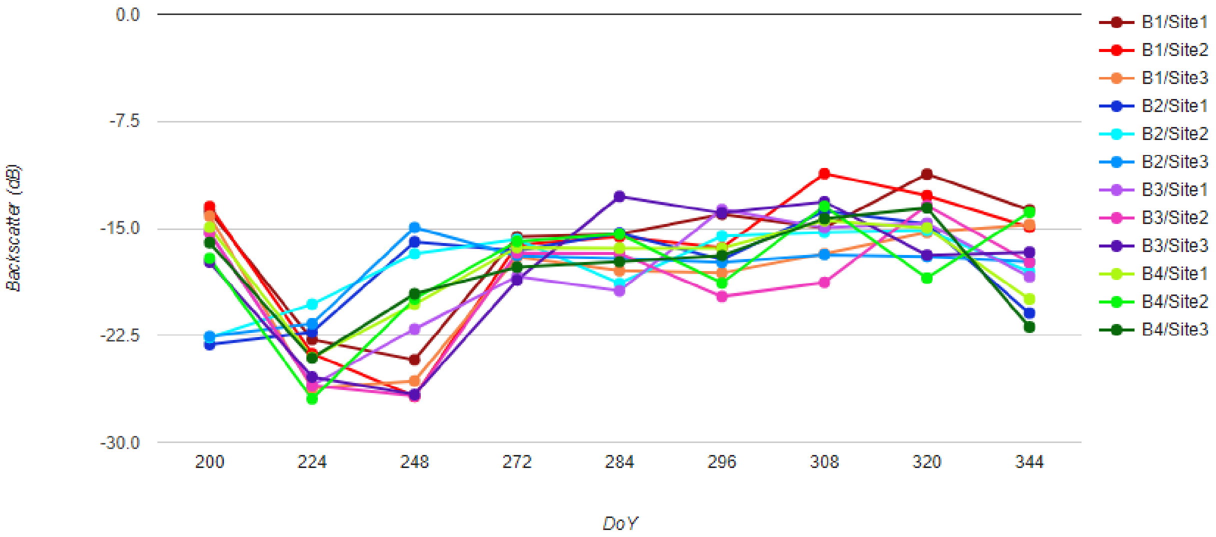

Figure 5: Temporal response of cross-pol (VH) backscatter coefficients for different sites of each Block.

Soil conditions (moisture and roughness) also affect microwave response. However, the contribution from the soil will depend on penetration depth which is determined by frequency and canopy development. One of the major advantage of the GEE platform is the processing of huge multitemporal data within a few seconds (~2.56sec.) Moreover, as the processing is performed over Google Cloud, there is no need for a high-performance workstation. Thus, the proposed technique is promising for rice phenology monitoring.

6. CONCLUSIONS

An approach has been demonstrated for rapid analysis of rice crop in temporal domain using GEE platform. Phenological approaches applied to time series Sentinel-1 SAR data allow for monitoring of rice with relevant information on crop inventory, inundation, and crop calendar. The sensitivity of C-band SAR to rice crop development and temporally observing inundation and dynamic range are the main drivers to enabling decision making and mapping of rice status information. This type of rapid analysis method has a crucial impact on our capacity to enumerate the food security programs such as AsiaRiCE, and GEOGLAM. Although a temporal analysis has been focused on GEE platform, a phenology based rice area mapping can be equally addressed which needs to be scale up in future.

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REFERENCE

Baup, Frédéric, Fieuzal, Rémy, Betbeder, Julie, 2015. Estimation of soybean yield from assimilated optical and radar data into a simplified agrometeorological model. IEEE International Geoscience and Remote Sensing Symposium (IGARSS). IEEE, pp. 3961-3964.

Chen, C.F., Son, N.T., Chen, C.R., Chang, L.Y. and Chiang, S.H., 2016. Rice crop mapping using Sentinel-1A. Phenological Metrics. ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, pp.863-865.

Duchemin, B., Fieuzal, R., Rivera, M.A., Ezzahar, J., Jarlan, L., Rodriguez, J.C., Watts, C., 2015. Impact of sowing date on yield and water use efficiency of wheat analyzed through spatial modeling and FORMOSAT-2 images. Remote Sens. 7 (5), pp. 5951–5979.

European Commission, 2014. The European Earth Observation Programme Copernicus, Retrieved August 30, 2016, from http://www.copernicus.eu/pagesprincipales/infrastructure/sentinels/.

Ferrant, S., Gascoin, S., Veloso, A., Salmon-Monviola, J., Claverie, M., Rivalland, V., Durand, P., 2014. Agro-hydrology and multi temporal high resolution remote sensing: toward an explicit spatial processes calibration. Hydrol. Earth Syst. Sci. Discuss. 11 (7), pp. 7689–7732.

Hamamoto, K., Sobue, S., Oyoshi, K. and Ikehata, Y., 2016, February. Rice crop growth and outlook monitoring using SAR in Asia. In AGU Fall Meeting Abstracts.

Lemoine, G. and Léo, O., 2015. Crop mapping applications at scale: Using Google Earth Engine to enable global crop area and status monitoring using free and open data sources. In IEEE International Geoscience and Remote Sensing Symposium (IGARSS), pp. 1496-1499.

Ma, Y., Wu, H., Wang, L., Huang, B., Ranjan, R., Zomaya, A., 2015. Remote sensing big data computing: challenges and opportunities. Future Generation Comput. Syst.51(1), pp. 47–60. doi: 10.1016/j.future.2014.10.029.

McNairn, H., and J. Shang., 2016. A review of multitemporal synthetic aperture radar (SAR) for crop monitoring. In: Multitemporal Remote Sensing. Springer, pp. 317–340.

Nelson, A., Setiyono, T., Rala, A.B., Quicho, E.D., Raviz, J.V., Abonete, P.J., Maunahan, A.A., Garcia, C.A., Bhatti, H.Z.M., Villano, L.S. and Thongbai, P., 2014. Towards an operational SAR-based rice monitoring system in Asia: Examples from 13 demonstration sites across Asia in the RIICE project. Remote Sensing, 6(11), pp.10773-10812.

Nguyen, D.B., Gruber, A. and Wagner, W., 2016. Mapping rice extent and cropping scheme in the Mekong Delta using Sentinel-1A data. Remote Sensing Letters, 7(12), pp.1209-1218.

Shelestov, A., Lavreniuk, M., Kussul, N., Novikov, A. and Skakun, S., 2017. Exploring Google Earth Engine platform for big data processing: Classification of multi-temporal satellite imagery for crop mapping. Frontiers in Earth Science, 5 (17), pp.1-10.

Torbick, N., Chowdhury, D., Salas, W. and Qi, J., 2017. Monitoring rice agriculture across Myanmar using time series Sentinel-1 assisted by Landsat-8 and PALSAR-2. Remote Sensing, 9(2), pp.199-221. doi:10.3390/rs9020119

Whitcraft, A.K.; Becker-Reshef, I.; Justice, C.O., 2015. A framework for defining spatially explicit earth observation requirements for a Global Agricultural Monitoring Initiative (GEOGLAM). Remote Sens. 7 (2), pp. 1461–1481.