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Short Communication

Modeling of rice crop biomass using Sentinel-1 backscatter coefficients: A case study over Nawagam, Gujarat

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Rice is one of the major crop grown in Nawagam region of Gujarat. Information on its temporal changes is very important for crop monitoring and yield estimation for policy makers at local as well as state level. The SAR observations are sensitive to growth stages, leaf area index (LAI), biomass, crop height, soil moisture, and inundation frequency and duration (Tan *et al.,* 2015). It is evident from the previous studies that backscatter response increases in accordance with crop growth cycle due to volume scattering. Analysis of Multi-temporal SAR data found to be more promising for discriminating different crop types by capturing dynamic random scattering occurring in crops throughout the entire growth cycle (Dave *et al.*, 2017). 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. In India, maximum net sown area falls under *kharif* season hence the usability of SAR data is quite high since the optical domain has a severe limitation for agricultural monitoring in cloudy conditions. Polarimetric data using empirical and semi-physical model plays a vital tool for crop biomass estimation (Carreiras *et al.*, 2012, Solberg *et al.*,2013, Wiseman *et al.*, 2014, Betbeder *et al.,* 2016). Initial studies have shown that the backscattering coefficient of rice obtained with space borne and airborne sensors presents obvious temporal variations corresponding to the high growth rate of rice plants. This temporal change in rice growth stages is crucial to distinguish different stages of rice crops (Tan *et al.,* 2017). However, the aforementioned information is limited to certain incidence angles, partial polarization, and particular satellite images. Multi temporal C band (4 GHz- 8GHz) (Wigneron *et al.,*1999) SAR gives appropriate results for low biomass crops but due to restriction in penetration depth high biomass crops are difficult to monitor.

Nawagam (22.77 ^{0}N, 72.56 ^{0}E), also known as the rice bowl of Gujarat is a rice cultivation farm under Anand Agriculture University, located in semi-arid region of west coast plains with rain-fed *kharif* rice and wheat in *rabi* as major crops. The soil at the station and its surrounding areas is medium black to very deep, poorly drained and salt affected. The annual mean temperature varies in range of 25^{o}C-40^{0}C. The annual precipitation is in range of 500 mm -750 mm. The study region receives 95–98% of annual rainfall from the south-west monsoon which generally starts in June and withdraws in late September. The Sentinel-1A IW Level 1 (L1) GRDH (ground-range detected, high resolution) product was used in this study. The Sentinel-1 C band (~ 5.40 GHz) SAR data has dual-polarization (VV and VH) with revisit time of 12 days. L1 data was pre-processed using ESA's open source 'Sentinel-1 Toolbox'. Pre-processing steps include orbit correction, geocoding, radiometric calibration and resampling(seehttps://sentinel.esa.int/web/sentinel/toolboxes/sentinel-1for a detailed description of the processing steps). Since this study is based on the investigation of (low-frequency) seasonal backscattering behavior, speckle ûltering was performed for temporal data sets. In the present study, we report the initial observations of temporal variation in backscatter coefficients ($\sigma_{VH,}\sigma_{VV}$), during different phenological stages of rice crop. Also, an attempt has been made to empirically model rice crop biomass using these data sets. Finally, all images are ortho rectified into map coordinates by simulating SAR image from the SRTM DEM 30m and using it to do co-registration. The image pixel size of the final data is about 10 m. Due to such high spatial resolution it is possible to monitor the change in backscatter at field scale. Since main rice research station at Nawagam, has well managed rice plots this study was carried out to investigate change in radar back scatter coefficients corresponding different phenological stages of rice.

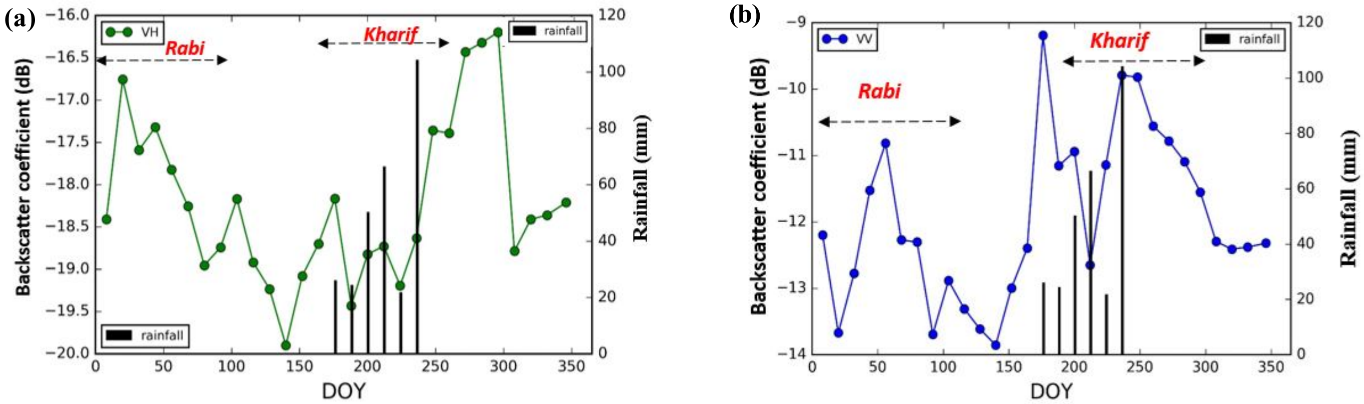

Fig. 1: Temporal variation of backscatter coefficient σ_{VH} and σ_{VV} over Nawagam, Gujarat

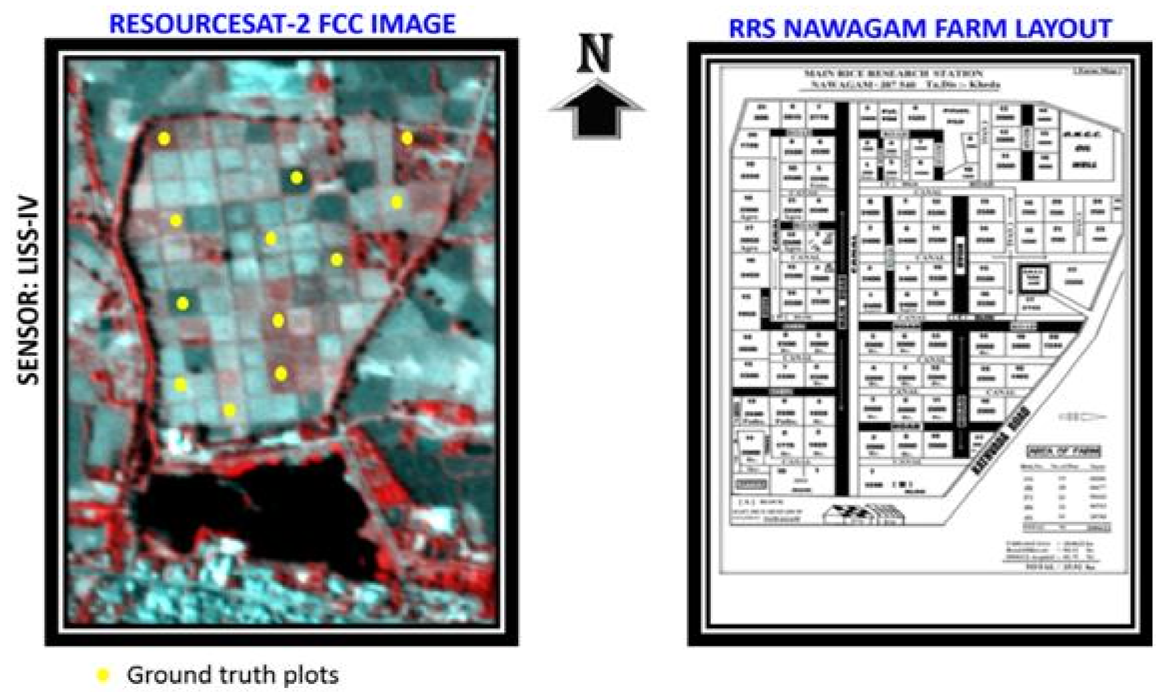

Fig. 2: Spatial distribution of Ground truth points over RRS Nawagam farm

Table 1: Field measurements during experiment period

Date	Canopy height(m)	LAI	NDVI
13th June	30.4	0.89	0.29
22nd June	65.6	0.96	0.31
8th July	78.9	1.19	0.36
18th July	86.4	1.36	0.39
7th August	96.5	1.89	0.41
18th August	104.6	2.47	0.46
9th September	110.8	2.89	0.53
18th September	116.4	3.45	0.56
3rd October	130.4	3.16	0.59
14th October	136.9	2.79	0.53

The temporal observation of rice growth is important for understanding the radar responses of rice plots at different stages of growth. Amplitude data is used for discrimination of various crop in the mixed crop scenario region. Paddy shows significant characteristic temporal profile which makes it easy to discriminate from other crops. There are three major periods of rice cultivation: the sowing period (starting according to the weather conditions from the end of May to mid-June), the growth period (up to September) and the harvest period (end of September to the beginning of October). Continuous water movement through irrigation compensates the variation of rainfall. VV and VH polarized backscatter coefficients (σ_{VV} and σ_{VH}) variation over selected rice ûelds during the study period are shown in Fig. 1(a and b) together with ground images. After sowing (mid-June) it

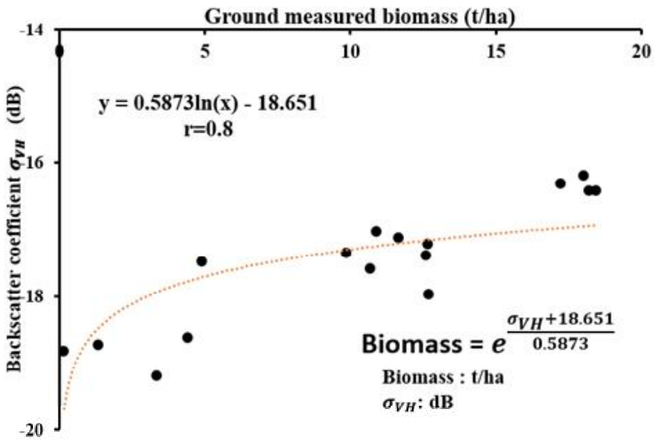

Fig.3: Relation between ground measured biomass and Sentinel-1A backscatter(σ_{VH})

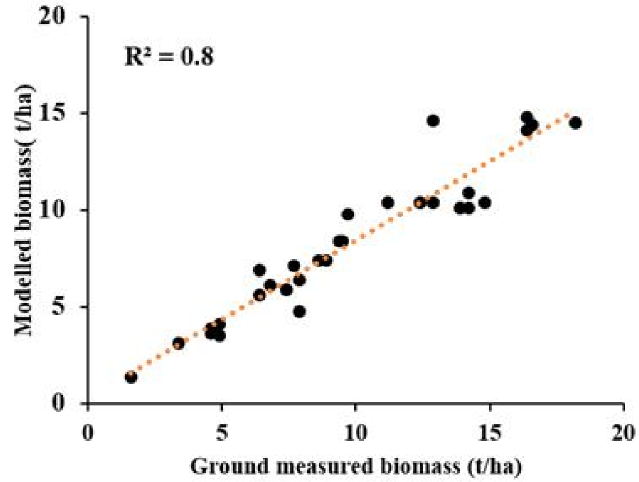

Fig.4: Validation of biomass model over Nawagam, Gujarat

was observed that from bare soil surfaces, there was very low backscattering at VH polarization than at VV polarization. Fig.1, shows the temporal evolution of the backscatter mean inside the rice fields. Both VV and VH shows same backscattering pattern, only intensity differs. The dip in the VV backscatter Fig. 1 (a) indicates the transplantation stage of rice where the backscatter ranges from -11 to -14 dB. The backscatter from paddy canopy increased up to -9 dB (shown in Fig. 1a) when plant volume increases and reaches peak vegetative stage. In VH, backscattering for paddy was in the range of -20 dB to -16 dB. The vegetated and ploughed fallow fields shows distinct profiles in VV when compared with VH polarization(Selvaraj *et al.,* 2019) Ploughed fallow because of high surface roughness shows high backscatter in the first date (Fig. 1 a, b), slightly started to decrease in the upcoming dates, as the continuous rainfall reduces the soil roughness. Both vegetated and ploughed fields shows constant backscattering from end of July to mid of Aug, and then backscattering response increases until it reaches its maximum on 250 DOY (approximately 70-80 days after sowing). This is because of again ploughing of smooth field and in vegetated field, this is due to the beginning of growth of rice crops(Selvaraj *et al.,* 2019). The NDVI is also found to be maximum during this period. NDVI is measured using VNIR SWIR portable field based Spectroradiometer. However occasional depression in VH polarized backscatter between DOY 170- DOY 240 corresponds to rainfall events which leads to change in soil moisture. The depression in VV backscatter during maturation is probably related to the disappearance of standing water in this period, as it can be seen from Fig. 1(a). The better temporal change in backscatter coefficient was observed in VH polarization and hence we limit our discussion to VH polarization only for biomass modelling.

Ground truth measurements of rice biomass were conducted in twelve reference plots at Rice Research Station (RRS) at Nawagam. A plot survey was carried out from May 2017 to November 2018 on the twelve rice reference plots selected to cover the variability of agricultural practices in this area as shown in Fig. 2. The reference plots were chosen in such a way that they could represent the rice fields in Nawagam farm and were not adjacent to each other. Ground truth data were collected in synchronous to satellite pass. The coordinates of the crop field were marked with GPS (Global Positioning System) receiver in that respect, the following measurements were made every ten days. Plant parameters like crop height, leaf area index of different crops and soil parameters like soil moisture and roughness were collected as mentioned in Table 1. The same crop fields were surveyed multiple times to observe the changes in crop phenology and minimum 5 sampling points per crop was collected.

The empirical model was developed using the relation between ground measured biomass and Sentinel-1A backscatter. It was found that, backscatter coefficients (σ_{VH}) have good correlation with ground observed biomass with the correlation coefficient of (R^2=0.8) (Fig.3). The higher values of biomass were observed in some plots which could be due to early sowing and different varieties of rice. The developed model was validated using independent dataset of ground measured biomass for the year 2017 and 2019 for the same region (Fig.4). It was found that during as canopy height LAI and NDVI increased, biomass also increased. It was observed that, the error in the estimated biomass was about 18.2%. This error could due to change in soil dielectric content of soil due the rainfall events and irrigation practices, which have affected the backscatter coefficients from radar. This study gives a beautiful insight on application of SAR data for monitoring crop phenology and biomass estimation in rice agro ecosystems. Further, attempt will be made to craft similar models for other crops such as wheat, sugarcane, jowar, bajra. This kind of approach will help us to overcome the constraints faced by optical data sets for biomass modeling during monsoon seasons.

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