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Behavior of Temporal Signature in VV (Vertical-Vertical) and VH (Vertical - Horizontal) polarization of Sentinel 1A SAR data for Rice crop

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ABSTRACT
A research study on 'Behavior of Temporal Signature in VV (Vertical-Vertical) and VH (Vertical - Horizontal) polarization of Sentinel 1A SAR data for Rice crop' was conducted during the rabi 2016 (Samba Season) in Tiruvarur district of Tamil Nadu. Multi temporal Sentinel 1A satellite data with VV and VH polarization at 20 m spatial resolution was acquired between September, 2016 and January, 2017 at 12 days interval. A dB stack was generated using eleven sets of Sentinel-1A data acquired after basic processing viz., orbital and radiometric correction, geo-coding, mosaicking and speckle filtering. Temporal signatures were extracted in VV and VH polarization for each monitoring field and used to generate the dB curves for rice fields for both VV and VH polarization. The dB values showed a minimum at agronomic flooding and a peak at maximum tillering stage and decreased thereafter. The dB values ranged from -12.76 to -9.95 for VV and from -19.25 to -15.15 for VH polarization with an average primary variation of 1.3 and 2.5 dB respectively.
Keywords: *Polarization, Temporal signature, mosaicking, spectral dB curve, Rice*

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INTRODUCTION
Agriculture is the backbone of Indian economy and the pivotal sector for ensuring food security. As per Statistics released by Government of India, during the year 2013-14, the State of Tamil Nadu secured first position in productivity of Maize, Groundnut and total Oilseeds, second in Sugarcane and third in Rice and Sunflower in the country. National Food Security Mission for Rice is implemented in 8 districts viz., Pudukkottai, Tiruvarur, Nagapattinam, Ramanathapuram, Sivagangai, Thanjavur, Tiruvannamalai and Cuddalore. During the year 2014-15, activities such as cropping system based demonstrations, distribution of certified quality seeds, farm machineries and agricultural inputs were taken up at Rs.25.04 Crore. During the year 2015-16, activities such as Demonstration on direct sowing method, line transplanting and distribution subsidy for high yielding paddy seeds are being taken up at an outlay of Rs.30.11 Crore. In the State, paddy is cultivated in about 21.00 L.ha, production is about 93.00 L.MT and productivity is about 4429 Kg ha^{-1}. Timely availability of information on agriculture is vital for taking informed decisions on food security issues. India is one of the few countries in the world that uses space technology and land-based observations for generating regular updates on crop production statistics and providing inputs to achieve sustainable agriculture. Satellite-based optical and radar imagery are used widely in monitoring agriculture crop. Radar imagery is especially used during monsoon season due to its capability to penetrate cloud and retrieve ground information. Remote sensing is beneficial because of its temporal frequency, scales of observation and variety of spectral bands that can be used to characterize and identify land management and land uses. In this study, the temporal signature for rice crop was generated using VV (Vertical-vertical) and VH (Vertical-Horizontal) polarization of Sentinel 1A SAR data.

MATERIAL AND METHODS
Study Area
Tiruvarur district is one of the 32 districts in the Tamil Nadu state of India. The district occupies an area of 2161 km^2. It lies between Nagapattinam district on the east and Thanjavur District on the west, and is bounded by the Palk Strait on the south (Fig. 1). Tiruvarur is located at 9.28̊ N and 79.3̊ E. It has a plain terrain of alluvial soil consisting of sand, silt and clay. Vennar and Vettar, the tributaries of river Cauvery are the major water source to the district. Surface water canals contribute 89% to irrigation, while the rest 11% is accounted by dug wells and tube wells. Paddy is the major crop while the others being black gram, green gram, groundnut and gingely. Tiruvarur receives an annual rainfall of 1,260 millimeters. It experiences tropical climate during summer from March to May. The proximity to sea results in high humidity throughout the year and peaks 70% from August to May. Paddy is cultivated in three seasons namely Kuruvai (June–August), Samba (August–January) and Thaladi (January–March). Being an agricultural district, the predominant industries are agriculture based like modern rice milling, palm oil refinery, poultry, live stock and coir based.
Satellite Data
Synthetic Aperture Radar (SAR) has the advantage of operating at wavelengths not impeded by cloud cover or a lack of illumination and can acquire data over a site during day or night time under all weather conditions. Sentinel-1A, with its C-SAR instrument, can offer reliable, repeated wide area monitoring. Sentinel-1A is a European radar imaging satellite launched in 2014. It is the first Sentinel 1 satellite launched as part of the European Union's Copernicus programme. It provides dual polarization capability, very short revisit times and rapid product delivery. For each observation, precise measurements of spacecraft position and attitude are available. The satellite carries a C-band Synthetic Aperture Radar which will provide images in all light and weather conditions with VV (Vertical–Vertical) and VH (Vertical–Horizontal) polarization and the data obtained at twelve days interval. Sentinel1-A has four standard operational modes, designed for interoperability with other systems. Level-1 ground range (GRD) product obtained by interferometric wide (IW) swath mode (1) of High Resolution (HR) is used for this research. The characteristics of IW1-GRD-HR product are given in Table1. In order to have a full coverage during the crop growing period of rice, the satellite data were downloaded for 19th September 2016 to 17th January 2017 at 12 days interval from https://scihub.copernicus.eu/dhus/.
Basic Processing of SAR Data for Multi-Temporal Analysis
A fully automated processing chain [2] will be used to convert the multi-temporal space-borne SAR SLC data into terrain-geocoded σ° values. The processing chain is a module within the MAPscape-RICE software. The basic processing chain included the following steps:

Strip mosaicking: To facilitate the overall data processing and data handling, single frames of the same orbit and acquisition date were mosaicked along their azimuth, generating long strips in slant range geometry. This step was performed exclusively when the SAR data were zero-Doppler focused.

Co-registration: Temporal Images acquired with the same observation geometry and mode will co-registered in slant range geometry. The co-registration was performed in three steps: (i) a gross shift estimation based on the orbital data; (ii) a set of sub windows was automatically identified based on a reference image and on the images to be co-registered, and subsequently, the shifts between pixels of corresponding sub windows were calculated, including elevation by means of cross-correlation; (iii) finally, the shifts to be applied in the azimuth direction and range direction were calculated by a polynomial function depending on the pixel position, respectively, in the azimuth and range.

Time-series speckle filtering: Within the multi-temporal filtering, an optimum weighting filter was applied to balance differences in reflectivity between images at different times [1]. Multi-temporal filtering was based on the assumption that the same resolution element on the ground was illuminated by the radar beam in the same way and corresponds to the same slant range coordinates in all images of the time series. The backscattering could change from one time to the next because of a change in the dielectric and geometrical properties of the elementary scatters, but should not change because of a different position of the resolution element with respect to the radar.

Terrain geocoding, radiometric calibration and normalization: A backward solution by considering a digital elevation model (DEM) was used to convert the positions of the σ° elements into slant range image coordinates. A range-Doppler approach is applied to convert the two-dimensional row and column coordinates of the slant range image into three dimensional object coordinates in a given cartographic reference system. During this step, the radiometric calibration was performed by means of the radar equation, in which scattering area, antenna gain patterns and range spread loss were considered. Finally, in order to compensate for the range dependency, σ° was normalized according to the cosine law of the incidence angle.

Anisotropic non-linear diffusion (ANLD) filtering: This filter significantly smoothened homogeneous targets, while enhancing the difference between neighboring areas. The filter used in the diffusion equation, in which the diffusion coefficient, instead of being a constant scalar, was a function of image position and assumed a tensor value [3]. In this way, it was locally adapted to be anisotropic close to linear structures, such as edges or lines.

Removal of atmospheric attenuation: Although microwave signals have the ability to penetrate clouds, it is possible that σ° from shorter wavelengths (X- and C-band) can be locally attenuated by water vapour in the range of several dB, because of severe (tropical) storms. The temporal signature of σ° can be affected by these events in two ways: (i) the thick layer of water vapour generates a strong decrease in σ° during the event, followed by a strong increase after the event; (ii) the intense rainfall generates a strong increase in σ° during the event, followed by a strong decrease after the event. These effects were removed by analyzing the temporal σ° signature: anomalous peaks or troughs were identified, and the σ° values were corrected by means of an interpolator. The correct application of this process relied strongly on *a priori* knowledge of the rice crop calendar and the weather conditions when the image was acquired.

Stacking of temporal SAR data (BSQ generation)

The data collected for the season were stacked using MAP Scape Rice software to retrieve temporal signatures. The stacking was carried out separately for VV (Vertical-Vertical) and VH (Vertical-Horizontal) polarization. Field observations were performed throughout the rice fields within the study area. Monitoring sites were fixed in major rice growing blocks of the study area and these fields were selected with the farmers' consent, prior to the start of the rice season and the image acquisition schedule. Observations were made on or as close to the image acquisition date as possible. Observations will include latitude and longitude from hand held GPS receivers, descriptions and photos of the status of the field, plant height, water depth, weather conditions and crop stage. Random stratified sampling method was adopted to collect Rice information at approximately 94 locations throughout the district. Locations were chosen such that the rice area was homogeneous in a 50 m radius around each GPS point for 20 m resolution imagery.

Results and Discussions

A dB stack was generated using eleven sets of Sentinel-1A data (Table 2) acquired after basic processing viz., orbital and radiometric correction, geo-coding, mosaicking and speckle filtering. Temporal signatures were extracted in VV and VH polarization for each monitoring field and used to generate the dB curves for rice fields for both VV and VH polarization. The temporal signature for a selected representative pixel in VV and VH polarization were presented in Fig.2. Both the VV and VH polarization signatures showed a minimum dB value at agronomic flooding and a peak at maximum tillering stage. At flooding, minimum dB value from -13.64 to -12.18 was recorded with an average of -12.55 and the average maximum value at peak tillering stage was found to be -10.47 with a range of -8.67 to -11.41 in VV polarization (Table 3) where as in VH polarization at flooding the minimum dB value ranged from -19.56 to -18.79 with an average of -19.23. At peak tillering stage in VH polarization average was found to be -16.35 with a range of -15.77 to -16.92 across Tiruvarur district (Table 4). Rice crop shows significant temporal behaviour and a large dynamic range (−14.4 to −8.41dB) during its growth period [4] [5] [6] [7]. The Minimum primary variation was found to be 1.3 and 2.5 dB corresponding to growth at vegetative and maximum tillering stage in VV and VH polarization respectively (Fig.3). The average db values curve derived from the selected rice points were shown in Fig.4.

The lowest values at emerging were due to less back scattering from less vegetation cover with rougher surface which was the moment to capture the start of the season for each pixel. This might be the due to soil moisture variation or sowing which made the soil surface smoother [8]. Nelson *et al*., 2014 recorded a similar minimum at early stage of rice crop with X-band (TerraSAR-X and Cosmosymed) SAR data across Asia in Philippines and Thailand.

Table 1. Characteristics of Sentinel1-A (IW1-GRD-HR) Data [9]

Parameters	Characteristics
Pixel value	Magnitude detected
Coordinate system	Ground range
Polarization options	Single(HH or VV) or Dual (HH+HV or VV+VH)
Resolution (range x azimuth in meters)	20.4x21.7
Pixel spacing (range x azimuth in meters)	10x10
Incidence angle (degree)	32.9
Radiometric resolution	1.7 dB
Ground range coverage (km)	251.8
Absolute location accuracy (m) (NRT)	7
Equivalent Number of Looks (ENL)	4.4
Number of looks (range x azimuth)	5 x 1
Range look bandwidth (Hz)	14.1
Azimuth look bandwidth (Hz)	327
Look overlap (range, azimuth)	0.250, 0.000
Bits per pixel	16

Table 2. Sentinel 1A data acquisition dates during Samba 2016 for Tiruvarur district

S.No	Date of Acquisition	S.No	Date of Acquisition
1	19 Sep 2016	**7**	30 Nov 2016
2	01 Oct 2016	**8**	12 Dec 2016
3	13 Oct 2016	**9**	24 Dec 2016
4	25 Oct 2016	**10**	05 Jan 2017
5	06 Nov 2016	**11**	17 Jan 2017
6	18 Nov 2016		

Table 3. Temporal dB values of Rice fields across Tiruvarur district (VV Polarization)

Satellite Pass no.	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Average
19-Sep-2016	-11.28	-10.19	-11.37	-10.58	-10.18	-10.85	-8.75	-11.66	**-10.6075**
01-Oct-2016	-12.18	-12.23	-12.69	-12.70	-12.31	-12.45	-12.22	-13.64	**-12.5525**
13-Oct-2016	-13.32	-11.09	-11.45	-12.10	-10.88	-12.98	-10.92	-12.94	**-11.96**
25-Oct-2016	-12.52	-10.19	-10.33	-11.60	-9.81	-11.83	-9.10	-11.67	**-10.8813**
06-Nov-2016	-11.65	-10.17	-9.85	-10.10	-9.55	-10.58	-8.42	-10.76	**-10.135**
18-Nov-2016	-10.33	-10.67	-10.10	-9.83	-9.58	-10.45	-8.54	-10.90	**-10.05**
30-Nov-2016	-10.38	-11.26	-10.74	-10.15	-9.87	-10.66	-8.67	-11.41	**-10.3925**
12-Dec-2016	-10.56	-11.12	-10.42	-10.95	-10.37	-10.89	-9.47	-11.48	**-10.6575**
24-Dec-2016	-10.67	-10.99	-10.52	-10.81	-10.92	-11.14	-10.45	-11.56	**-10.8825**
05-Jan-2017`	-10.99	-10.73	-10.97	-11.14	-11.01	-10.95	-10.63	-11.70	**-11.015**
17-Jan-2017	-11.81	-10.48	-11.73	-11.41	-11.10	-10.78	-10.82	-11.85	**-11.2475**

Table 4. Temporal dB values of Rice fields across Tiruvarur district (VH Polarization)

Satellite Pass no.	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Average
19-Sep-2016	-18.124	-19.277	-17.845	-17.763	-18.728	-17.886	-17.928	-17.702	**-18.1566**
01-Oct-2016	-19.732	-19.763	-18.983	-18.792	-19.01	-19.11	-19.564	-18.906	**-19.2325**
13-Oct-2016	-18.525	-18.839	-18.504	-19.009	-18.372	-18.904	-19.062	-18.824	**-18.7549**
25-Oct-2016	-17.582	-18.078	-18.072	-18.519	-17.815	-18.297	-17.972	-18.211	**-18.0683**
06-Nov-2016	-16.679	-17.887	-17.05	-17.626	-17.593	-17.857	-16.942	-17.343	**-17.3721**
18-Nov-2016	-16.179	-16.982	-16.485	-16.341	-16.583	-17.238	-16.313	-16.891	**-16.6265**
30-Nov-2016	-16.442	-16.327	-16.763	-15.769	-15.987	-16.746	-15.834	-16.921	**-16.3486**
12-Dec-2016	-15.902	-16.293	-16.417	-15.333	-16.066	-16.632	-15.547	-17.044	**-16.1543**
24-Dec-2016	-15.438	-15.697	-15.998	-15.234	-16.022	-16.409	-15.251	-16.171	**-15.7775**
05-Jan-2017`	-15.11	-15.557	-16.059	-13.931	-14.843	-15.329	-14.278	-15.074	**-15.0226**
17-Jan-2017	-15.455	-15.361	-15.979	-15.013	-15.652	-15.787	-15.224	-15.255	**-15.4658**

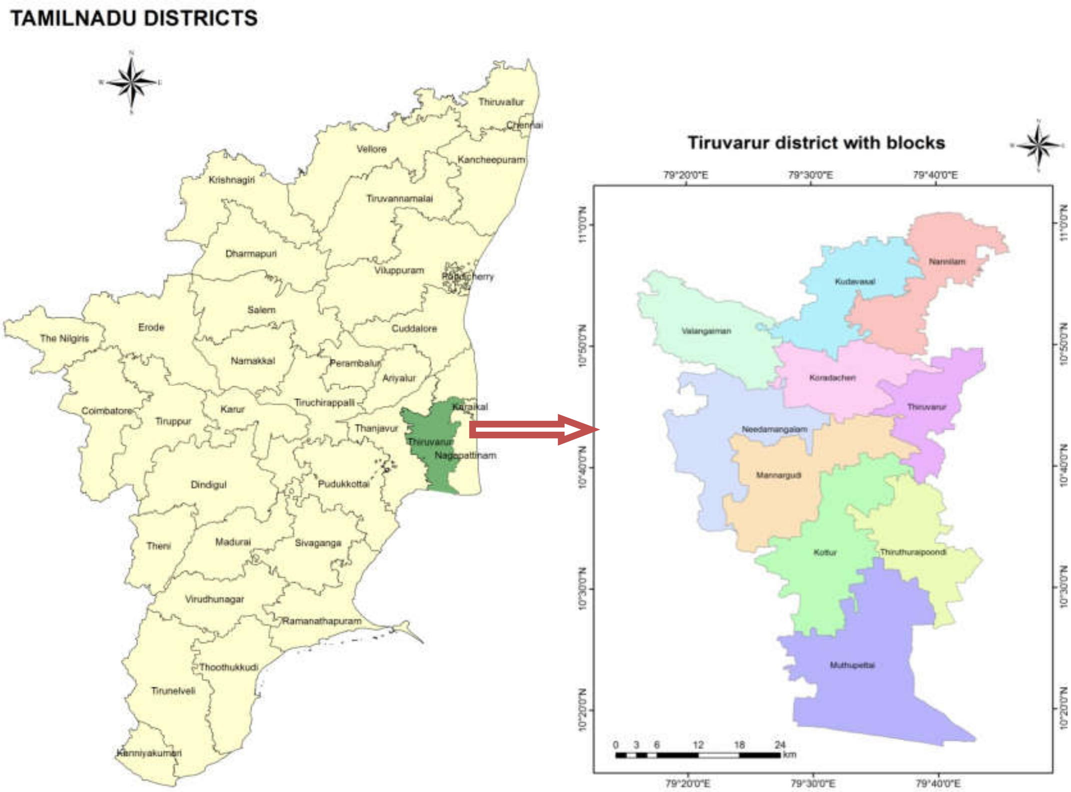
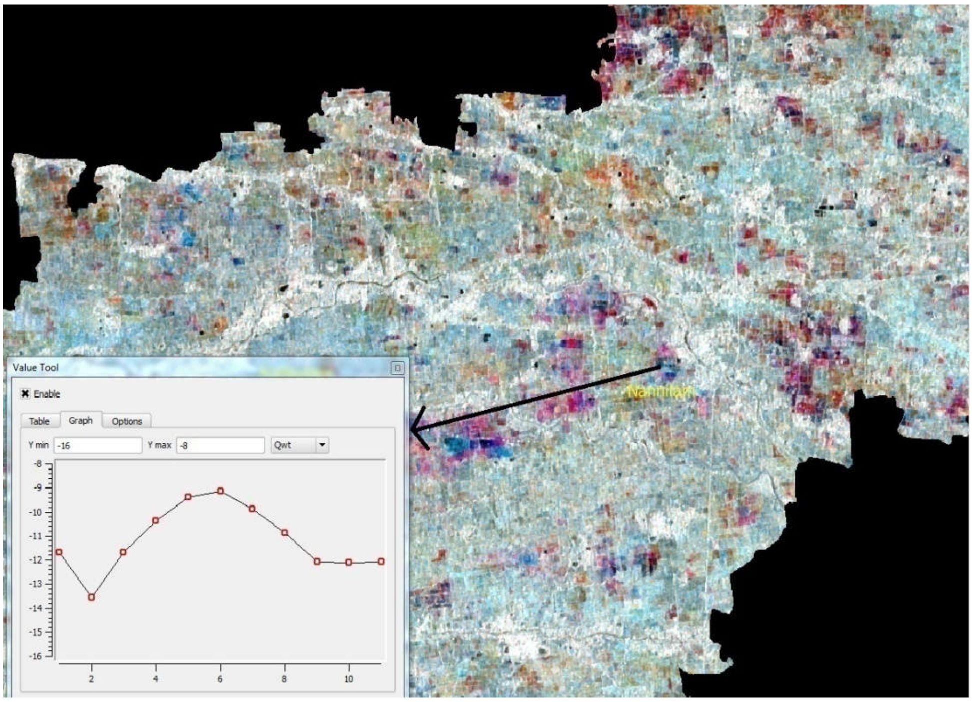


Fig.1 Location Map of Tiruvarur district in Tamil Nadu

(a)



(b)

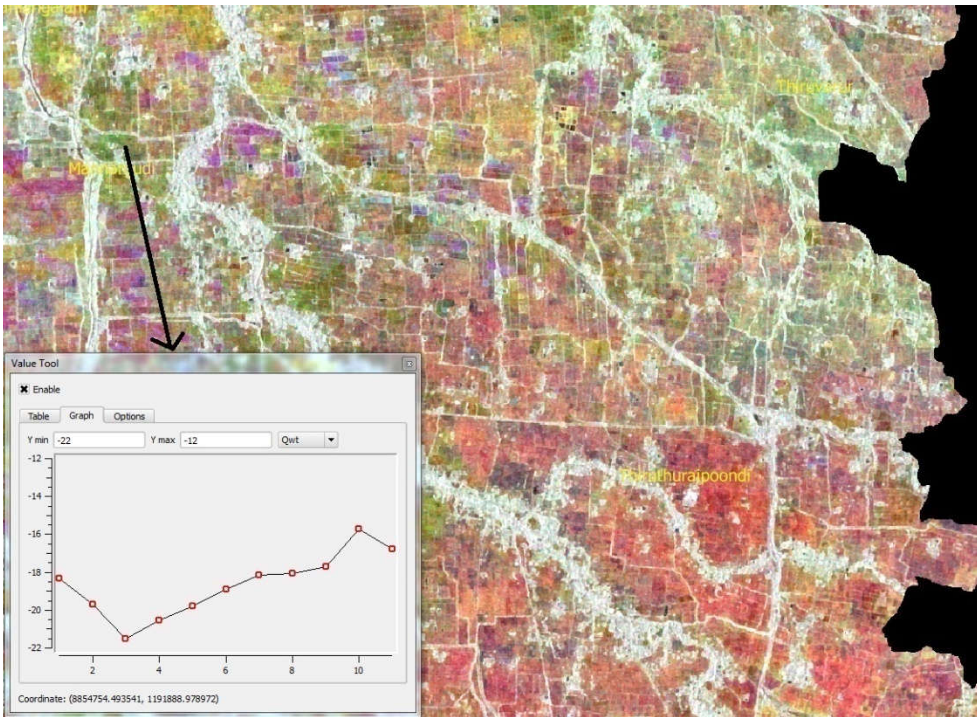
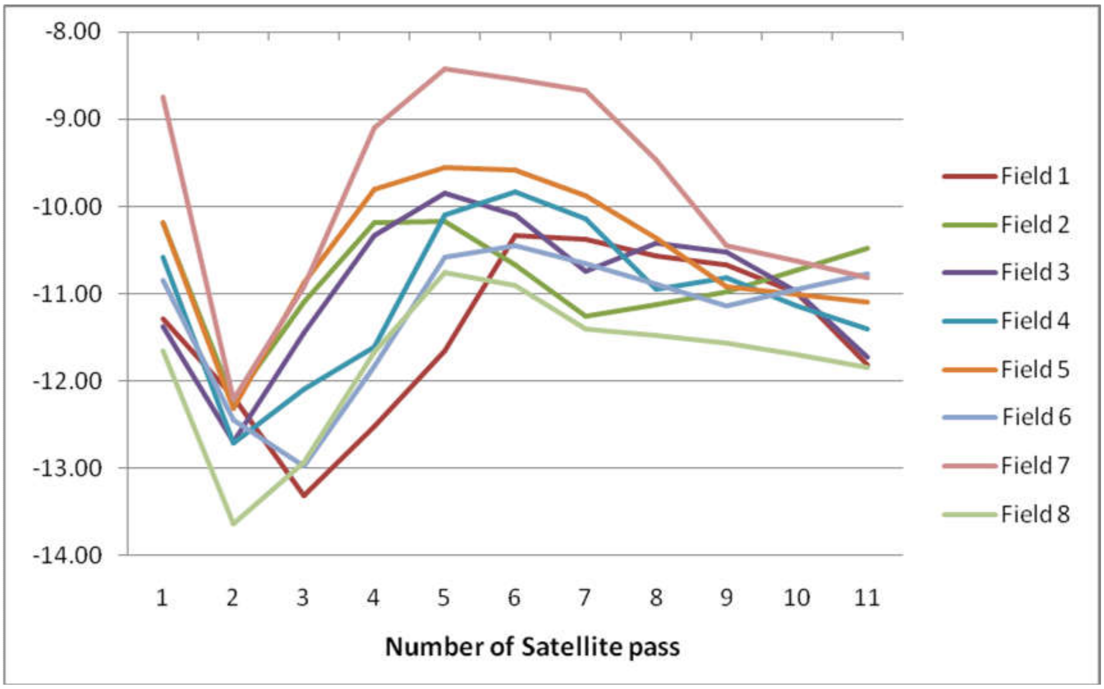


Fig.2 dB stack generate with Sentinel 1A data and Rice temporal curve (a) VV (b) VH

(a)



(b)

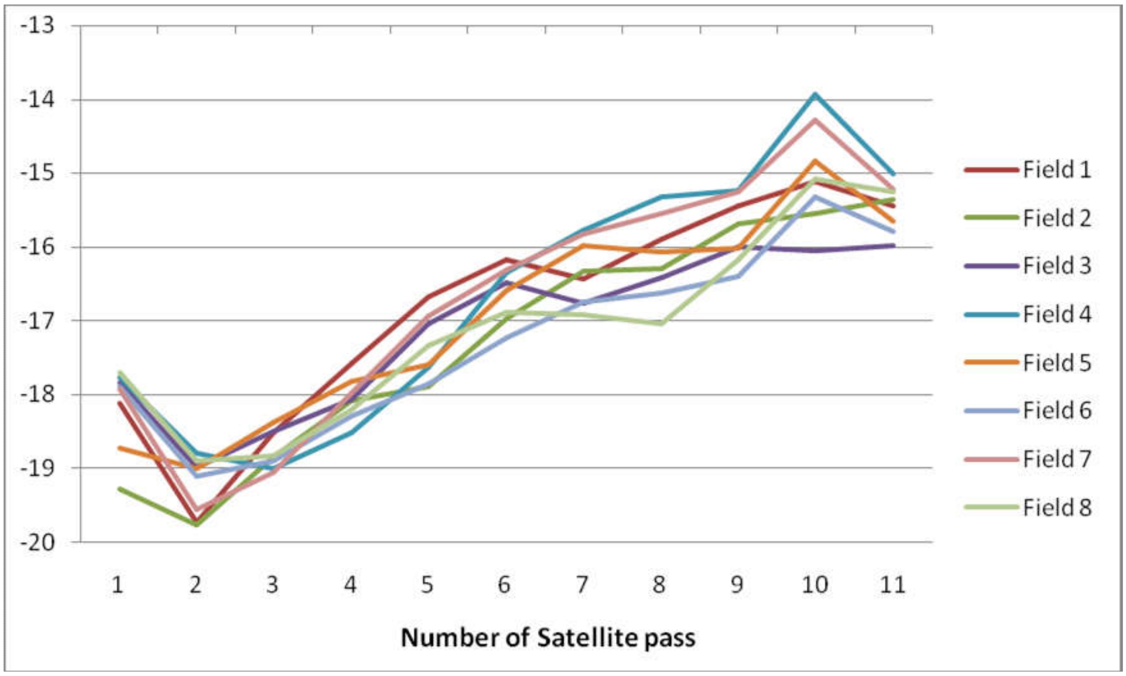


Fig.3 Temporal dB curves for rice at selected sites (a) VV (b) VH

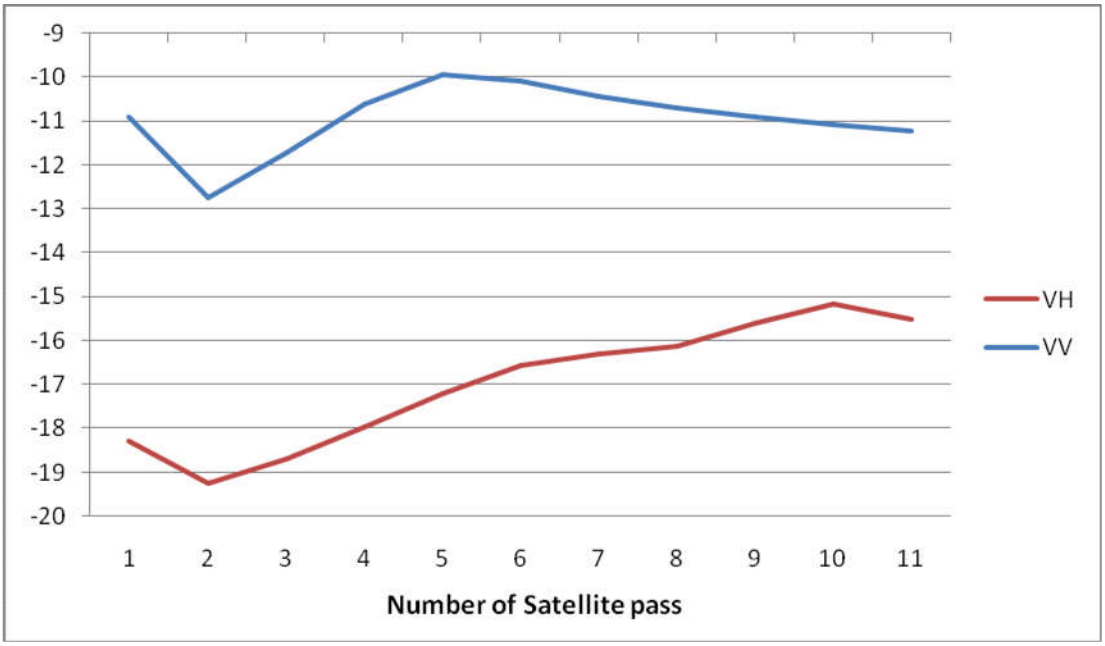


Fig.4 Temporal dB curve for Rice Crop Sentinel 1A

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