Crop phenology identification using NDVI time-series and its dissemination using WebGIS

Shweta Mishra*, Markand P. Oza and Shashikant A. Sharma
Space Applications Centre (ISRO), Ahmedabad
Email: jaiswals@sac.isro.gov.in

KEY WORDS:

OCM, Proba-V, FFT, Gaussian

ABSTRACT

Information of crop phenology is essential for crop management. Remote Sensing has been found to be one of the consistent and reliable ways for crop phenology estimation. Time series data of various vegetation indices derived from medium and high-resolution sensor data are widely used for vegetation monitoring on a global or regional level. Normalized Difference Vegetation Index (NDVI) is one of the popular indices to study vegetation phenology. NDVI time series is related to vegetation changes and follow annual cycles of growth and decline of vegetation. Using temporal analysis of smoothed NDVI series, it is possible to estimate cropping intensity, which is the numbers of crops (single, double and triple) per year in a unit cropland area. Although NDVI data sets are pre-processed to mitigate noises due to orbital and sensor degradation, still sum noise remains in the data sets primarily due to clouds and atmospheric variability. This necessitates filtering of the data. For smoothening NDVI curves two filtering methods namely, Gaussian filtering and Fourier Transform filtering algorithm based on harmonic analysis, were applied and compared. Using spatio-temporal analysis of smoothed NDVI series, variations in annual vegetation phenology were estimated. Based on annual crop cycles at particular pixel location, number of crops is estimated at that location. OCM and Proba-V NDVI data series of one agricultural year over Gujarat is used for carrying out this study.

It was found that Fourier transform based algorithm works better than the Gaussian filter for mitigating noise in temporal NDVI datasets. Multi crop were not detected in results obtained using Gaussian filter. While Fourier Transform based algorithm was able to detect multi crops. Automated module is developed for NDVI smoothing and crop cycle estimation. Finally output showing crop intensity in one agriculture year (2015-2016) over study area is derived and presented using Web-GIS technology.

1. INTRODUCTION

Agriculture and its allied sectors play a vital role in Indian Economy. To achieve food security for entire nation, proper planning and management of agriculture is required. Information of crop phenology is essential for crop management such as production estimation, supporting decisions about water supply etc. But it is not easy to estimate and evaluate it using traditional methods i.e. Agriculture Census. Remotely sensed time series data provides a regular, consistent and reliable measurement of vegetation response at various growth stages of crop. Information about the crop cycle (i.e. number of crops in a parcel of land and their planting & harvesting dates and date of peak vegetative stage) is essential for proper agriculture management (Patel and Oza, 2014). Various methods have been developed for detecting crops and vegetation phenology using time-series datasets of different Vegetation Indices (Sakamoto et al., 2004; Bradley et al., 2006; Patel and Oza, 2014; Dash et al., 2010). Study was done for determining annual and inter-annual variation in vegetation phenology in India using time-series data of the satellite measured index of terrestrial chlorophyll content (MERIS Terrestrial Chlorophyll Index) (Dash et al., 2010). Time Series data of Normalized Difference Vegetation Index (NDVI) is one of the well-known indices often used to study the vegetation phenology. NDVI Datasets from the MODerate-resolution Imaging Spectroradiometer (MODIS) sensor were used for extracting key elements i.e. no. of crops per year, crop growth cycle in a Gujarat region of India (Patel and Oza, 2014). Annual and inter-annual phenology trends were also derived using NDVI time series datasets derived from Advanced Very High-Resolution Radiometer (AVHRR) satellites (Bradley et al., 2006). These studies have been made possible because NDVI is highly correlated to the amount of green vegetation biomass. However, NDVI derived from remote sensing are accompanied by noise caused by cloud contamination and other atmospheric effects. These disturbances greatly affect the monitoring of land cover and terrestrial ecosystems and show up as undesirable noise (Chen et al., 2006). It is required to minimize the noise effects before using datasets efficiently and effectively for phenological studies. It is now standard procedure for many publicly available remotely sensed NDVI datasets to be composited before distribution (Carreiras et al., 2003). But even after pre-processing, noise still remains in NDVI datasets and requires further filtering for noise removal.

In last few decades, various techniques have been developed and used to reconstruct noise free Vegetation Indices (VI) time series data. These techniques include Best index slope extraction (BISE) (Viovy et al., 1992), Savitzky–Golay (Bojanowski et al., 2009; Chen et al., 2004), median filters (e.g. Vandijk et al., 1987), splines and weighted least squares (White et al., 2005), locally adjusted cubic-splines (Chen et al., 2006), the asymmetric Gaussian (Patel and Oza, 2014), and discrete Fourier transformation (DFT) (Dash et al., 2010; Geerken et al., 2005; Jakubauskas et al., 2001). Some of these techniques were evaluated by (Geng et al., 2014) using different types of multi-temporal NDVI data of AVHRR, Satellite Pour l' Observation de la Terre (SPOT) VEGETATION (VGT), and MODIS. They evaluated that Savitzky-Golay (S-G), the changing-weight filter (CW), and the Whittaker smoother (WS) techniques perform better than the other tested techniques. They found that best de-noise technique varies with different vegetation types and NDVI data sources.

Irrigation and multiple-cropping agriculture in India is a key component of economic development and poverty alleviation. Most of the multiple-cropped areas are irrigated and generally receive higher amounts of chemical fertilizers than single cropped and rainfed crop fields. Cropping intensity may have significant impact on irrigation water use (Frolking et al., 2006), biogeochemical cycle (Li et al., 2003) and climate. Cropping intensity varies substantially year by year, mostly driven by weather and climate, regional and global markets of crop production and individual farmer's decisions on crop cultivation. Therefore, there is a need to have accurate and updated estimates of multiple-cropping croplands for a region. The present study investigated the use of smoothed time series NDVI datasets in extracting crop phenological information (i.e. cropping intensity like single, double and multi crop) by interpreting temporal variations in spatial domain for crop calendar generation. WebGIS is distributed Information system which can disseminate spatial information simultaneously to multiple users in cost effective manner. It combines the capabilities of Internet and GIS (Mishra and Sharma, 2016). Thus, output thematic maps showing crop cycle intensity over study region are disseminated using WebGIS based application.

2. STUDY AREA AND DATA USED

2.1 Study area

The study area was taken as Gujarat states of India (Figure 1). It is located in the west of India between 20°N to 24°N latitudes and 68°E to 74°E longitudes. It has wide-ranging cropping pattern which include food grains & pulses, cash crops and oil seeds. Gujarat is the main producer of tobacco, cotton, cumin and groundnuts crops. Other major crop production include rice, wheat, mustard, jowar, millet, maize, tur, and gram (www.nfsm.gov.in). Multiple cropping systems are mainly practiced in the northern Gujarat. The rotation of winter wheat– maize and the relay intercropping of winter wheat–cotton is generally practiced in areas where a double cropping system is used (Patel and Oza, 2014)

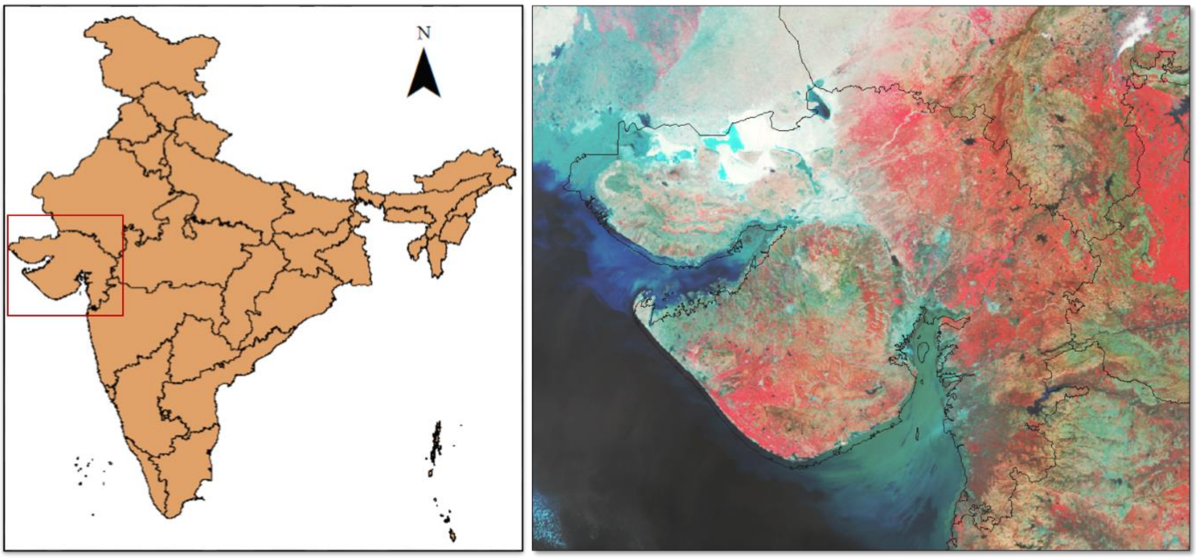

Figure 1: FCC of OCM data covering the study area (Gujarat, India)

2.2 NDVI

NDVI (Normalized Deviation Vegetation Index) exhibits the absorptive and reflective characteristics of vegetation in the red and near infrared portions of the electromagnetic spectrum. Therefore, changes in the NDVI time-series represent changes in vegetation conditions proportional to the absorption of photosynthetically active radiation (Sellers, 1985). Study of NDVI time series datasets enables dynamic assessment of crop vigour and crop condition and it has been used to estimate crop yields, drought monitoring and forest biomass among others (Sharma and Mishra, 2012). NDVI time series are related to vegetation changes and follow the crop cycle of vegetation. Therefore, it is used here to estimate cropping intensity i.e. single, double and triple crops per year in a unit cropland area. Values of the NDVI range between –1.0 and +1.0. NDVI is defined as

$$\text{NDVI}= (\rho_{\text{NIR}} - \rho_{\text{R}})/(\rho_{\text{NIR}} + \rho_{\text{R}}) \qquad (1)$$

where, ρ_{NIR} represents reflectance in Near Infrared region (NIR) and ρ_{R} in red region of electromagnetic spectrum, respectively. Downloaded NDVI datasets are stored as positive integer -Digital Number (DN) - values to reduce storage size. Thus, DN values were converted to NDVI values. For, PROBA-V datasets, the equation used is defined as below:

$$\text{NDVI} = (\text{DN} * 0.004) - 0.08 \qquad (2)$$

For OCM data, the formula is defined as below:

$$\text{NDVI} = \text{DN} / 200 \qquad (3)$$

2.3 Data Used

Two data sources were analysed for carrying out this research: (i) 15-day OCM NDVI composite datasets (ii) 10-day Proba-V NDVI composite datasets

OCM NDVI Datasets: Payload named Ocean Color Monitor (OCM) has 8 multispectral channels, which operate in Visible and Near Infra-Red range, and has swath of 1420 km. OCM NDVI products were generated at 1 km resolution (http://bhuvan.nrsc.gov.in/). The herein used data are 15-day NDVI time series data product derived from Oceansat-2 OCM. NDVI datasets of one agriculture year from June 2015 to May 2016 (26 datasets) were used.

Proba-V NDVI Datasets: The radiometric and geometric properties of Proba-V, in combination with atmospherically corrected products provide a substantial way for carrying out studies of this nature. Its swath of 2295 km ensures daily near-global coverage (90%) and full global coverage is achieved every 2 days. Final products disseminated have either 333m or 1km resolution. Segment products are L1C level Top of Atmosphere (TOA) products whereas syntheses products are single day S1 TOA + Top of Canopy (TOC) and 10 days S10 TOC products. S10 Syntheses TOC products have been used in the present study. Proba-V NDVI products are corrected for atmospheric constituents, such as aerosols and gaseous absorption. A NDVI datasets of one agricultural year (from June 2015 to May 2016) derived from Proba-V satellite were used (http://vito-eodata.be/).

3. METHODOLOGY:

The methodology used to extract and for dissemination of phenological variables from the NDVI time-series data consists of four steps: (i) Data filtering (ii) Data smoothing (iii) Crop intensity estimation (iv) WebGIS based dissemination.

3.1 Data Filtering:

Although NDVI data sets are pre-processed to mitigate noise due to orbital and sensor degradation, still clouds and atmospheric variability could lead to erroneous NDVI values. Hence, the first step was to remove or reduce such errors from NDVI time series datasets followed by temporal smoothing. A temporal moving average window function is utilized to correct erroneous value at every pixel in all datasets. For each pixel, the NDVI value at time 't' (F(t)) is checked for its correctness. If it is 20% (threshold) dropout than previous NDVI value, then an average (F(t)) of the immediate temporal data neighbourhood of NDVI values at times 't-1' and 't+1' is calculated. In this study, a threshold of 20 percent was used (Viovy et al., 1992; Patel and Oza, 2014). NDVI indicates the gradual crop growth and Sudden rises or falls in NDVI are not attuned with the gradual process of growth, but may be due to atmospheric variability or sensor viewing geometry. Concept behind using this method is to eliminates high frequency 'noise' values and allows genuine changes in NDVI. The neighbourhood check is limited to one temporal neighbour in order to preserve the trend in NDVI values. The equation is as follows:

*F'(t) = [F(t-1) + F(t+1)] / 2; if F(t) < F(t-1) - F(t-1) * 0.20* (4)

3.2 Data smoothing

The raw NDVI time-series data included errors that were minimized by applying a smoothing algorithm. Various techniques have been developed and used for temporal interpolation of erroneous or missing data in a time-series. Most of these techniques require an iterative approach to adjust the model parameters such as noise-threshold and size of temporal neighbourhood to achieve reliable smoothing (Atkinson et al., 2009) and most of the time these adjustments are not static due to phenological variation within and across land cover classes (Dash et al., 2010).

In this study, two methods have been analysed and compared for smoothing of NDVI datasets: (i) Gaussian Filter (ii) Fourier transform based on harmonic analysis.

Gaussian Filter: Gaussian filter is a linear smoothing filter that is used to remove detail and noise from images. Gaussian filter smooths in such a way that each pixel get replaced with a weighted average of the neighbouring pixels such that the weight given to a neighbouring pixel decreases monotonically with distance from the central pixel. This property is important because smoothing operation that gives more significance to pixels farther away will distort the features (Jain et al., 1995). For this study, 5-point Gaussian Filter was used.

Discrete Fourier Transform: Fourier analysis provides analysis of the vegetation phenology using only the amplitude and phase of the most important periodic components (Mingwei et al., 2008). Data in time domain can be decomposed into frequency domain using Fourier analysis. Here, frequency information is represented as constituent sine and cosine functions. Spectrally decomposed signals can be converted back to the time domain using an inverse Fourier transform. If the original data is discrete and available at specific and regular intervals, then the discrete Fourier transform (DFT) is used. (Moody and Johnson, 2001). Fourier transform approach have advantage of minimal user input as it only requires number of harmonics for reconstructing time series datasets (Dash et al., 2010).
Any time series can be expressed as a combination of cosine and/or sine waves with differing periods and amplitudes.

Discrete Fourier transform is defined by Eq. (6):

$$y_k = \frac{1}{N}\sum_{k=0}^{N-1} c_k \, e^{-i2\pi k}/N \tag{5}$$

where N is the number of samples in the time series, k is an index representing the current sample number, i is an imaginary number, and c is the kth sample value. Applying Euler's equation, Equation is expanded a Eq. (7):

$$f(x) = a_0 + \sum_{k=1}^{n} \left(a_k \cos\frac{2k\pi n}{N} + b_k \sin\frac{2k\pi n}{N}\right) \tag{6}$$

Here, a_0 is the mean,a_k and b_k are kth-order harmonics. Eq. (7) consists of two parts cos (real) and sine (imaginary)) where Cosine part is:

$$\mathrm{y}(c) = \sum_{k=1}^{n} \left(a_k \cos\frac{2k\pi n}{N}\right) \tag{7}$$

Sine part is expressed as:

$$\mathrm{y}(s) = \sum_{k=1}^{n} \left(b_k \sin\frac{2k\pi n}{N}\right) \tag{8}$$

Using Equation (8) and (9), Fourier magnitude is calculated as:

$$y_m = \sqrt{y^2(c) + y^2(s)} \tag{9}$$

Phase is defined as:

$$y_{p=\tan(y(s)/y(c))} \tag{11}$$

To reconstruct the phenological signals from the Fourier transform it is needed to select the appropriate number of harmonics. The first two harmonics of the discrete Fourier transform (DFT) concisely summarize the amplitude and phase of annual and semi-annual cycles in time series datasets (Moody and Johnson, 2001). Using first two harmonics it may be difficult to represent a naturally varying phenological cycle. Double and multi crops cannot be represented using first two harmonics (Dash et al., 2010). First four harmonics could adequately represent uni-modal vegetation growth patterns (Jakubauskas et al., 2001). Dash et al. (2010) have utilized the first four harmonics to extract the "onset" or "end" of season in India. In the present study, six harmonics were considered to extract the phenology in agricultural areas. In this study, The DFT was applied to the OCM and Proba-V NDVI datasets on a per pixel basis for the study area. It was used for decomposing time-series datasets into frequency domain and six harmonics were used in the inverse DFT to generate a smoothed time-series and extracting double/ multi crops in region under study.

3.3 Crop Intensity Estimation

A peak finder algorithm was developed to find number of crops per pixel. Patel and Oza (2014) developed a peak finder algorithm to extract number of crops and same has been used in this study for deriving crop cycle over the study area. From the smoothed NDVI data, all the local peaks and troughs were identified. Conditions used for considering trough – peak – trough as a valid crop cycle is that its duration must be greater than 60 days and peak NDVI value is greater than higher of the two trough values by at least 0.1. Assumption taken here is that crop would be of at least 60 days.

A flow chart showing methodology followed is shown in Figure 2.

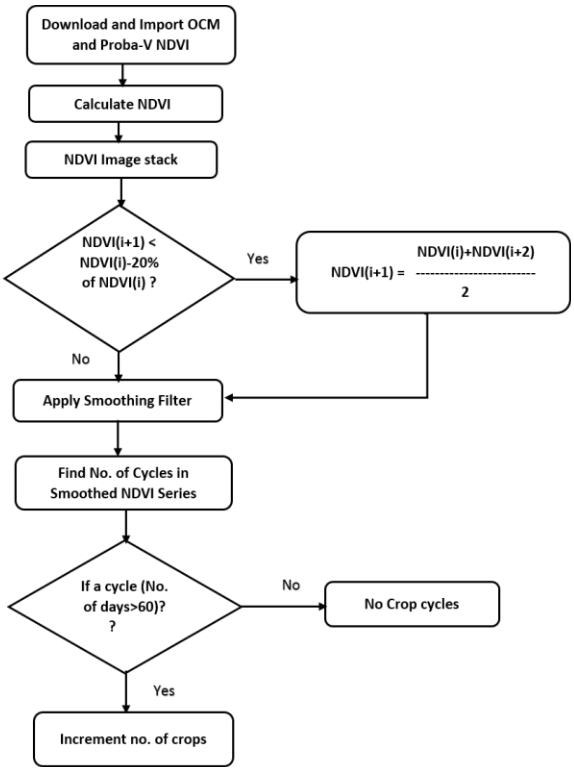

Figure 2: Flowchart for Crop Intensity Estimation

3.4 WebGIS based dissemination

WebGIS based application is developed for dissemination of generated Crop Intensity maps for Gujarat as Web Map Service (WMS). The WMS is Open Geospatial Consortium (OGC) standard which defines the interface for accessing geospatial data uniformly from remote servers in a standard format, such as Portable Network Graphics (PNG) and Joint Photographic Exerts Group (JPEG), Graphics Interchange Format (GIF), through Hypertext Transfer Protocol (HTTP). Application is developed using open source software and libraries i.e. GeoServer (http://geoserver.org), OpenLayers (http://openlayers.org), GeoExt and ExtJS (http://geoext.org). User interface of system is designed in such a way that it provides a very simple and interactive way of visualizing Crop Intensity maps along with other overlay layers. Overlay layers include Administrative Boundaries, Roads, Rivers and LISS-

III Mosaic (24m) etc. Thematic Layers were taken from Natural Resources Data Base (NRDB) (www.nnrms.gov.in) having GCS WGS84 projection. Styled Layer Descriptor (SLD) is used for visual portrayal of the geospatial Layers.

4. RESULTS AND DISCUSSION

For carrying out this work, 26 NDVI datasets (15-day composite) of OCM and 42 NDVI datasets (10-day composite) of Proba-V satellite of one agriculture year (from June 2015 to May 2016) were used and shown in Figure 3.

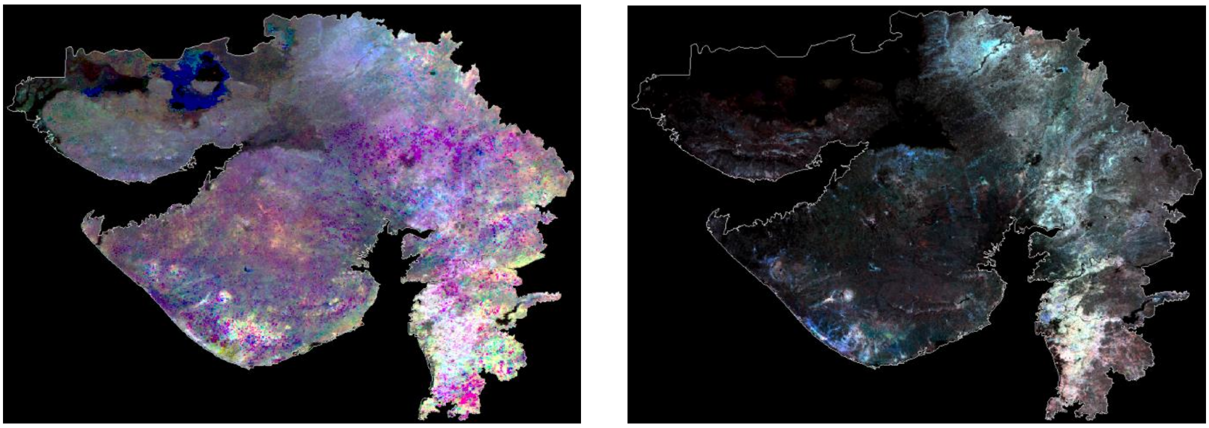

Figure 3: (a) OCM (15-day composite) and (b) Proba (10-day composite) NDVI Stack for June 2015 to May 2016

A graph in Figure 4 indicates the raw NDVI (for OCM) at one pixel. Fluctuating behaviour of raw NDVI requires indicate necessity of filtering and smoothing operations to obtain smooth data for further analysis. First step involves filtering (20% threshold). After filtering, fluctuations were reduced to some extent as shown in as shown in graph in Figure 4. performing smoothing methods were considered and analysed: The Gaussian filtering algorithm and the Fourier Transform filtering algorithm. Results obtained after applying both methods are shown in same graph in Figure 4. Results shows that the DFT is capable to detect inter-annual variations in better way as compared to results obtained using Gaussian filter. Same as been shown in graph and resulted classified image. Fourier Transform based algorithm could detect multi crops along with other crops. Thus, fast Fourier transform (FFT) has shown to be particularly useful for NDVI time series analysis to describe and quantify fundamental temporal characteristics. Same method has been applied for Proba-V NDVI dataset. Results for sample pixel are shown in graph in Figure 5. Here, Results indicates both DFT and Gaussian Filter can detect inter-annual variations. Figure 6 and Figure 7 shows the thematic images generated after applying DFT and 5-pt Gaussian Filter in OCM and Proba-V NDVI datasets respectively.

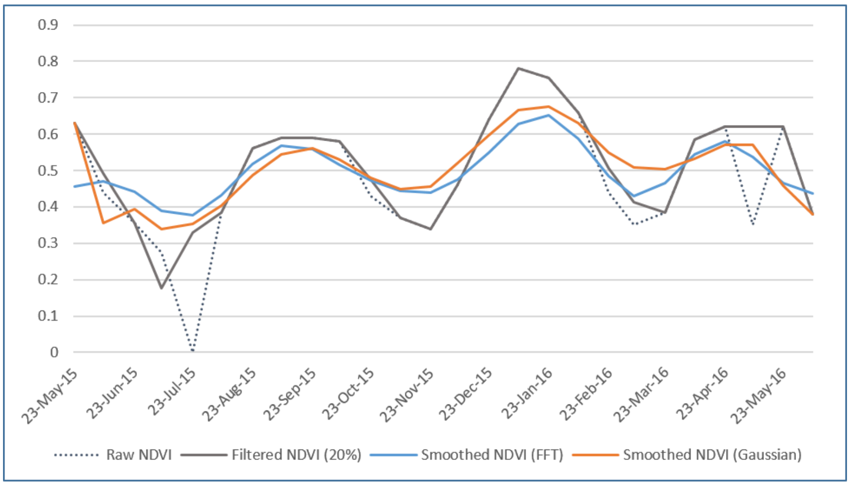

Figure 4 Spatial distribution of crops for Gujarat in 2015-16 using OCM (15-day composite) after applying (a) Discrete Fourier Transform (b) 5-point Gaussian Filter.

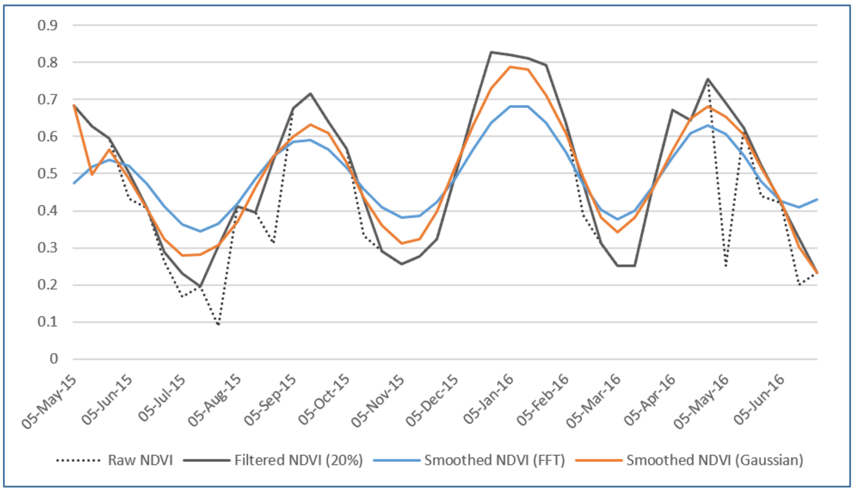

Figure 5: Spatial distribution of crops for Gujarat in 2015-16 using Proba-V (10-day composite) after applying (a) Discrete Fourier Transform (b) 5-point Gaussian Filter.

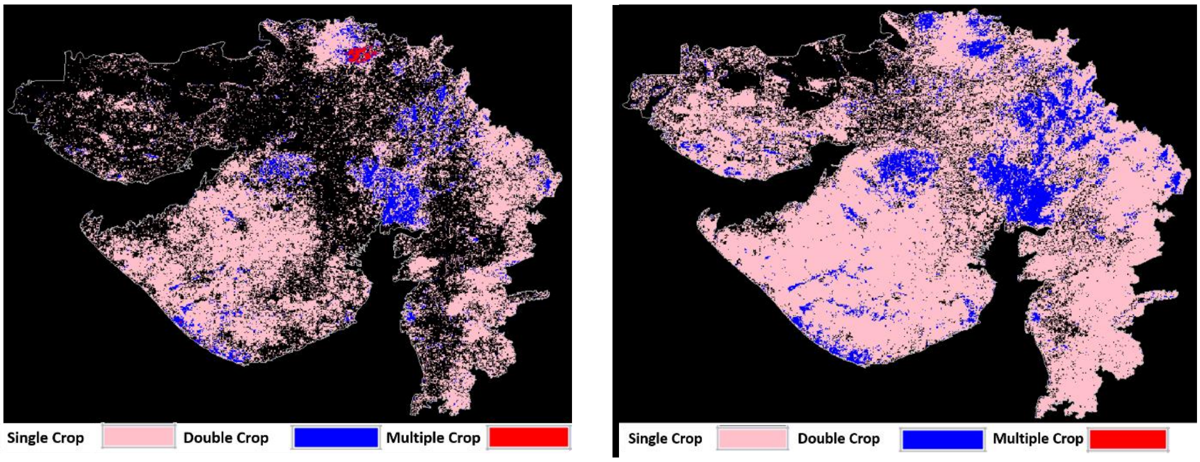

Figure 6: Spatial distribution of crops for Gujarat in 2015-16 using OCM (15-day composite) after applying (a) Discrete Fourier Transform (b) 5-point Gaussian Filter.

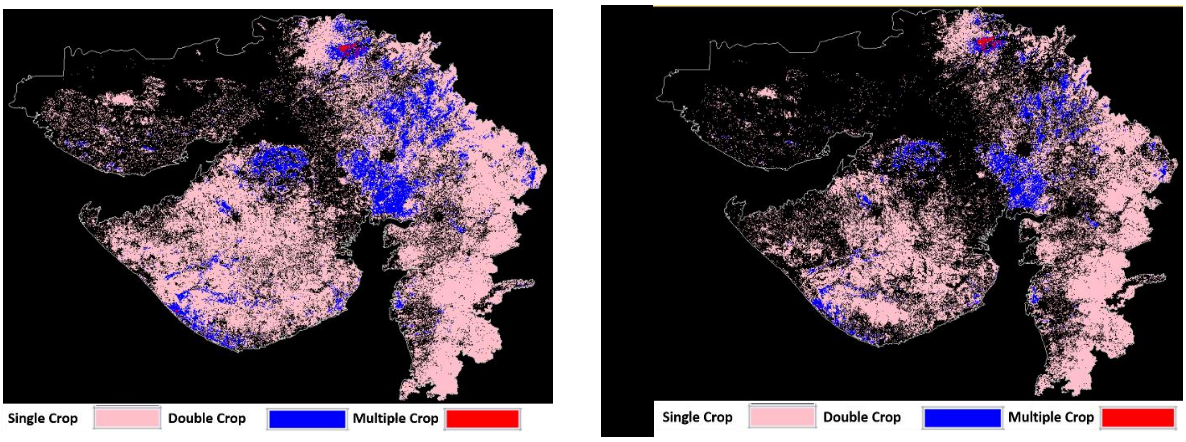

Figure 7: Spatial distribution of crops for Gujarat in 2015-16 using Proba-V (10-day composite) after applying (a) Discrete Fourier Transform (b) 5-point Gaussian Filter.

An interactive Web GIS-enabled application is developed for disseminating generated crop intensity maps from both OCM and Proba-V NDVI datasets for Gujarat shown in Figures 8 and 9. Developed application provides the functionalities of zooming, panning, measure distance and area, add marker for entered longitude/latitude etc. Hence, it is evident that modern tools like WebGIS technology can be effectively used in disseminating and analysing phenological information over any spatial region.

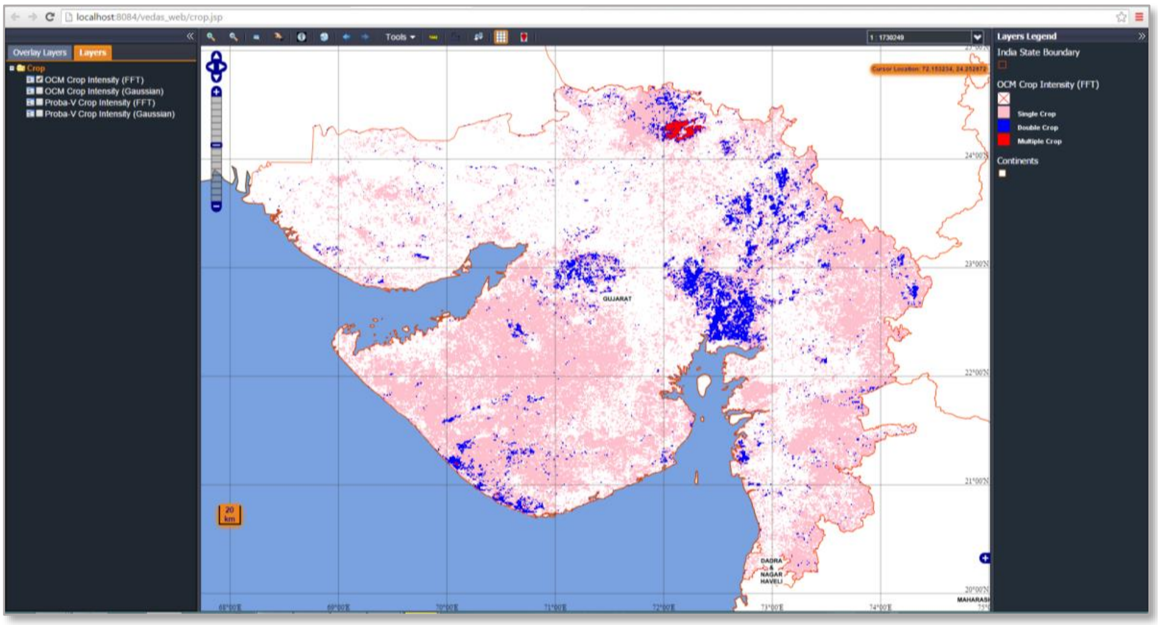

Figure 8: User Interface depicting Web-GIS enabled crop intensity maps with legends for Gujarat overlaid with state boundary.

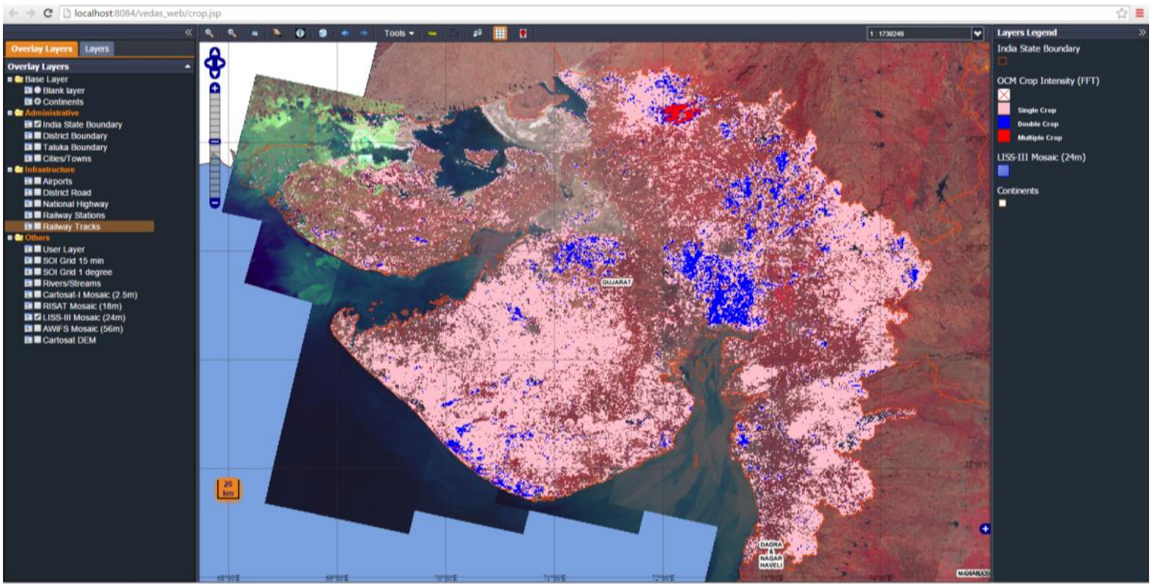

Figure 9: Web-GIS enabled crop intensity maps overlaid with LISS-III (24 m) mosaic.

5. CONCLUSION

Temporal behaviour of NDVI from two sensors (OCM and Proba-V) is used to study vegetation phenology. Using temporal analysis of smoothed NDVI series, number of crop cycles per pixel over one agriculture year have been extracted for study area of Gujarat. It was found that Fourier transform based algorithm works better than the Gaussian filter for smoothing OCM NDVI Datasets. Automated module is developed for NDVI smoothening and crop cycle estimation. Finally output showing crop intensity in specified period over study area are presented using Web-GIS technology. The developed WebGIS based application facilitate researchers, and end users across the scientific community to analyze, visualize the spatial distribution of crops over Gujarat which can be helpful for crop management and further analysis.

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