DERIVING PHENOLOGY METRICS AND THEIR TRENDS USING TIMES SERIES OF AVHRR-NDVI DATA

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ABSTRACT:

In this study, an attempt has been made to derive the spatial patterns of temporal trends in phenology metrics and productivity of crops grown, at disaggregated level in Indo-Gangetic Plains of India (IGP), which are helpful in understanding the impact of climatic, ecological and socio-economic drivers. The NOAA-AVHRR NDVI PAL dataset from 1982 to 2001 available at a pixel size of 8x8 km and at an interval of 10 days was stacked together as per the crop year (June to May) and subjected to Savitzky-Golay filtering to remove residual noise. For crop pixels, maximum and minimum values of NDVI, their time of occurrence and total duration of kharif (June-October) and rabi (November – April) crop seasons were derived for each crop year. These derived parameters were subjected to pixel-wise linear regression with time to derive the rate and direction of change. The maximum NDVI value is showing moderate to high increasing trends across IGP during both kharif and rabi seasons indicating an increase in productivity of crops. The trends in time of occurrence of peak NDVI during kharif dominated with rice is showing that the maximum vegetative growth stage is happening early across most of Punjab, North Haryana, Parts of Central and East Uttar Pradesh and some parts of Bihar and West Bengal. Only central parts of Haryana are showing a delay in occurrence of maximum vegetative stage. During rabi, no significant trends in occurrence of peak NDVI are observed in most of Punjab and Haryana except in South Punjab and North Haryana where early occurrence of peak NDVI is observed. Most parts of Central and Eastern UP, North Bihar and West Bengal are showing a delay in occurrence of peak NDVI. In general, the rice dominating system is showing an increase in duration in Punjab, Haryana, Wesetrn UP, Central UP and South Bihar whereas in some parts of North Bihar and West Bengal a decrease in the duration is also observed. During rabi season, except Punjab, the wheat dominating system is showing a decreasing trend in crop duration.

1. INTRODUCTION

Agro-ecosystems are one of the most dynamic systems which are having all pervasive and profound effects on functioning of bio-sphere on earth. Agro ecosystem dynamics in general is determined by meteorological factors, landscape features and human interventions. Many recent studies have shown that agro ecosystems are witnessing a general degradation, declining yields and total factor productivity. Climate change in general and global warming in particular may be contributing to agro-ecosystem degradation. In order to detect and study such changes, it is essential to quantify the spatial and temporal trends in agro-ecosystem parameters at regional scales. For such purposes, field data currently available are generally difficult to use because such data are traditionally collected at small spatial and temporal scales and vary in their type and reliability. Satellite derived remote sensing data in this context provides objective and reliable measurements of parameters which can be used for quantification of regional trends.

Many studies have reported use of time series of normalized difference vegetation index (NDVI) derived from NOAA/AVHRR, SPOT/VEGETATION and TERRA or AQUA/MODIS for quantification of regional trends in agro-ecosystem parameters and modeling response. Agro-ecosystem parameters derived from NDVI are crop type distribution, leaf area index, fraction absorbed photosynthetically active radiation, net primary productivity and vegetation phenology. The derived data on vegetation phenology is of prime importance to characterize agro-ecosystem dynamics as it is highly sensitive to climatic variability besides being responsive to changes in production technology. Vegetation phenology is an effective indicator of intra as well as inter annual changes in vegetation caused by climatic and anthropogenic factors. As a result, the NDVI derived vegetation phenology has recently emerged as a key area of research in biosphere-atmosphere interactions, climate change and global change biology.

Traditionally, vegetation phenology refers to the specific life cycle events and their timing based on in-situ observation but phenology from satellite is aggregate information at coarse spatial resolution that relates to the timing and rates of greening (growth) and browning (senescence), timing of maximum photosynthetic

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activity and duration of active growth phase at seasonal and inter-annual time scales. Many approaches of estimating penology from time series of NDVI have been published in literature but there is no consensus on the optimal approach for producing vegetation phenology at pixel or regional scales. Zhang et al. (2003) identified key phenological phases of vegetation by fitting a continuous logistic function to time series of MODIS VI data and estimating phenological transition dates based on inflection point of the curve. Based on this approach global maps of annual ecosystem phenologies were produced and their comparison with in-situ measurements showed realistic estimates of phenological dates identified (Zhang *et al.*, 2006). White and Nemani (2006) used phenoregion specific normalized difference vegetation index threshold to analyze the phenological behaviour of group of pixels. Schwartz *et al.* (2002) employed a simple method of Seasonal Midpoint NDVI (SMN) in which a SMN threshold is defined to determine the start and end of season in case of broad leaf forest. Schwartz *et al.* (2004) showed that satellite derived SOS correlate well with surface phenology model outputs for deciduous trees and mixed woodland but observed lowest correlation of 0.37 for short grasses. Zhang *et al.* (2006) reported strong correspondence of phenological metrics estimated from MODIS data with temperature pattern in mid and high latitude climates, with rainfall seasonality in dry climates and with cropping patterns in agricultural areas.

This study aimed at deriving the seasonal phenology metrics of agroecosystem dominant in short grasses (cereal crops) from multi-date NOAA AVHRR PAL dataset for Indo-gangetic plains of India. The phenology measures were derived separately for kharif (June-October) and rabi (November – April) crop seasons for 19 years from 1982 to 2001 and dominated by rice and wheat crops, respectively. The spatial patterns of temporal trends in phenology metrics for both the seasons were derived and analyzed at disaggregated level (pixel-wise) and at aggregated level (State wise).

2. METHODOLOGY

2.1 Study Area

The study was carried out for Indo-Gangetic plains (IGP) of India which are under intensive cultivation for long. The states which falls in the Indian IGP are Punjab, Haryana, Himachal Pradesh, Uttar Pradesh (including present day Uttaranchal), Bihar (including present day Jharkhand) and West Bengal covering a total area of 57.66 M ha (Figure 1).During kharif season, rice is the dominant crop throughout IGP with some area under cotton and maize also, whereas, during rabi season wheat is the dominant crop in all States except in West Bengal where rice and potato dominate.

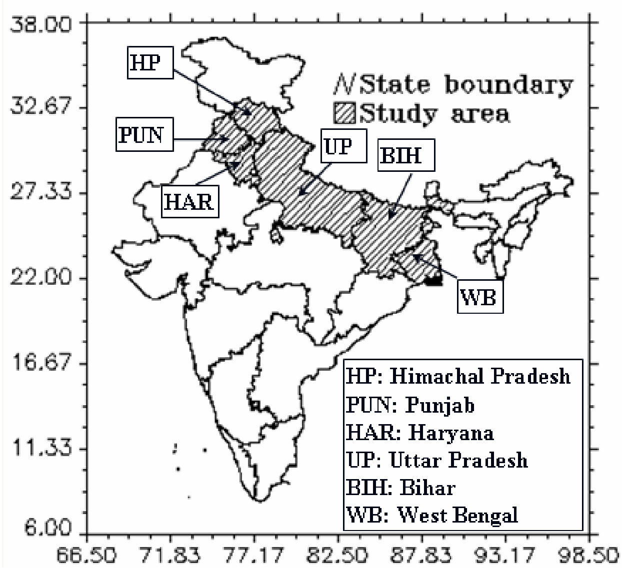

Figure 1. India State Map Showing Study Area (Shaded) Falling in Indo-Gangetic Plains

2.2 Satellite Data Pre-processing

The study used NDVI Land data set produced as a part of NOAA/NASA Pathfinder AVHRR 8 km land (PAL) generated from series of NOAA satellites .The PAL datasets provides a continuous and uniformly processed daily and 10 days composite dataset from July 1981 to September 2001. This dataset incorporates normalization with respect to sensor calibrations, solar elimination conditions and noise due to atmospheric constituents such as aerosols, ozone etc. The dataset was downloaded from the website of distributed active archieve of Goddard space flight centre. The 10-day NDVI regional dataset available for asia continent in goods homosoline projection were stack together corresponding to each crop year i.e. June of first year to May of next year and the area corresponding to Indo-Gangetic plains of India were extracted. Though the NDVI is composited on the 10 day interval many studies have reported diminished utility of PAL NDVI dataset due to significant residual cloud contamination, atmospheric variability, and bi-directional effects (Lovell *et al.*, 2001; Chen *et al.*, 2004). So the yearly NDVI time series images were subjected to pixel wise filtering by following Savitzky-Golay filter based technique (Chen *et al.*, 2004). The algorithm for Savitzky-Golay filter based technique was coded in IDL-ENVI. Savitzky-Golay filter is a simple robust method to smooth out noise in NDVI time series specifically that caused primarily by cloud contamination and atmospheric variability. This method make data approach the upper NDVI envelope and to portray the NDVI change to an iteration process. The IGBP DISCover 1 kilometer global land cover dataset (Loveland *et al.*, 2001) aggregated to 8km pixel size was used to develop cropland mask for the study area.

2.3 Computing Phenology Metrics

The phenology metrics derived for each of the two crop seasons (kharif and rabi) in the study were:

1. Peak value of NDVI (Ym)
2. Time of the peak NDVI (Xm)
3. Time of start of the season (Xleft)
4. Time of end of the season (Xright)
5. Duration of the active growth season (FWHM)

As there is no consensus on the optimal approach for deriving vegetation phenology especially for agricultural crops, a simple approach based on fitting a second order parabolic curve to seasonal filtered NDVI profile was implemented. This approach is illustrated in figure 2. A parabolic curve was fitted to the seasonal NDVI values as given by the following equation:

$$ax2 + bx + c=0 \quad (1)$$

where, a and b are coefficients, c is the constant and x refers to time. The time of maximum NDVI (Xm) was calculated as follows:

$$Xm= (-b/2a) \quad (2)$$

The value of maximum NDVI (Ym) was computed by substituting value of Xm in eq (1).

As the NDVI profiles were not starting from the origin but having an offset in values, so a base NDVI value (NDVIbase) was chosen for each season depending on the minimum NDVI obtained between the kharif and rabi season profiles. The half of peak NDVI value ($Y_{1/2}$) was computed as follows:

$$Y_{1/2} = (Ym-NDVIbase)/2 + NDVIbase \quad (3)$$

Now in order to determine the time when the $Y_{1/2}$ value intersect the left side and right side of NDVI profile, straight line equation was fitted separately for left and right sides such that this line pass through $Y_{1/2}$.

$$Yleft = Mleft * X + Cleft \quad (4)$$

$$Yright = Mright * X + Cright \quad (5)$$

The time of start of the season (Xleft), end of the season (Xright) and duration of active growth season (FWHM) were calculated as follows

$$Xleft = (Y1/2 - Cleft)/ Mleft \quad (6)$$

$$Xright = (Y1/2 - Cright)/ Mright \quad (7)$$

$$FWHM = Xright – Xleft \quad (8)$$

It may be noted that Xleft and Xright are indicator of start and end of season, respectively, but are not actually start and end of season in true sense. These phenology metrics were computed for kharif and rabi season of each year of the study period at pixel level and were also aggregated for crop pixels at state level.

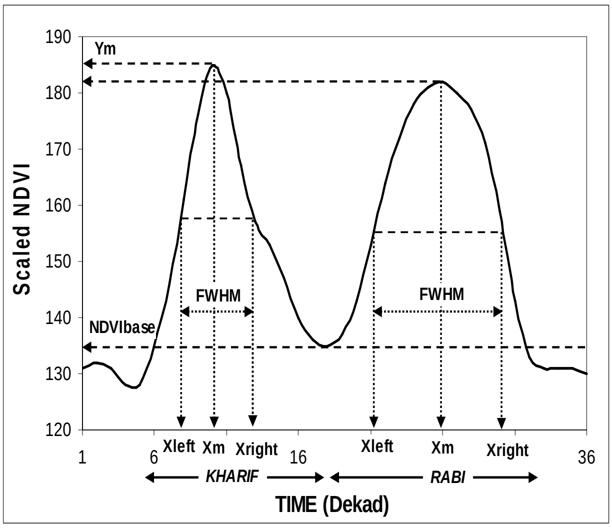

Figure 2. Schematic Showing Phenology Metrics for Kharif and Rabi Seasons

2.4 Spatial Trends in Phenology Metrics

The year-wise seasonal five phenology metrics were subjected to linear regression with time to derive the rate and direction of change in them as well as their Person correlation coefficient. Based on degrees of freedom (n=19) and 90% confidence level (2-tailed), a correlation coefficient between -0.3 to 0.3 was considered no change in parameter, whereas value less than -0.3 showed a significant decreasing trend in parameter over time and a value above 0.3 showed a significant increasing trend in parameter over time. The pixel wise correlation coefficient images for each parameter were density sliced as per this criteria and direction of change maps were generated for kharif and rabi seasons. Range and mean statistics of the phenology metrics were calculated at State level and for the whole IGP.

3. RESULTS

State-wise percentage of net sown area (NSA) showing significant increasing and decreasing trends in different phenology metrics for kharif and rabi seasons are given in Table 1. The density sliced maps of trends in phenology metrics are shown in Figure 3 for both kharif and rabi seasons.

State	Season	Ym		Xm		Xleft		FWHM	
		DT	IT	DT	IT	DT	IT	DT	IT
PUN	Kh	0.5	70.5	63.6	1.3	59.2	2.1	10.2	33.7
	Ra	1.2	62.5	43.2	0.7	52.0	2.7	3.1	47.7
HP	Kh	0.0	51.8	20.3	5.1	28.5	2.7	6.4	28.1
	Ra	3.0	12.3	2.7	24.7	12.7	5.8	7.4	5.6
HAR	Kh	0.4	63.1	14.6	18.2	46.7	1.0	2.5	54.5
	Ra	0.1	92.2	28.0	4.9	9.6	22.4	14.7	12.0
UP	Kh	0.8	71.7	22.7	6.3	25.4	3.3	7.6	38.5
	Ra	0.8	54.2	5.3	30.4	3.9	38.9	24.3	7.1
BIH	Kh	1.4	65.4	25.8	3.4	5.3	19.6	9.1	22.5
	Ra	6.2	35.0	2.0	38.4	6.4	20.2	22.7	5.4
WB	Kh	0.8	65.1	22.8	4.5	7.7	28.1	17.9	17.4
	Ra	2.7	56.1	4.1	45.8	11.4	20.9	26.5	7.5
IGP	Kh	0.9	68.1	25.8	5.8	22.9	10.3	9.1	32.4
	Ra	2.4	52.7	9.5	29.6	10.4	26.7	21.2	10.7

DT: Decreasing trend; IT: Increasing trend; Kh: Kharif season; Ra: Rabi Season

Table 1: Percentage of Net Sown Area of States and IGP Showing Significant Decreasing and Increasing Trends of Different Phenology Metrics During Kharif and Rabi

The peak value of NDVI (Ym) is showing increasing trend in both kharif and rabi seasons. Of the net sown area of IGP, about 68% in kharif and 53% in rabi is showing significant increasing trend in peak NDVI, whereas, 31% in kharif and 45% in rabi is not showing any significant trend. The area showing decreasing trend in both the seasons is negligible. It shows that crop yields have increased in majority of the area in IGP in both kharif and rabi seasons which is mainly a result of improvement in technology leading to better management of crops during the study period.

The trends in time of occurrence of peak NDVI (Xm) during kharif dominated with rice is showing that the maximum vegetative growth stage is happening early across most of Punjab, North Haryana, Parts of Central and East Uttar Pradesh and some parts of Bihar and West Bengal. Only central parts of Haryana are showing a delay in occurrence of maximum vegetative stage. During rabi, no significant trends in occurrence of peak NDVI are observed in most of Punjab and Haryana except in South Punjab and North Haryana were early occurrence of peak NDVI is observed. Most parts of Central and Eastern UP, North Bihar and West Bengal are showing a

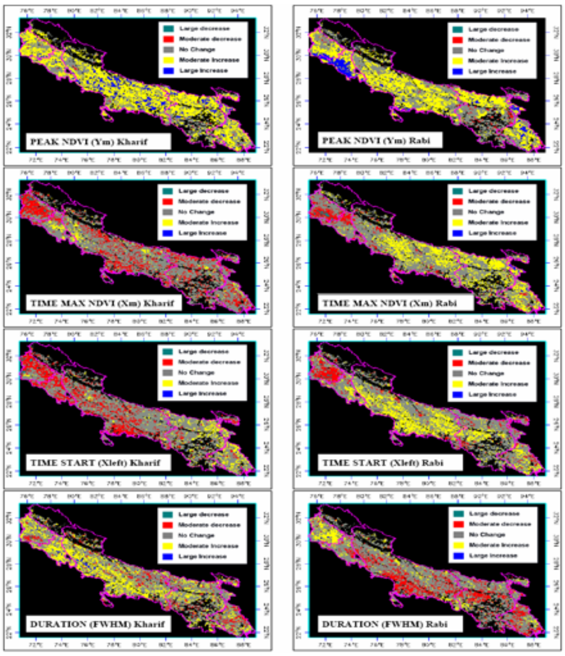

Figure 3. Maps Showing Trends in Different Crop Phenology Metrics for Kharif and Rabi Seasons in Indo-Gangetic Plains of India

delay in occurrence of peak NDVI. In North Bihar a delay in occurrence of maximum vegetative stage is observed. Overall, across IGP 26% of NSA is showing early occurrence of peak NDVI during kharif whereas 30% of NSA is showing delay in occurrence of peak NDVI during rabi for the study period. On the average for IGP, time of peak NDVI is happening 16 days early during kharif and is getting delayed by 19 days during rabi across IGP during 1981 to 2001.

The trends in time of start of the season (Xleft) during kharif is showing that season is starting early across Punjab, Haryana and Uttar Pradesh, whereas, in some areas of East Bihar and West Bengal, it is getting delayed. During rabi, the time of start of season is getting delayed across most of Uttar Pradesh, Bihar and West Bengal but is happening early in south Punjab and north Haryana. Across IGP, 26% of NSA is showing that kharif season is happening early but getting delayed in 6% of NSA. In rabi season, 10% of NSA is showing season starting early but getting delayed in 27% of NSA. On average across IGP, kharif season is starting 15 days early, whereas start of rabi season is advancing by 25 days.

The duration of kharif season (FWHM) is showing increasing trend across Punjab, Haryana, Wesetrn UP, Central UP and South Bihar whereas in some parts of South Punjab, North Bihar and West Bengal a decrease in the duration is also observed. During rabi season, except Punjab and some pockets of Haryana, the wheat dominating system is showing a significant decreasing trend in crop duration. During kharif, 9% of NSA is showing decreasing trend and 32% of NSA is showing increasing trend in season duration, whereas, during rabi, 21% of NSA is showing decreasing trend and 11% of NSA is showing increasing trend in duration. On average across IGP, the duration of kharif season is increasing by 40 days whereas duration of rabi season is reducing by 24 days during the study period.

CONCLUSION

The study presented a methodology of preprocessing of AVHRR-NDVI images, deriving season-wise various phenology metrics for croplands and generating their trends during 1982 to 2001 period in IGP of India.

The study clearly shows that crops productivity is showing increasing trend through out the IGP during both the seasons. The phenology metrics of time of start of season, time of peak vegetative stage and duration of season are showing significant trend (either increasing or decreasing) in about 40% of NSA.

In general, the kharif season dominated with rice is showing an increase in duration which is the result of early start of season resulting in early occurrence of peak vegetative stage. In contrast, the rabi season is showing decrease in duration. The study shows that it is happening due to clear delay in start of rabi season which is also resulting in delay in time of occurrence of peak vegetative stage. Exception is Punjab state where rabi season duration is showing moderate increase and an early start of season with early happening of peak vegetative stage.

This study demonstrates usefulness of multi-temporal satellite dataset for deriving spatial patterns in trends of crop phenology metrics. Such spatial and temporal patterns are important source of information to study the impact of natural causes and anthropogenic interventions on agro-ecosystem in long run. Further, long term changes in climatic parameters can be related to spatial and temporal pattern of crop phenology to quantify the impact of climate change and variability on functioning of agro-ecosystem at regional scales.

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REFERENCES

Chen Jin, Jönsson, P., Tamura, M., Gu ZhiHui, Matsushita, B., Eklundh, L., 2004. A simple method for reconstructing a high-quality NDVI time-series data set based on the Savitzky-Golay filter. *Remote Sensing of Environment*, 91(3-4): 332-344.

Loveland. T.R., reed, B.C., Brown, J.F., Ohlen, D. O., Zhu, J.,Yang, L., and Merchant, J.W., 2001. Development of a global landcover characterstics database and IGBP DISCover from 1 km AVHRR data. *International Journal of Remote Sensing*, 21(6/7):1303–1330.

Lovell, J.L., Graetz , R.D., 2001. Filtering pathfinder AVHRR land NDVI data for Australia. *International Journal of Remote Sensing*, 22(13), 2649–2654.

Schwartz, M.D., Reed. B.C. and White, M.A., 2002. Assessing satellite derived start-of-season (SOS) measures in the conterminous USA. *International Journal of Climatology*, 22(14): 1793–1805.

Schwartz, M.D. and Reed, B.C., 2004. Surface phenology and satellite sensor-derived onset of greenness: an initial comparison. *International Journal of Remote Sensing*, 20: 3451 –3457.

White, M.A. and Nemani, R.R., 2006. Real-time monitoring and short term forecasting of land surface phenology. *Remote Sensing of Environment*, 104: 43–49.

Zhang, X., M.A. Friedl, C.B. Schaaf, A. H. Strahler, J.C.F. Hodges, and F. Gao 2003. Monitoring Vegetation Phenology Using MODIS. *Remote Sensing of Environment*, 84: 471–475.

Zhang, X., M.A. Friedl, and C.B. Schaaf, 2006. Global vegetation phenology from Moderate Resolution Imaging Spectroradiometer (MODIS): Evaluation of global patters and comparison with in situ measurements. *Journal of Geophysical Research*, Vo. 111.