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An Agro Climate Study - Atmospheric Teleconnection

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Abstract

The year climate signal of the equatorial Pacific Ocean sea surface pattern in association with the Southern Oscillation has been responsible in altering weather systems in impacting the aberrated climate scenario across the globe. A comparison of Normalized Difference Vegetation Index(NDVI) pattern over the five selected regions in India with the derived moisture adequacy from the water balance model and multivariate ENSO index unfolded the phenological feature of greenness up and down with a lag. It is assumed that a 60% of moisture adequacy is essential for the sustenance of crop or vegetation growth and development and can be traced in metric of NDVI. A statistical model is suggested for All India rice yield and is of useful in agrometeorological advisories.

Keywords: Soil wetness; Evapotranspiration; Crop growing period; NDVI; SST

Introduction

India is an agriculture oriented country and the arrival along with its performance of the SW monsoon is of significant factor every year and any change in the rainfall pattern surfaces as a constraint for the agricultural operations which in turn affects the economy and agricultural yields. It is also reported that the coming decades of 21 century are going to experience increased number of extreme weather events such as heavy rainfall events, floods and droughts [1]. The vegetation that prevails over the region either by native or by cultivation exerts provinces since the vegetal cover of the region is highly governed by the variations of the regional climate status [2]. Monitoring of the vegetal cover at regular intervals is of importance in understanding the nature of climate type over the region [1]. The transfer of fluxes in terms of moisture and energy from the vegetal cover of the given climate province asserts not only regional but also global climates [3]. Most of the region over the earth's surface is covered by some vegetal cover which strongly modulates the surroundings depending upon the density of micro, meso and macro scale and hence the climate [1,4].

Crop growing period

The basic parameter that favors the choice of crops and crop variety in a given region is the number of days in the growing period [1]. The duration of the growing period (LGP) is the sum of the rainy days after meeting the water need of the place together with the field capacity of the soil. LGP depends not only on the rainfall distribution but also on soil type, depth and water holding capacity. The simple graphical method [5] is followed to estimate the LGP using rainfall (P) and Potential Evapotranspiration (PET) by Venkateswarlu et al. [6] in estimating effective cropping season at different Dryland Centers. Ramana Rao et al. [1] observed that the above method can provide reliable estimates of LGP in regions with shallow soils. Kassam et al. [2] and Kassam [7] used precipitation and PET to determine LGP for crops in tropical Africa. Higgins and Kassam [8] have improved this concept. This method considers the growing period to start when precipitation is greater than 0.5 times of the water need of the place and ends soon after the utilization of accumulated soil water and is followed by a fall in rainfall and which is less than the water need of the place. Velayutham [9] consulted the said method in understanding the performance of the same in working out LGP over different regions of India. One reliable approach for estimation of LGP is through the revised water balance approach of Thornthwaite and Mather [10] that estimates Actual Evapotranspiration (AET) on monthly or weekly basis. It enables to estimate Index of Moisture Adequacy (IMA), i.e., the ratio of AET to PET and expressing in percentage. Krishnan and Thanvi [11] worked out the normal duration, commencement and cessation dates of crop growing season with nil or slight water stress under rain fed farming areas of India. The length of growing season as well as the start and end for some selected Dry land stations was estimated using IMA approach by Rao et al. [12]. Victor et al. [13] have worked out the commencement and end of growing season for different districts of Andhra Pradesh by following the forward and backward accumulation of weekly rainfall as is suggested by Morris and Zandastra [14]. Singh et al. [15] worked out length of growing season for 11 spatially distributed locations in the Rabi sorghum regions of India. Rao et al. [12] determined the crop growing period (CGP) in arid/semi-arid regions of Rajasthan, based on soils, crop water requirement and assured rainfall of the region. Victor et al. [16] suggested a method for quantifying the growing period by considering the variations in the prevalence of rainy season. Sarma and Sivaram [17] reported the weekly growing periods over India using rainfall and water need by adopting the model of Higgins and Kassam [8] that subjects the performance of the crop and it was shown that the humid days are less during El Nino episode.

Normalized vegetation index

Manual surveys of vegetal cover sprawl at regular intervals are the best but takes lots of time but with the advent of remote sensing from satellites the task made easy for retrieving this type of data for making an inter comparison study with the climate elements. The scientific community of the present era is being widely using the satellite derived vegetation indices to study the ground vegetal cover. One such index is Normalized Difference Vegetation Index (NDVI) that can be defined as the difference between Near Infrared (NIR) and visible (VIS) reflectance values and are normalized over the sum of the two [18,19]. The derived vegetation index is of much helpful in understanding agricultural

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pattern, gravity of rainfall excess or deficit impacts triggered by weather pattern [19-27]. NDVI is commonly used to monitor the seasonal and annual variation in vegetation pattern also [19,28,29]. Hess et al. [30] pointed out rightly that the NDVI reflects or traces the vegetal cover over the given landscape in correlating with the climate of the place. Nayak et al. [31] observed that NDVI provides ample information to study the changes in vegetation cover over time.

Thapliyal et al. [32] reported the variability in NDVI over India during the SW monsoon period. Cihlar et al. [33] correlated the NDVI with rainfall, temperature and evapotranspiration to unfold the exertion of vegetation on climate. The remote sensing data is made use of not only in deriving soil wetness over A.P. but also its response to ENSO condition [34]. Sarma and Lakshmi Kumar [35] investigated the high sensitivity of integrated NDVI with soil moisture adequacy. Seasonal characteristics of plants such as emergence and senescence (increase or decrease of greenness) are closely related to characteristics of lower atmosphere, including the annual cycle of weather pattern shifts, and temperature and humidity characteristics. Shifts in dates of phenological events signal the year to year climatic variations that are the indicators of the implications of the global environmental changes. Vegetation phenology, the study of recurring of vegetation cycles and their relation to climate, is an important aspect in a wide variety of Earth and atmospheric science applications [4]. The vegetation canopy effectively influence the regional to global models [36,37] including the coupled biosphere atmosphere GCMs [38] along with the land surface parameterization schema [39]. Schwartz [40] highlighted the growing season impact on the transfer of energy and moisture fluxes. The phenology of a given province is highly variable [41] and responsive to long-term variation in climate [42]. Justice et al. [19] studied global phenology from NDVI data. Malingreau [43] employed NDVI data to study the dynamics in vegetation such as emergence and closure of growing period and obtained the finger print of climate variation in the temporal curves of NDVI. Lloyd [44] employed a phenological approach to global vegetation cover classification from NDVI multitemporal profiles. Reed et al. [45] identified onset of greenness not only from the moving average method but also the greatest increase in NDVI during the year. White et al. [46] obtained greenness onset along with its offset and the biomass of the grass land over temperate latitudes. Temporal and spatial correlation between NDVI and climatic factors are investigated in many research works [47-49] that reported good correlation in the arid regions both in spatial and temporal wise. The relationship between NDVI and temperature are reported to be weaker but significant as evidenced from studies [50-53]. A high correlation of NDVI is observed not only with potential evapotranspiration [54] but also with soil moisture [55]. Kowabata et al. [50] studied the global mapping of NDVI trends in the northern mid and high latitude areas along with equatorial regions. Ichii et al. [56] analyzed that the interannual variations in the NDVI and climate variables have a significant effect on biospheric activity, and vegetation growth in semiarid regions.

El nino-southern oscillation

Fearnside [57] reported that the interannual variations in photosynthesis and respiration might be due to climate variations. Nagai et al. [58] reported that the interannual changes in precipitation and temperature caused by El Nino- Southern Oscillation (ENSO) plays a decisive important role in vegetation activities over tropical rainforest regions in the Amazon basin and southern Asia. One of the important aspects of vegetal cover of the given climate province is studying its interannual and intra seasonal variation from NDVI along with the ENSO years that was analyzed by Anyamba and Eastman [59] and Eastman and Fulk [60]. Sudipta Sarkar and Menas Kafatos [61] too reported the NDVI fields in ENSO episodes. Mahamoud Damizadeh et al. [1,62] highlighted the very survival of vegetal cover on rainfall from NDVI fields over the region. Sarma and Lakshmi Kumar [63] showed that the warm phase of ENSO suppress the vegetal cover. Yang et al. [54] observed that NDVI is strongly correlated with the growing degree days of the crop.

Braswell et al. [64] and Richard and Poccard [47] investigated the exertions of vegetation and soil on one another using NDVI. Piao Shillong et al. [65] reported the trends of NDVI in China are heterogeneous. Scanlon et al. [66] studied the interannual variability of NDVI over bare soil. Li et al. [49] made use of the AVHRR data for drought monitoring. Savin and Flueraru [67] used the decadal products of NDVI to determine the drought severity in Romania. Xulin Guo and Pierrot Richard [68] reported the consecutive droughts that occurred in Canadian prairie by comparing the MODIS vegetation index with moisture variables.

Apart from other factors the agricultural systems have strong bearing not only on the climate but also its variability [69]. It is reported that the climate affects reflect in regional weather and which in turn affects the crop yield [70]. Failure of seasonal rains due to El Nino is a setback in tropical Asia [71] and monitoring of large swaths of agricultural crops from remote sensed data plays a primary role [72-74]. Rice is one of the major crops that have been growing in Asia and the crop is subjected to stress [75] and extreme variations in rainfall and temperature that markedly suppress the rice yield [76]. The aberration in climate along with its interannual variation influences the crop yield and the study of Yao et al. [77] aimed in unfolding the rice yield under change in scenario of B2 climate. The extent of rain fed and irrigation determine the potentialities of rice crop in China and Korea [78].

Bishnoi et al. [79] analysis showed pearl millets dependence on rainfall. It is clearly known that elevated temperatures are detrimental but increments in rainfall profitable to agriculture [80]. Lareef Zubair [81] pointed out that the ENSO reflected in lowering rice yields in Yala season while an increase in Maha season in Sri Lanka. Sarma and Lakshmi Kumar [3,82] illustrated that the ENSO phase has crippling effects on the crop productivity by modulating the agro climatic elements. Das et al. [83] explained that the anomalies in SST of equatorial Pacific affects the performances of the SW monsoon over India and on whose foot prints the rice yields depend also gets affected. Chakraborty et al. [84] study on Normalized Difference Vegetation Index (NDVI) with rice yield in estimating the yield resulted in good correlation. The integrated NDVI is strongly correlated with moisture adequacy indicating the vigor of the vegetation or crop depends more on the water need of the place [35].

The increased or decreased trend in greenness is well in agreement with the cooling and warming phases of the short term signal that emanate from the equatorial Pacific region and might be the causal factor in conjunction with the SSTs and Southern Oscillation and this is made use of in developing the agro climate model for rice yields [85]. It is also very important to note that higher temperatures favor plant respiration but at the same time it decreases net photosynthesis that finally results in decreased crop yield [86,87]. Crop yield estimation is also retrieved from growing degree days along with the effective temperature [88] and rainfall and temperature [89].

Materials and Methods

The present study adapts NCEP/NCAR reanalysis data for some of the needs of climate studies in the context of India. The mean monthly temperature data of 2.5° × 2.5° spatial resolution was from NCEP/NCAR reanalysis data website for the period from 1951 to 2007. The data has 2.5° × 2.5° spatial resolution and was converted to 1° × 1° resolution by the nearest neighbor method. The monthly rainfall is derived from the daily precipitation data (India Meteorological Department) that has 1 × 1 degree spatial resolution for the period 1951 to 2007. Normalized Vegetation Index (NDVI) data was taken from www.jjsao.washington.edu that covered the period 1982 to 2000 with the same resolution as that of rainfall.

The coupled ocean -atmosphere interaction from equatorial Pacific Ocean triggers inter annual climate variability and is resolved from Multivariate ENSO Index (MEI) as suggested by Walter and Timlin [90] that adopts a) sea level pressure (P), b)zonal (U) and meridional (V) wind of surface, sea surface temperature (Tc), surface air temperature (TT) and total cloudiness fraction of the sky (C) and was from www.cdc.noaa.gov/climate Indices for 1982 to 2000 period. India Harvest Data Centre for monitoring Economy Private Limited is consulted for All India rice yield data that spans from 1982 to 2000.

In obtaining the monthly moisture adequacy (IMA), the modified water balance model [10] is followed and is forced using precipitation and potential evapotranspiration along with the assigned field capacity as inputs for the period 1951 to 2007. The moisture adequacy is a ratio of actual evapotranspiration (AE) to potential evapotranspiration (PE) and expressed in percentage.

The parameters such as soil moisture storage (St), Actual evapotranspiration (AE), water deficit (WD), and water surplus (WS) are obtained in understanding the agro climatic potentialities of the region.

The Index of moisture adequacy (IMA) on a monthly basis is as follows

Monthly Index of moisture adequacy (IMA)=AE/PE*100----1

The greenness over the given region can be retrieved from the reflectance of channel 1 (visible: 0.58-0.68 micron meter) and channel 2 (near infrared: 0.725-1.0 micron meter) of the Advanced Very High Resolution Radiometer (AVHRR). The quantum of greenness from AVHRR is made use of in obtaining the Normalized Vegetation Index (NDVI) and is the ratio of the difference of these two channels to the sum of the reflectance.

NDVI=Difference in reflectance of the 2nd channel-1st channel/Sum of the reflectance of 1 and 2----2

The NDVI varies from -1.0 to 1.0 but the typical range is from 1.0 to 0.7 and higher values indicate higher greenness cover. The NDVI is obtained for the selected five regions of India for 1 × 1 grid resolution to understand the seasonal cycles of NDVI and its variability with the index of moisture adequacy and Multivariate ENSO index. The senescence feature in terms of greenness increase and reduction compared to the index of moisture adequacy along with the Multivariate ENSO index are detailed. The magnitude of 60% of soil moisture adequacy is assumed for the sustenance of the crop or vegetation growth and is used in deriving the phonologic metric for the regions under investigation. The present investigation address the cause and effect of variation among the NDVI, soil moisture adequacy and. Multivariate ENSO index for the selected regions of India compared to normal and in El Nina and La Nina events The analysis also points out the variability in the length of the growing period in space and time over India .For cereals the relationship between weather and crop yields is more complicated and the attempts of Chakraborty et al. [84] and Yang et al. [54] are worth mentioning in estimating crop yield from NDVI measurements and NDVI and Degree Day concept respectively. The strong relation of IMA with NDVI [82] has paved the way for the present study. The suggested agro climate model of Sarma et al. [86] for All Andhra Pradesh rice involved rainfall, Southern Oscillation Index (SOI), Nino 3 SST, Growing Degree Day and Integrated NDVI but to increase the accuracy of rice yields the Multivariate ENSO Index (MEI) is incorporated. It is worthwhile to note that the magnitude and pattern of agro climatic variables indicate the important characteristics of the SW monsoon strength that might be affecting the agriculture yield production profoundly.

Results

Length of growing period

The variability in the growing period for the five selected regions through the year for the normal and in selected El Nino and La Nina years is reported here to understand the stretching and shrinking of moist, humid and moderate dry periods and is diagrammed in Figure 1. Normally in the north the growing period decreases from NE India to NW India through Central India while in south the growing period decreases from west Central India to Peninsular India. The increment in humid period in El Nino year is noticed starting from NW India and extended to Peninsular India through Central India whereas in La Nina year it elongated the humid and moist periods. The shrinkage in the number of growing days is observed in the El Nino year over Central NE India and Peninsular India (Table 1). It is also clear the shortening of moderate days occurred in the La Nina year. The expansion of humid days is remarkable over the regions that cover NE, Peninsular and West Central India during El Nino and La Nina episodes compared to normal. The total number of normal crop growing days for NW India is 153 only with 35 humid, 47 moist and 71 moderate because of its geographical location (Table 1). NE India recorded the maximum number (308) of crop growing days that consists of 216 humid, 74 moist and 18 moderate dry. The LNSO year witnessed Lengthening of crop growing days compared to normal with an exception to NW India.

Agro climate condition – satellite derived NDVI

The present investigation makes use of IMA and assumes 60% as the threshold value for vegetation growth and is essential prerequisite in progressing for the onset of greening. Figure 2 display the seasonal cycles in potential evapotranspiration (PE), Index of moisture adequacy (IMA) and Normalized Difference Vegetation Index (NDVI) during normal and for selected years of El Nino and La Nina. The NE India region recorded higher than 60% moisture adequacy through the year in spite of extremity with a green up duration of 6 months with a photosynthesis rate of o.o4 per month with a lag of 2 months in the maxima of moisture adequacy and vegetation index. An increment of 0.06 per month in photosynthesis rate is observed in NE India even in El Nino and La Nina events (Table 2). The climatic province of NW India which normally records higher than 60% of moisture adequacy for 2 months in the year is prolonged to a period of 3-4 months with a simultaneous elevation in photosynthesis rate of 0.08 and 0.07 respectively. The photosynthesis rate of green up from NW India during El Nino year is maximum (0.08) and is high compared to Central northeast, NE and Peninsular India (Table 2). Moisture

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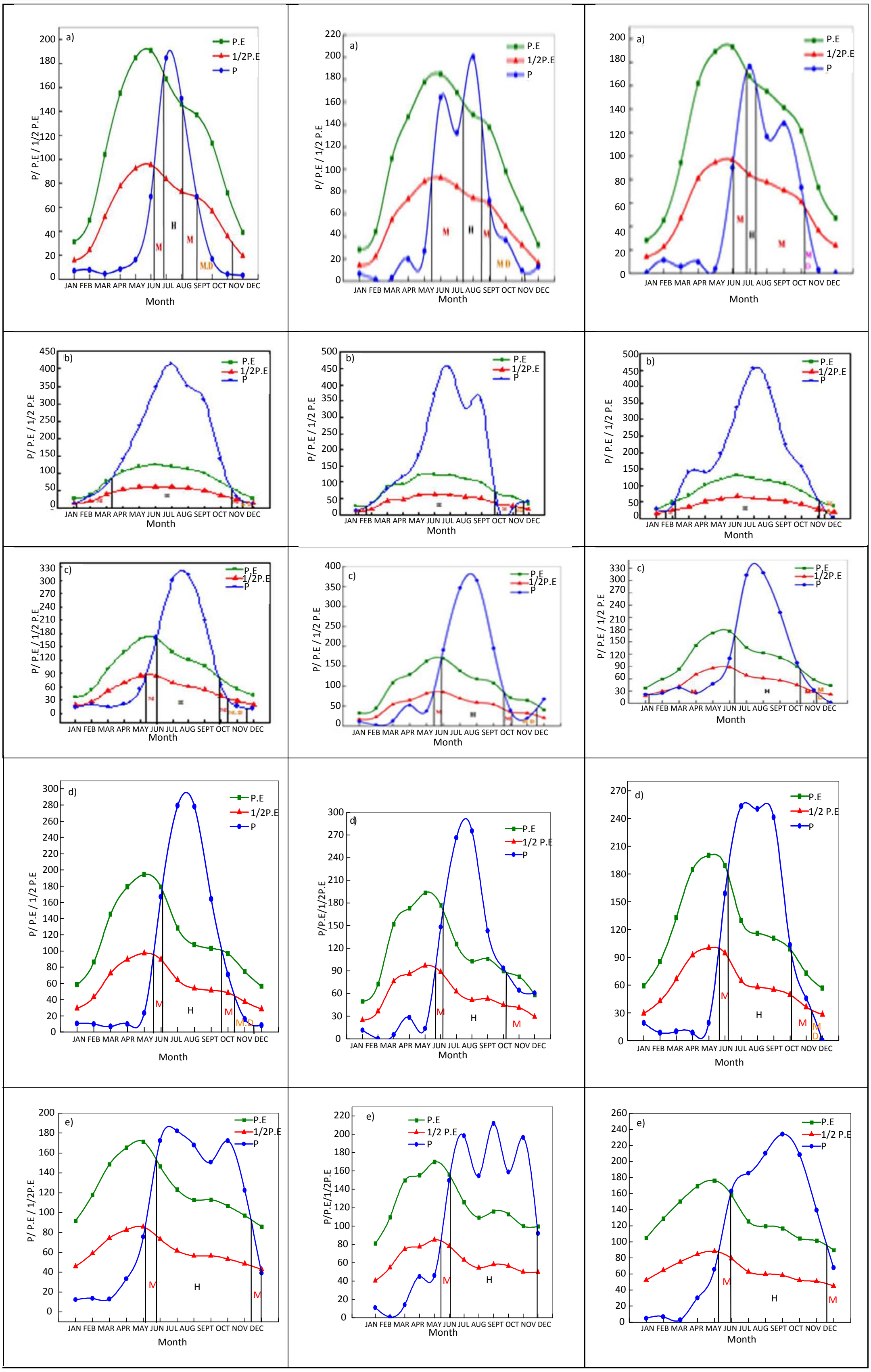

Figure 1: Length of Growing Period (LGP) over a) NW b) NE c) Central NE d) West Central and e) Peninsular India for Normal (1982-2000, Left) , El Nino Year (1997, Middle) and La Nina Year (1998, Right).

adequacy values of greater than 60% for a period of 7 months in the year with an associated greenness up period of 4 months accompanied by a photosynthesis rate of 0.06 per month with a lag of 1 month in between maxima of moisture adequacy and vegetation index .The noticeable point is that the photosynthesis rate elevated even in El Nino years by excluding Peninsula India.

The impacts of extreme weather events such as El Nino or La Nina induce variations in the strength and circulation pattern of monsoonish weather over India which in turn delays or modulates the phenological events and the same is attempted here to unfold the spatiotemporal variations in phonological gradients over India. The occurrence of maximum value of NDVI is advanced over NW India compared to Central NW India, NE India and West central India by one month (August) as against September. Peninsular India delayed by two months in recording maximum NDVI a feature clearly highlights the gradient in the phenological event. The triggering of early onset of maximum NDVI over Peninsular and West central India during the El Nino event but the La Nina year supported higher NDVI by making one month of an early advancement over Central India and West Central India (Table 3 and Figure 2). Table 4 presents the statistic of estimating NDVI from monthly data of IMA and potential evapotranspiration for the selected regions of India for the selected El Nino, La Nina event years along with the normal. R is maximum (0.82 to 0.86) for NW, West central India and Peninsular India in the La Nina event period with a strong correlation and was minimum (0.30 to 0.49) over NE and NW including Peninsular India during La Nina and El Nino events respectively. Even for normal condition the degree of relation among the agro climate variables that are considered here fluctuated 0.57 to 0.58 over NW and Peninsular India while over Central NE India and West Central India it was 0.74 to 0.76. Estimated NDVI values with IMA and PE for the five selected regions are well in agreement with the observed.

Seasonal cycles of IMA, NDVI and MEI

In discerning not only the influence of Multivariate ENSO Index (MEI) on NDVI during El Nino and La Nina years compared to normal but also the seasonal cycles in them are presented in Figure 3. The increase in MEI commenced from January till May/June associated with a fall in IMA during this period. The magnitude of IMA improves and has a bearing on the onset and progress of the SW monsoon over India and on whose finger prints the response of the NDVI till September follows. The retreat of SW monsoon begins from October accompanied by a simultaneous fall in NDVI over India excluding Peninsular India. A constant rise in MEI is the characteristic feature during a ENSO event year commencing from January to December from a value of less than zero to as high as three. It is interesting to note the magnitude of IMA has not recorded 100% value during SW monsoon period with an exception to July for Central NE India suggesting there by that the SW monsoon might not completely satisfy the water need of the region under consideration. The La Nina episode of the year of 1998 imparted a fall in the magnitude in MEI since the month of May till December. The MEI is out of phase with the IMA and NDVI during the monsoon period. The NW India that normally records 2 months with higher than 60% as its IMA did register three months in LNSO event of 1998.

Homogeneous regions	Days											
	Humid (H)			Moist (M)			Moderate dry (M.D)			Total number of days		
	N	E	L	N	E	L	N	E	L	N	E	L
Central NE India	119	114	118	35	22	184	36	45	20	190	181	322
North East India	216	246	270	74	48	27	18	19	11	308	313	308
North West India	35	37	15	47	73	93	71	62	34	153	172	142
Peninsular India	169	179	171	37	19	63	--	--	--	206	198	234
West central India	107	122	119	34	94	53	37	--	14	178	216	186

Table 1: Number of humid, moist and moderate dry days.

Homogeneous Regions	Duration (months)						Photosynthesis rate per month					
	Green - Up			Green - Down			Green - Up			Green - Down		
	N	E	L	N	E	L	N	E	L	N	E	L
Central north east India	6	4	4	2	2	3	0.04	0.07	0.05	-0.06	-0.05	-0.04
North east India	6	4	5	2	2	1	0.04	0.06	0.06	-0.03	-0.05	-0.07
North west India	3	3	4	3	3	2	0.07	0.08	0.07	-0.03	-0.03	-0.02
Peninsular India	4	5	5	1	--	1	0.06	0.05	0.05	-0.03	0	-0.03
West central India	4	3	3	2	3	3	0.08	0.11	0.1	-0.04	-0.02	-0.01

Table 2: Duration of green up / down and photosynthesis rate.

Homogeneous Regions	Lag in months between Max. SLMADQ and Max. NDVI			Soil moisture adequacy (Months)						Maximum NDVI Months		
				>60%			>60%					
	N	E	L	N	E	L	N	E	L	N	E	L
Central north east India	2	2	2	7	5	10	3	7	2	October	October	September
North east India	2	3	3	12	12	12	0	0	0	October	October	November
North west India	2	1	1	2	4	4	10	8	8	September	September	October
Peninsular India	1	2	1	7	6	6	5	6	6	November	September	November
West central India	2	1	2	6	6	6	6	6	6	October	September	September

Table 3: Lag between IMA and NDVI, maximum of IMA and NDVI during Normal (N), El Nino (E) and La Nina (L) years –Monsoon regions of India.

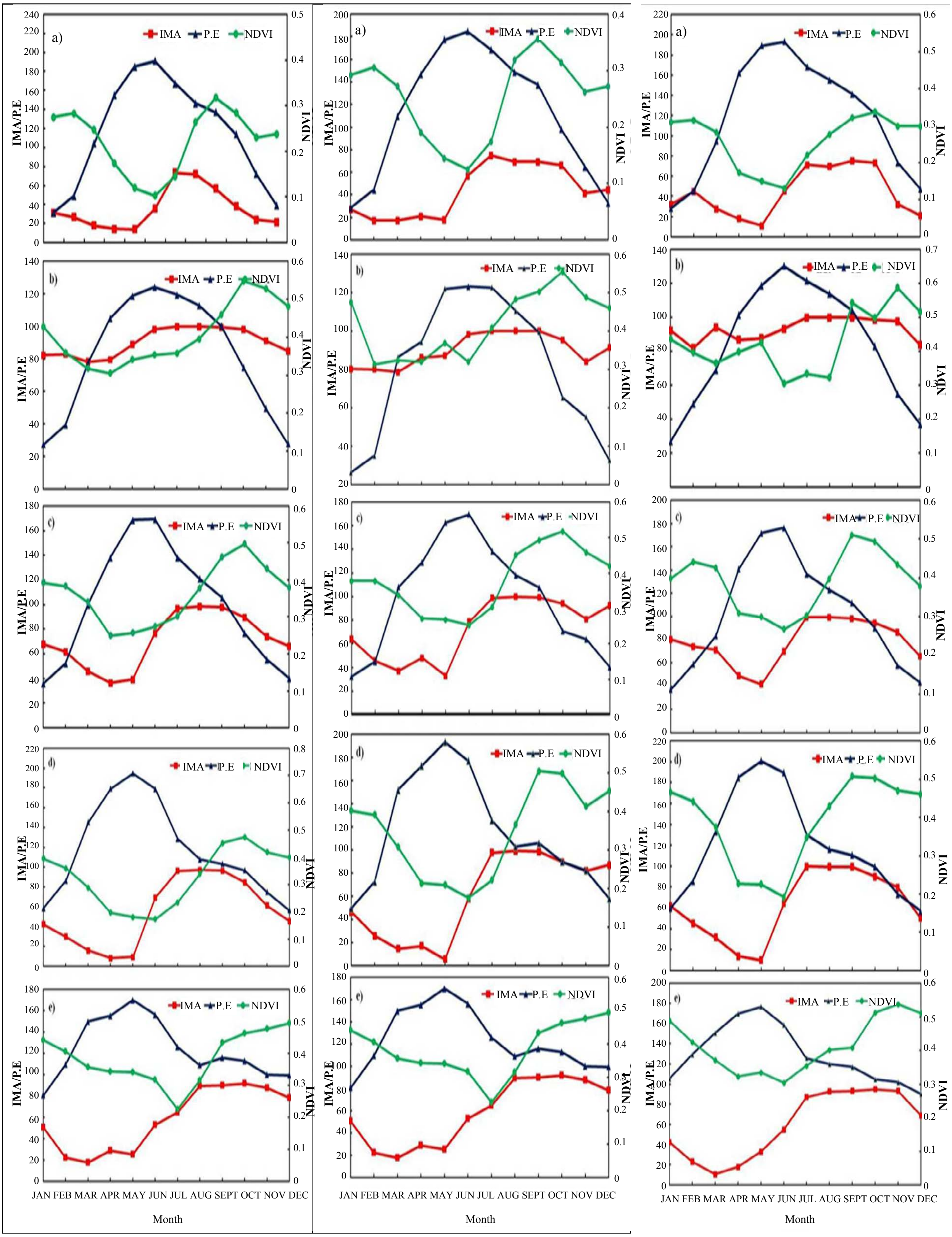

Figure 2: Seasonal cycles in IMA, P.E and NDVI over a) NW b) NE c) Central NE d) West Central and e) Peninsular India – Normal (Left), El Nino Year (1997-Middle) and La Nina Year (1998-Right).

Homogenous regions of India	Normal	ENSO (1997)	LNSO (1998)
Central north east India	NDVI=0.00183 (IMA)-0.00108 (P.E)+0.341 and R2=0.74	NDVI=0.00188 (IMA)-0.00107 (P.E)+0.346 and R2=0.64	NDVI 0.00169 (IMA)-0.00086 (P.E)+0.346 and R2=0.55
North east India	NDVI=0.00818 (IMA)-0.00205 (P.E)-0.165 and R2=0.75	NDVI 0.0083 (IMA)-0.00174 (P.E)–0.188 and R2=0.50	NDVI 0.00362 (IMA)-0.00152 (P.E)+0.218 and R2=0.30
North west India	NDVI=0.00131 (IMA)-0.00096 (P.E)+0.288 and R2=0.57	NDVI=0.00134 (IMA)-0.00094 (P.E)+0.299 and R2=0.49	NDVI=0.00174 (IMA)-0.00105 (P.E)+0.309 and R2=0.85
Peninsular India	NDVI=-0.000475 (IMA)-0.00258 (P.E)+0.702 and R2=0.58	NDVI=0.00027 (IMA)-0.00169 (P.E)+0.593 and R2=0.34	NDVI 0.00055 (IMA)-0.00295 (P.E)+0.826 and R2=0.82
West central India	NDVI=0.00042 (IMA)-0.00186 (P.E)+0.520 and R2=0.76	NDVI 0.00045 (IMA)-0.00179 (P.E)+0.525 and R2=0.67	NDVI 0.00079 (IMA)-0.00183 (P.E)+0.555 and R2=0.86

Table 4: Regression of NDVI with Index of moisture adequacy and potential evapotranspiration during Normal, El Nino and La Nina years-Monsoon regions of India.

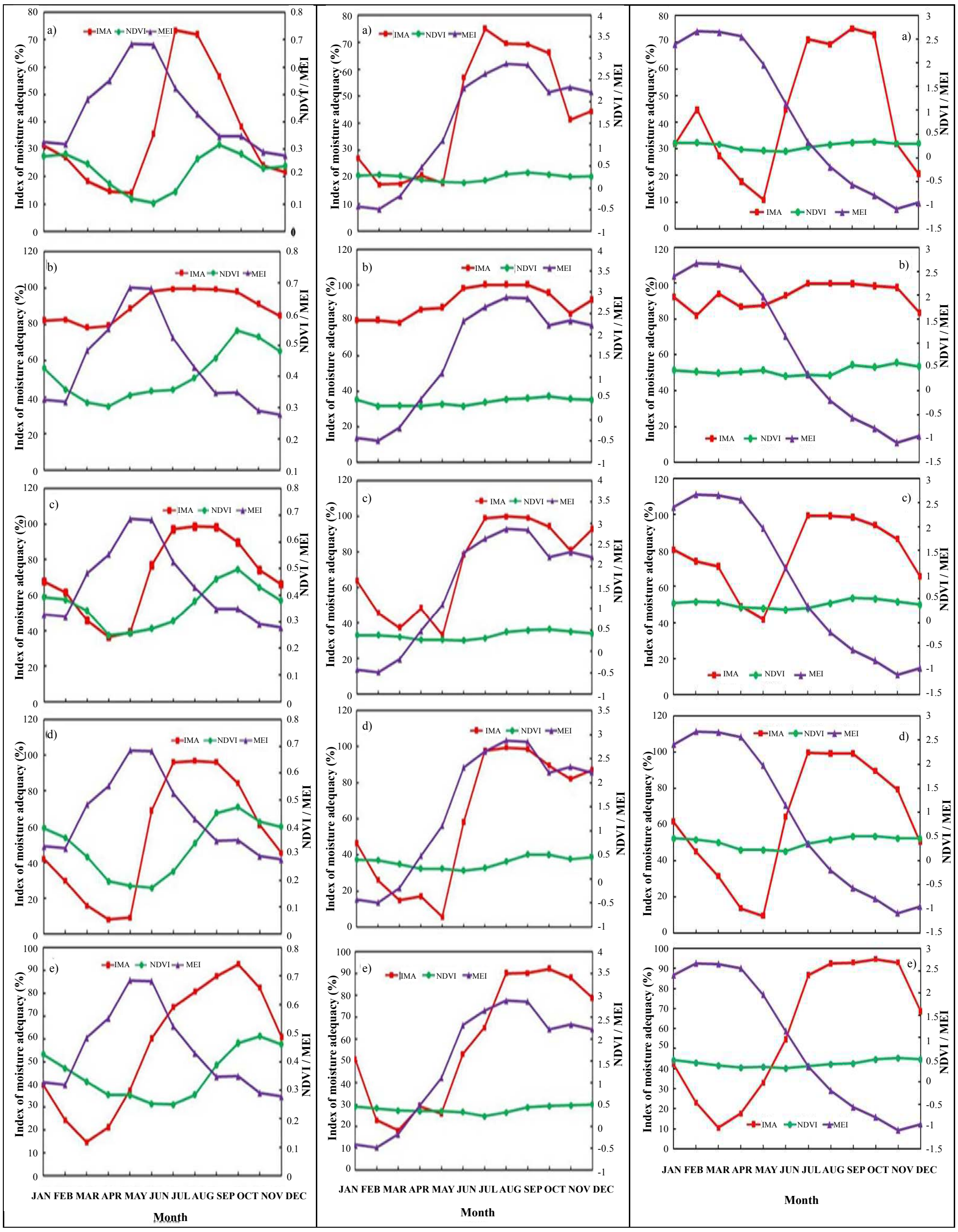

Figure 3: Seasonal cycles in IMA, NDVI and MEI over a) NW b) NE c) Central NE d) West Central and Peninsular India– Normal (Left), El Nino Year (1997, Middle) and La Nina Year (1998, Right).

Rice yield with meteorological parameters

Even though the Asian province is influenced by SW and NE monsoon systems it is the former ones that yields large amounts of rainfall in space and time associated with the variability that spans from June to September while the latter wind system is highly selective ones by impacting parts of NE and Central India in north and Tamilnadu in South India. The crop calendar is more or less in agreement with these wind systems and any fluctuation in arrival, strength and amount of rainfall might dent agricultural production and stocks and commodities market in pronounced way. It is worth to note here that that the brewing of El Nino/La Nina climate phenomena from Pacific Ocean is a consequence of coupled ocean-atmosphere interaction. The present investigation address variability in All India rice yields in relation to moisture adequacy, vegetation index, growing degree day along with the multivariate ENSO index. Figure 4 diagrams the time series of All India rice yields and moisture adequacy. A perceptible feature is that the rise and fall in moisture adequacy are concurrent with the occurrence of El Nino and La Nina events and are reflected in All India rice yields. A point that is to be noted here is that any variation in agro climate elements that too in moisture aggravates the performance of crop and ultimately results in agricultural yields.

Figure 5a sketches the time series of All India rice yields and moisture adequacy for the period 1982 to 2000. A clear linear trend with an increase is characterized the All India rice yields whereas in moisture adequacy no trend is evident. The index of moisture adequacy and rice yields are correlated with a value of 0.21 only in spite of moisture role in crops performance over the given province. The most important aspect of the anthropocene era is the management of shortcomings in water need with intense irrigation facility and this was the reason for a low value of correlation. Multivariate ENSO Index variability was marked on a year wise and fluctuated from -0.87 in 1999 with a yield of 1921 kg/ha to a high value of 1.67 for a yield of 1471 kg /ha by the year 1987 (Figure 5b). The negative trend of rice yield with MEI was clear from the Pearson correlation magnitude of -0.23. Figure 5c illustrates the increase of rice yield as NDVI climbs to higher values and this amply proved with a correlation of 0.62 and was significant at 0.01 levels. The growing degree days displayed a correlation of -0.12 with rice yield with no significance (Figure 5d). The maxima and minima of rice yield of 1746 and 1645 kg/ ha are noticed in the years of 1987 and 1997 that are preceded by El Nino episodes.

Agro climatic model

The successful regression [85] of rainfall, southern oscillation, Nino-3 SST, growing degree day along with NDVI on All Andhra Pradesh (India) rice yield encouraged the present study to apply for All India rice yields to propose the statistical model incorporating a) moisture adequacy which alone ascertain in matching with the water need of the crop with the available rainfall together with the soil moisture b) preference of Multivariate ENSO Index compared to Nino-3 SSTs, c) Normalized Vegetation Index and d) Growing degree day.

The suggested regression expression in estimating the rice yields is reasonably in agreement with the actuals. The actual yields are correlated with the estimated is 0.83 and is substantial and is significant at 0.01 level (Figure 6a). The highest difference for the estimated with the actual was 271 kg/ha in the year 1983 whereas a difference of 247 kg/ha was in the year 2000 compared to the estimated yield (Figure 6b). The present study brings out the importance of regional meteorological variables along with the distant teleconnection that originates from ocean-atmosphere coupling variables (Equatorial Pacific Ocean along

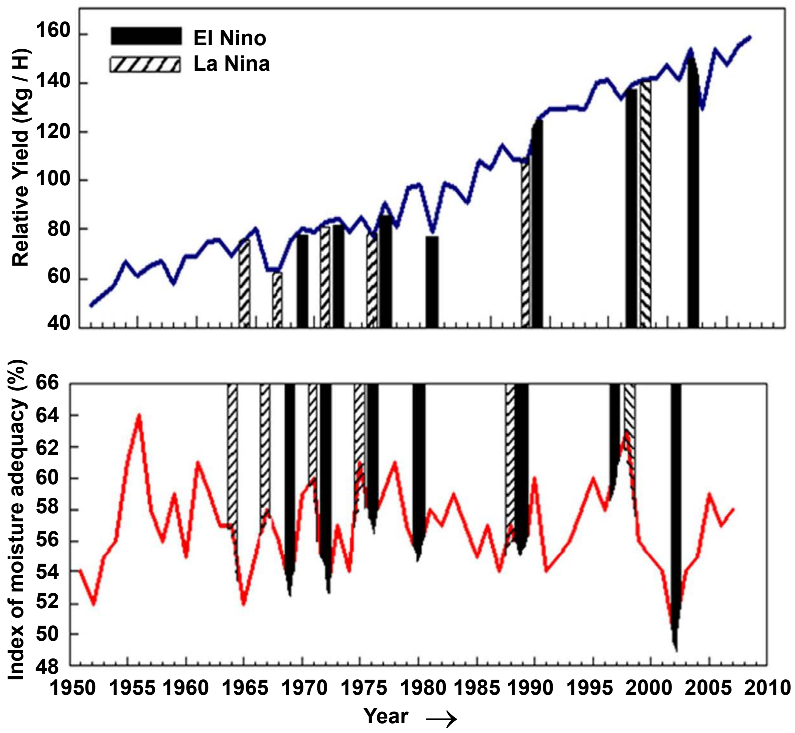

Figure 4: Yearly march of a) All India rice yield and b) Index of Moisture Adequacy (IMA).

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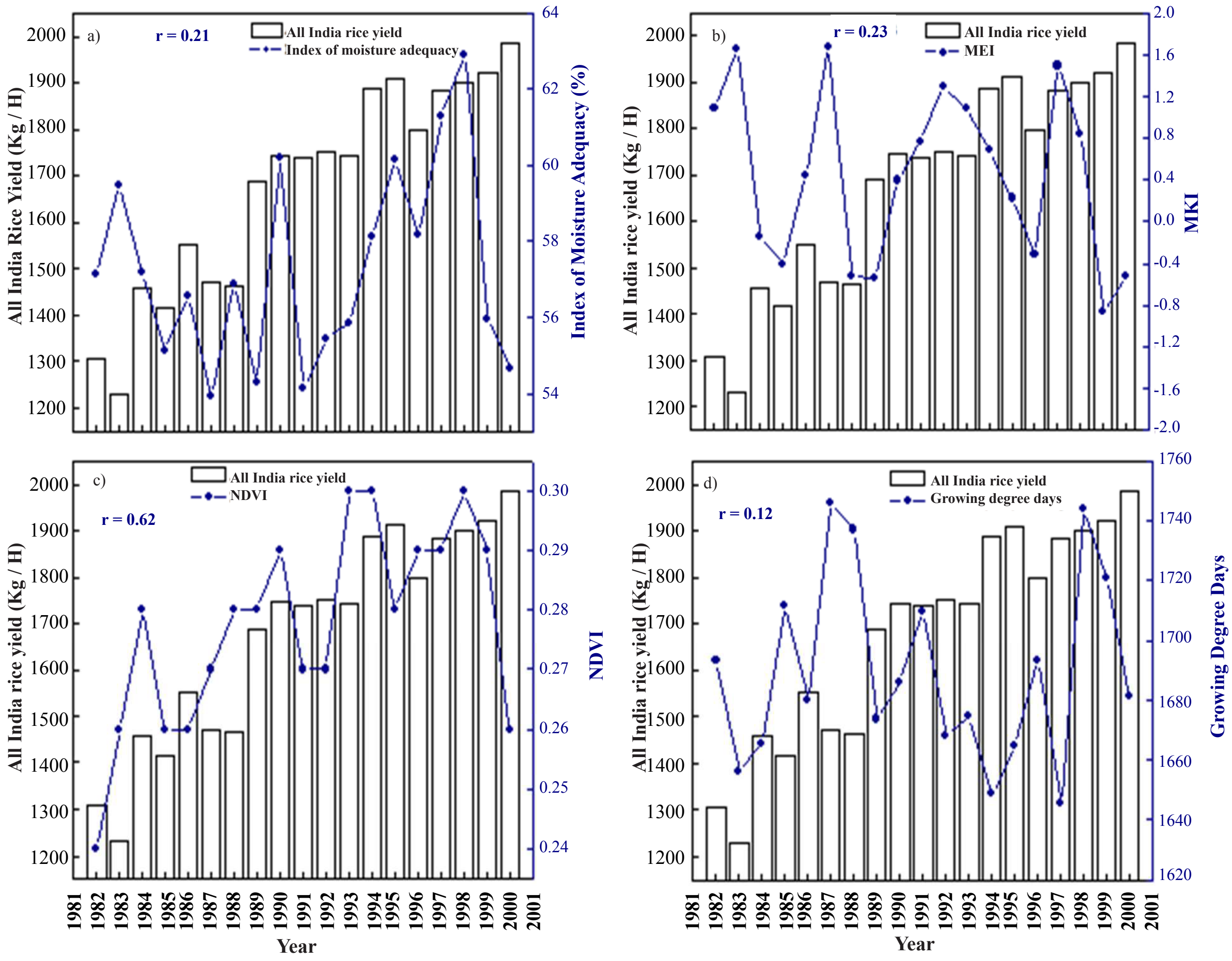

Figure 5: Yearly march of All India rice yield with (a) Index of moisture adequacy (IMA) b)Multivariate ENSO Index (MEI) c) Normalized Difference Vegetation Index (NDVI) and d) Growing Degree Days (GDD).

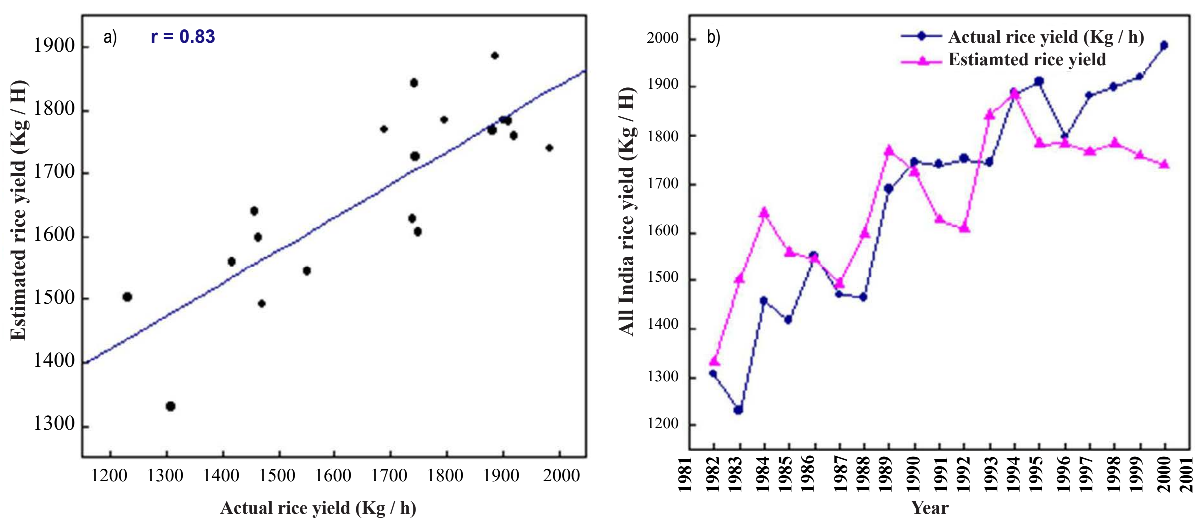

Figure 6: Linear fit and Yearly march of for actual and estimated rice yield-India.

with the Southern Oscillation) in modulating the agricultural output from the region under consideration.

The regression expression in obtaining the All India rice yields is as follows:

Rice yield (Kg/ha) = -0.198 (IMA)-54.96(MEI) + 8211.34(NDVI)-1.021(GDD)+1159.98 --------3

Conclusion

Spatiotemporal variations in the phonological events of either a crop or vegetation over the selected regions in India are clearly perceptible in occurrence of maximum NDVI earlier over NW India in the month of September compared to Central NE India, NE India and west Central India while in Peninsular India a delay of two months (November) in recording the highest NDVI-a feature that explains gradient in phonological events over the landscape under consideration.

The correlation (R) was substantial (0.82 to 0.86) in obtaining the NDVI data from moisture adequacy and potential evapotranspiration over NW, west Central India and Peninsular India for the La Nina episode whereas R square was low (0.30 to 0.49) for the NE, NW and Peninsular India during La Nina and El Nina events . The estimated NDVI from regression for the regions over India was well in agreement with the observed.

It is observed from seasonal cycles that the MEI increases from January to May / June with a fall in IMA during this time. The elevation in moisture adequacy in space and time over India is in accordance with the schedule of onset and vigor of the SW monsoonish weather and on whose heels the growth of vegetation (NDVI) has a strong bearing.

Normally the length of growing period increases from NW to NE India via Central NE India but the same decreases from West Central India to Peninsular India .The number of humid days increased in the length of the growing period during El Nino and La Nina episodes.

Enrichment and depletion of moisture adequacy over the selected regions are associated with the prevalence of La Nina and El Nino episodes respectively. It is observed that fluctuations in moisture adequacy results in large fluctuations in All India rice yield and the rice yield displayed a linear trend but no trend is noticed in moisture adequacy.

Even though the correlation of moisture adequacy with rice yield was low (0.21), the former exerts substantial impact on the latter but because of the reason that irrigation facilities are improved and this could be the primary factor in weakening the correlation value . The multiple regressions that is suggested incorporates not only local parameters but also the distant region teleconnection (Equatorial Pacific Ocean) in explaining the impacts of climate mayhem in All India rice yields and whose correlation was as much as 0.83 and was significant at 0.01 level.

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