Evolution and Progression Characteristics of Indian Summer Monsoon

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Abstract

Indian summer monsoon is the principal rainy season for India and thus the commencement and the cessation of this season bears a great significance. The initiation of the cross equatorial flow off the Somalia coast of Africa during May in response to the heating over the South Asian continent marks the beginning of the summer monsoon evolution process over the Arabian sea. The onset of monsoon over the South Kerala coast is manifested as a consequence of significant changes of atmospheric circulation, cloudiness etc and evolves gradually over the Arabian Sea. Long term records of onset over Kerala suggest that the event is more or less regular and its normal onset date of arrival over kerla is 31st May with standard deviation of about eight days. The recent studies with the large scale analyses of the summer monsoon over the Indian region (Ramesh et al. 1996, Swati et al. 1999, Fatsullo and Webster 2003, Prasad and Hayashi 2004) suggest that it is possible to determine the onset of monsoon objectively by using potential indicators. In this study the onset, progression and withdrawal of the Indian summer monsoon was retrospectively studied using ERA-40 data for the period 1958-2001. In addition , the temporal evolution of OLR fields from NOAA long term OLR data sets to determine the association of cloud cover with the onset of monsoon.

Key word : Monsoon, Onset, ERA-40, Withdrawal, objective method

1. Introduction.

The need for objective criteria for the determination of onset/withdrawal dates for the Indian summer monsoon (ISM) has been recognized for a long time. Such a criteria is useful as a diagnostic tool for studying the monsoon transitions as well as to evaluate the performance of general circulation models in simulating the monsoon. It can also aid objective assessment of the capabilities of numerical models in reproducing monsoon variability. The temporal and spatial structures of the atmospheric circulation with the climatology and inter-annual variations of the ISM are one of important indices to study. More over it can also help in forecasting the monsoon onset/withdrawal dates using numerical model out puts. The ability to accurate prediction of an early or late monsoon onset and withdrawal is also of substantial economic consequence, even if such forecast can apply to broad regions.

Various methods have been proposed to determine the date of onset based local rainfall or convection activity indicated by the satellite-observed data. (Tao and chen,1987;AnanthKrishnan and Soman,1988;, Murakami and Matsumoto, 1994; Lau and Yang,1997;Wang and Linho,2002). Some other methods are based on the change of prevailing winds (Holland,1986) or combined wind-convection criteria (Wang and Wu 1987;MasuMuto,1997, Xie et.al 1998). However a variety of dynamic and thermodynamic precursors are known to exist (AnanthKrishnan and Soman,1991; Murkami et.al, 1986). Using such selected precursors Ramesh et al 1996, Swati et al 1999, Fasulo and Webster,2003 and Prasad and Hayashi 2004 developed some objective criteria for determining onset and withdrawal dates of ISM.

The present study focuses specifically on the onset/withdrawal of the Indian summer monsoon system especially Arabian Sea branch and Bay of Bengal branch by using European Center for Medium Range weather forecasts (ECMWF) reanalysis (ERA 40) data sets.

2. Data & Objective Criteria.

The ECMWF Reanalysis (ERA) data sets with spatial resolution of 2.5 deg x 2.5 deg for the period 1957-2002 was used in this study (Gibson et al. 1997). The re-analysis was carried out using three dimensional variational technique using T159L60 version of the Integrated Forecasting system to produce the analyses every six hours. As the reanalysis model also exerts an influence on the final output fields, outputs are categorized by type. For type-A fields, such as the rotational wind and upper-air temperatures, the output is strongly influenced by assimilated data and considered the most reliable. However, for type-B fields the influence of both observations and the model during the assimilation processes can be important. Humidity and divergent wind fields are examples of type-B fields. Fields, such as rainfall and evaporation, that are purely model derived subject to the constraints imposed by assimilated observations, are categorized as type-C. In the present study efforts were made using A and B type fields.

The studies of Prasad and Hayashi ,2004 shown that, there is well-defined large-scale moisture variability at the time of ASM onset, particularly over the Arabian

Sea. Further, Fasullo and Webter (2003) clearly shown that hydrological processes such as Vertical Integrated Moisture Transport (VIMT) are linked to the basic monsoon forcing. They defined VIMT as:

$$\text{VIMT} = \int_{\text{surface}}^{300\text{ mb}} q\mathbf{U}\, dp,$$

where q is specific humidity, U is wind vector. Above 300 hPa specific humidity in the tropics is at least two orders of magnitude smaller than near the surface and moisture transports are of therefore negligible influence to the calculation of Total VIMT. Earlier studies of Webster and Yang (1992) also clearly brought out that the variability of the summer monsoon reflects in time mean Zonal Wind (u) Shear between 850 and 200 hPa (ZWS). Parasd and Hayashi, 2004 also shown that at the time of withdrawal, wind changes are more prominent then the changes in the moisture regime. In that study they developed and tested objective procedures to determine the onset and withdrawal of ASM using normalized time series of the above VIMT and ZWS. The time series χ is normalized by transformation:

$$\bar{\chi} = 2 X \{[\chi - \min(\bar{X})]/[\max(\bar{X}) - \min(\bar{X})]\} -1$$

where, $\bar{x}$ is the mean annual cycle χ is the normalized time series such that the climatalogical annual cycle ranges from -1 to +1.

Figure 1 depicts the annual cycle of normalized time series of VIMT and ZWS for all the years (1957-2001) of the ERA 40 data averaged over the Arabian Sea region (65-75E, 10-17.5N). Both the figures a and b clearly shows a very distinctive seasonal cycle and they are having maximum amplitude during monsoon and reducing before and after that. The onset of the monsoon is defined as the times of year at which VIMT index exceeds the zero and withdrawal is defined as the times of year at which ZWS index falls below the zero. Further studies shows that the above will be fulfilled for Arabian Sea branch only. But With a slight modification to the onset and withdrawal criteria the same index can be applied to other regions of ISM also. The onset criteria, is modified as the starting day of the period with more number of positive HOWI days than negative HOWI days in a cycle. Then withdrawal is the first day of the period with more number of negative ZWS days compared to positive ZWS days in a cycle after onset.

In order to show the check the objective criteria by means of large-scale circulations associated with monsoon onset, pentad means (by centering onset day) of daily fields has been composed. The onset day is denoted as day 0 while the signs of '-' and '+' denotes prior to and after the onset day, respectively. Then pentad mean fields are obtained with pentad 0 representing 0 to +4 and pentad –1 denoting day –1 to day –5.Similler procedures are done for other successive pentads.

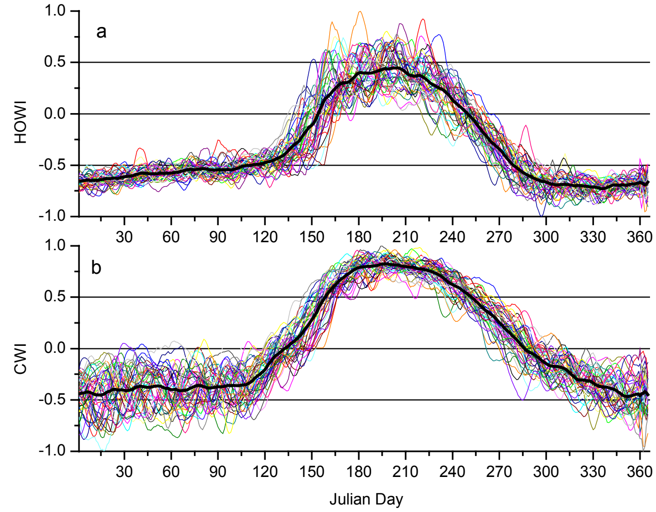

Fig 1: Seasonal evolution of daily a) HOWI and b) CWI for Arabian Sea branch (50° -70°E and 10° to 17.5 °N) along with climatological mean values are denoted by thick line.

Figure 2 depicts the 850 hPa wind pentad composite based on Onset date for the Bay of Bengal branch. This clearly shows that onset criteria used is successfully able to judge onset day with clear observable change in zero pentad, with strong monsoon circulation after the pentad and near absence of such features before that. It also shown that onset over Bay of Bengal occurs earlier than that of Arabian sea branch. Similarly to show the broad scale circulation features at the time of withdrawal pentad means centered on withdrawal dates are composited The pentad means in figure 3 composited based on the date of withdrawal. It clearly shows the absence of south-westerlies in the region and by +1 and +2 they are replaced by mid-latitude circulation. The above figures clearly indicates that the objective criteria for determining onset /withdrawal dates is comparatively judges better.

The onset and withdrawal dates for the period of 1957-2001 are computed for both Arabian Sea and Bay of Bengal braches of ISM using ERA-40 data and by applying the above objective criteria. The results are tabulated in the Table-I along with the All India Rainfall index (Parthasarathy et al 1992; parthasarthy et al 1995;]. While the methods for determination of monsoon withdrawal are very few there are number of objective methods for determination of monsoon onset. Earlier studies by Fasullo and Webster 2003 show that the association between total ISM rainfall and both monsoon onset and withdrawal when onset dates from the traditional onset dates from the IMD are considered.

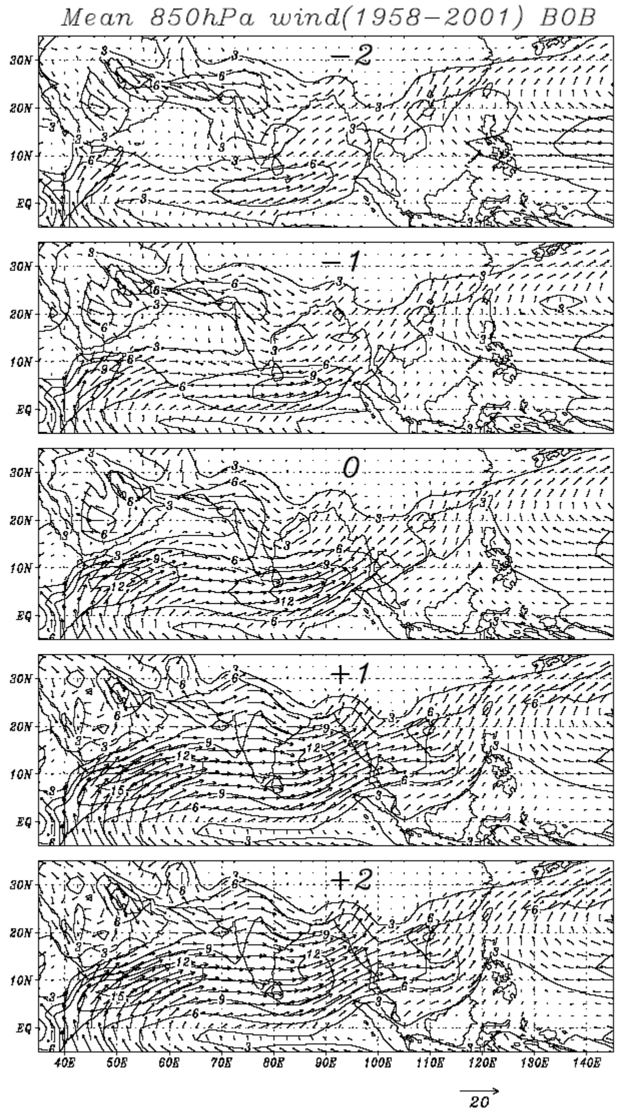

Fig 2. Pentad mean evolution of the composite 850 hPa wind vector with centering the onset dates for Bay of Bengal region. Here 0 denotes the onset pentad and "-"and "+" refer to prior to and after the onset pentad respectively. See the text for detail definition of onset pentad.

However the present criteria shows strong correlation between total ISM rainfall both onset and withdrawal. Thus the length of monsoon is shown to be strongly correlated to its over all strength. Length of monsoon is computed using both Arabian Sea and Bay of Bengal branches.

Using similar approach Prasad and Hayashi 2004 are able to determine multiple transitions of Asian summer monsoon and thus they proved that the above objective criteria is able to identify the onset/withdrawal over wide regions. In the present study attempts are made to use these two indexes for monitoring the progress and withdrawal of ISM. For this purpose some 46 points evenly spread over India as suggested by

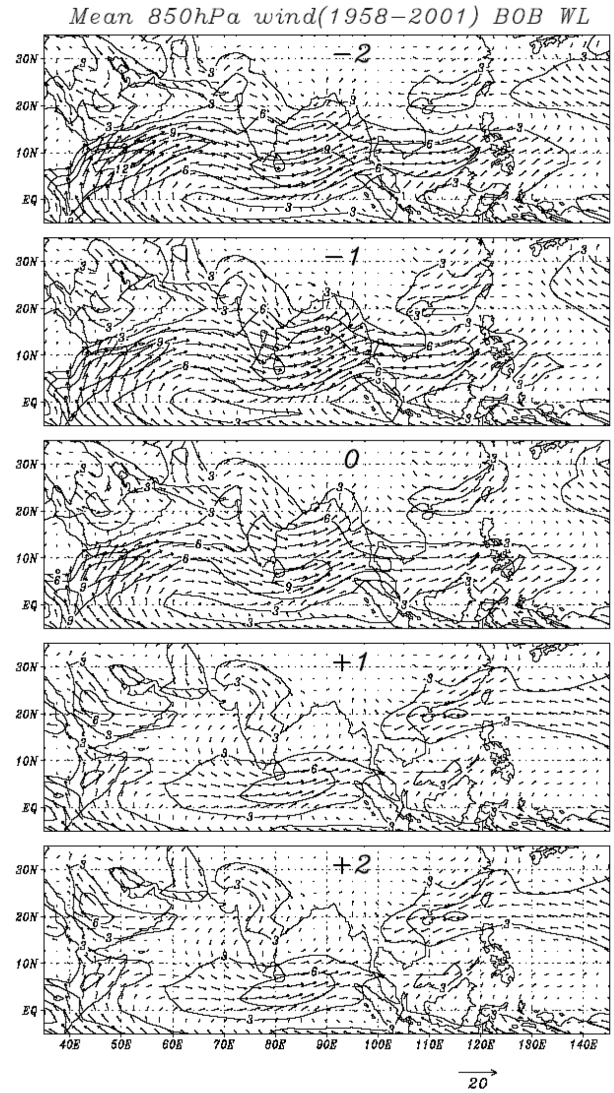

Fig 3. Same as fig2 but for centered at date of the withdrawal.

Ramesh et al are selected. Then daily variations of the above indexes were computed for all 46 points of total ISM period for monitoring progress and retreat of ISM using ERA-40 data. The results thus obtained will be presented in this paper. These aspects of the summer monsoon over the India play crucial role in the initiating the crop sowing process with the commencement of rainy season and also for the planning of various other agriculture operations over the different parts of Indian sub-continent. In the present study these aspects were computed retrospectively. But it has lot of potential for using in forecasting using global circulation model out puts.

Year	AIRI	Bay of Bengal		Arabian Sea	
		Onset	Withd.	Onset	Withd.
1958	889	02Jun	29Oct	13Jun	18Oct
1959	944	23May	20Oct	22May	19Oct
1960	839	16May	24Oct	04Jun	15Oct
1961	1020	18May	29Oct	02Jun	15Oct
1962	809	28May	16Oct	6Jun	11Oct
1963	857	24May	28Oct	2Jun	13Oct
1964	922	30May	13Nov	07Jun	18Oct
1965	709	23May	08Oct	04Jun	04Oct
1966	740	30May	14Oct	06Jun	14Oct
1967	860	13May	14Oct	10Jun	11Oct
1968	754	02Jun	25Oct	09Jun	07Oct
1969	831	13May	26Oct	27May	27Sep
1970	939	14May	01Nov	27May	21Oct
1971	886	28May	04Nov	24May	28Oct
1972	652	11May	16Oct	15Jun	26Sep
1973	913	03Jun	22Oct	03Jun	14Oct
1974	748	20May	09Nov	01Jun	24Oct
1975	962	23May	13Nov	31May	03Nov
1976	856	20May	04Oct	28May	01Oct
1977	883	11Jun	09Oct	04Jun	05Oct
1978	909	22May	16Oct	18May	13Oct
1979	707	15Jun	07Oct	12Jun	08Oct
1980	882	27May	08Oct	01Jun	09Oct
1981	852	27May	21Oct	03Jun	08Oct
1982	735	28May	04Oct	04Jun	01Oct
1983	955	28May	28Oct	13Jun	19Oct
1984	836	24May	27Oct	28May	16Oct
1985	760	21May	21Oct	25May	20Oct
1986	743	09Jun	22Oct	04Jun	12Oct
1987	697	31May	17Oct	01Jun	08Oct
1988	861	27May	26Oct	08Jun	09Oct
1989	866	17May	25Oct	27May	17Oct
1990	908	07May	19Oct	19May	13Oct
1991	784	31May	03Nov	05Jun	13Oct
1992	784	10Jun	26Oct	12Jun	19Oct
1993	896	24May	21Oct	28May	15Oct
1994	938	29May	16Oct	01Jun	19Sep
1995	790	06May	20Oct	08Jun	19Oct
1996	852	11Jun	10Oct	01Jun	11Oct
1997	870	16May	04Oct	12Jun	29Sep
1998	851	14May	29Oct	06Jun	23Oct
1999	820	18May	04Nov	18May	02Nov
2000	773	12May	28Oct	15May	27Oct
2001	804	20May	19Oct	21May	23Oct

Table :1 showing the Onset and witdarwal dates of ISM alon with all India rainfall Index.

Reference:

AnanthKrishnan, R., and M.K. Soman, 1988; The onset of south-west monsoon over Kerla: 1901-1980. J. Climatol., 8, 283-296.

AnanthKrishnan, R., and M.K. Soman, 1991: The onset

Fasullo J and P.J. Webster, 2003: A Hydrological Definition of Indian Monsoon onset and withdrawal. J. Climate, 16, 3200- 3211.

Fieux, M., and H.Stommel 1977; Onset of southwest monsoon over the Arabian Sea from marine reports of surface winds: Structure and variability. Mon. Wea. Rev, 105, 231-236.

Flatau, M.K.,P.J.Flattau, and D. Rudnick, 2001: The dynamics of double monsoon onsets. J. climate, 14, 4130-4146.

Gibson, J.K., P. Kallberg, S. Uppala, A. Hernandez, A. Nomura and E. Serrano, 1997: ERA description. ECMWF Reanalysis Project Report Series: 1, 72pp.

He, H, J.W. McGinnis, Z. Song and M. Yanai, 1987: Onset of the Asian monsoon in 1979 and the Effect of the Tibetan Plateau. Mon Wea. Rev, 115, 1966-1995.

Holland,G.J.,1986: Interannual variability if the Australian summer monsoon at Darwin-1952-82., Mon Wea. Rev,114, 594-604.

Kawamura, R. Y. Fukuta, H. Ueda , T. Matsuura and S. Iizuka, 2002: A mechanism of the onset of the Australian summer monsoon. J. Geophys. Res., 107,10.1029/2001JD001070.

Lau, K.M., and S. Yang,1997: Climatology and interannual variability of the southeast Asian monsoon. Adv. Atmos. Sci., 14, 141-162.

MatsuMuto J., 1997: Seasonal transition of summer rainy season over Indochina and adjacent monsoon region. Adv. Atmos. Sci., 14, 231-245.

Murkami, T., L.Chen and A. Xie, 1986: Relationships among seasonal cycles, low frequency oscillations and transient disturbances as revealed from outgoing longwave radiation data. Mon. Wea. Rev., 114, 1456-1465.

Murakami, T. and J. Matsumoto, 1994: Summer monsoon over the Asian Continent and western north Pacific, J. Met. Soc. Japan, 72, 719-745.

Parthasarthy, B, R.R. Kumar, and D.R. Kothawale, 1992: Indian summer monsoon rainfall indices, 1871-1990. Meteor. Mag.,121,174-186.

Prasad, V.S, Taiichi Hayashi,2004: Diagnostic determination of onset/withdrawal of Asian summer monsoon (in press).

Ramesh, K.J, Swati Basu ,and Z.N. Begum, 1996: Objective determination of onset, Advancement and Withdrawal of the summer monsoon using large scale forecast fields of a global spectral model over India, Meteor. and atmospheric Physics,61, 137-151.

Rao, Y.P,1976: Southwest monsoon: Synoptic Meteorology, Meteorology Monograph, No 1/1976, India Meteorological Departmet,367pp..

Swati Basu, K.J. Ramesh and Z.N. Begum,1999: Medium Range Prediction of summer monsoon activities over India vis-avis their correspondence with observational features, Adv. in Atmos. Sci.,16,1,133-146.