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Association between mid-latitude circulation and onset of Indian summer monsoon over Kerala

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सार – इस शोध–पत्र में 1971 से 1989 की अवधि में, विभिन्न क्षेत्रों में मध्य अक्षांशीय परिसंचरण और केरल में भारतीय ग्रीष्मकालीन मानसून वर्षा ऋतु के आरंभ के बीच दूरसंयोजनों की जाँच की गई है। याम्योतरी परिसंचरण अक्षांक और क्षेत्रीय प्रवाह के सामान्य क्षोभ तथा केरल में मानसून के आरंभ के बीच महत्वपूर्ण नकारात्मक संबंधों का पता चला है। 160°पू. से 45°प. के क्षेत्र में क्षेत्रीय सूचकांक की बारम्बारता और केरल में मानसून के आरंभ की तारीखों के बीच सुदृढ और महत्वपूर्ण सकारात्मक संबंधों के होने का भी पता चला है।

ABSTRACT. Teleconnections between mid latitude circulation over different sectors and onset of Indian summer monsoon over Kerala for the period of 1971-89 have been examined. Significant negative relationships are observed between the meridional circulation indices and general perturbation of zonal flow and the monsoon onset over Kerala. Strong and significant positive relationships are also observed between frequency of zonal index over sector 160° E to 45° W and onset dates of monsoon over Kerala.

Key words – Teleconnection, Zonal index, Onset monsoon, Mid latitude circulation.

1. Introduction

Indian summer monsoon brings welcome rains to India in almost unremitting regularity for thousands of years. However, the onset of Indian summer monsoon, its activity during the season and its withdrawal shows large variations from year to year. The past history of Indian rainfall suggests that once every fourth or fifth year the monsoon might be deficient. A delay in the onset of the monsoon is associated with the lowering of levels in hydroelectric reservoirs resulting reduction in the generation of hydroelectricity. This reduction in the generation of hydroelectricity and the resulting power cut in industries critically affect country's economy from year to year.

An exciting concept that emerged over the years suggests a link between climatic anomalies that are separated by large distances and long intervals of time. These are often referred to as meteorological teleconnections.

Many researchers have studied Teleconnection study between onset of monsoon over India and various parameters. Sutcliffe and Banon (1966) observed that 200 hPa easterly wind at Aden is related with onset over Kerala. Flohn (1960) observed relationship between onset dates and zonal index over the hemisphere. Rai Sirkar and Patil (1961) suggested that 300 hPa level temperature during May can be useful predictors of early or late onset of the monsoon. Rai Sirkar and Patil (1962) also found the relationship between east-west wind vector at 300 hPa level over India and arrival of the monsoon over the south peninsula. Ramaswamy (1965) examined that early onset of monsoon is associated with much less cellular circulation at 500 hPa level in the atmosphere than in a year of late monsoon. Ramaswamy (1971) also found that late onset of summer monsoon is in association with

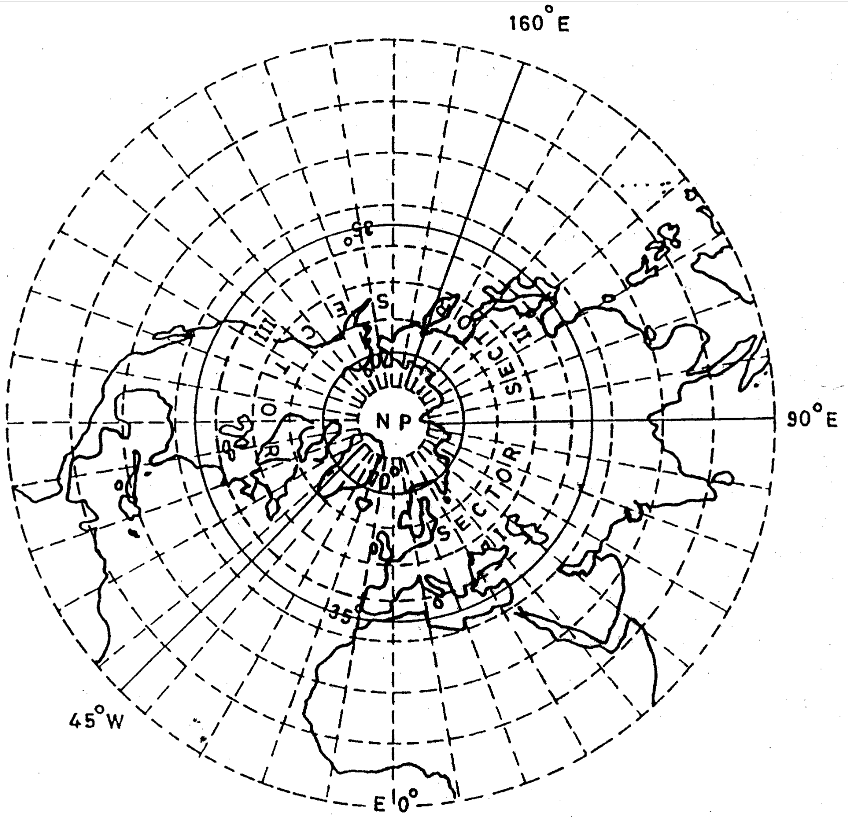


Fig. 1. Schematic diagram of three sectors over which circulation indices are defined

anomalous westerly flow at 500 hPa over northern India. Kung and Sharif (1980) developed a regression model for prediction of the onset dates of the summer monsoon over Kerala. Kung and Sharif (1982) considered 700 hPa January zonal wind and 700 hPa March temperature over Australia, April Indian Ocean temperature over area 10°-20° N, 60° -70° E and developed regression equations for predicting the monsoon onset dates over Kerala. Dey and Kathuria (1986) observed the association of Himalayan snow cover and onset of monsoon over Kerala. India Meteorological Department uses multiple regression equations for long range predictions of onset (Thapliyal, 1993). Rajeevan and Dubey (1995) developed regression equation for long range prediction of onset date over Kerala using April mean surface temperature index and winter Eurasian snow cover as independent variable. Chattopadhyay and Bhatla (1994, 1994, 1999) had already established the relationship between meridional, zonal and perturbation of zonal flow with monsoon rainfall respectively.

In the present paper the authors examined the association of onset of monsoon over Kerala with zonal index, meridional index and the ratio of these two indices. The index of zonal circulation over a particular geographical area is expressed as the strength of the middle latitude westerlies in the mid-troposphere. Generally, zonal index may be said to periodically fluctuate between two extreme states. The one characterized by strong zonal westerly circulations with a contracted circumpolar vortex is representative of high index and the other marked by strong meridional circulations with meandering or cellular patterns and with an expanded circumpolar vortex, representing a low index. A rough cyclic variation of the general circulation between high and low index situation is called index cycle, the period of which generally varies from 3 to 8 weeks. An extremely low or high index situation may persist, though rarely, for over a month, resulting in abnormal weather throughout the world (Wada, 1975). The zonal index (I_z) is the measure of the strength of the zonal westerlies at 500 hPa over a geographical sector or whole hemisphere in the mid-latitude.

The meridional exchange of air between higher and lower latitudes occurs by occasional large outbreaks of polar air transporting heat and moisture to the higher latitudes. Such inter-zonal exchange in the mid-troposphere is expressed in terms of index of meridional circulation over a particular geographical area or the whole hemisphere in the mid-latitude. The meridional index characterizes the intensity of transfer of air in the meridional direction over a geographical sector of the mid-latitude zone. Like zonal index, meridional index (I_m) also may be said to periodically fluctuate between two extreme states. The one characterized by low meridional circulations with a contracted circumpolar vortex and the other marked by strong meridional circulations with meandering or cellular patterns and with an expanded circumpolar vortex.

In addition to this, another index namely the ratio of meridional to zonal index *i.e.* I' ($=I_z/I_m$) is sometimes defined as general perturbation of the zonal flow. The importance of zonal index, meridional index and perturbation of the zonal flow on the onset of monsoon over Kerala has been examined in this paper.

2. Details of data

The dates of onset of monsoon over India for the period 1901-78 have been taken from Shukla (1987). For the recent years, *i.e.* 1979-90, these dates have been obtained from the Indian Daily Weather Reports issued by the Indian Meteorological Department.

The zonal index and meridional index data are available from 1971 to 1989 for 19 years only. The indices are obtained from the synoptic bulletins, northern hemisphere, published by the Department of World Weather, Hydrometeorological Center of USSR. The zonal index and meridional index data refer to 500 hPa level for the latitudinal period 35° N-70° N, for three sectors 45° W and 90° E (sector 1), 90° E to 160° E (sector 2), and 160° E to 45° W (sector 3). Fig. 1 shows the various sectors over which the indices are defined.

It is clear from the figure that sector 1 cover the whole Europe and half of Asia covering most of the Indian monsoon region while sectors 2 and 3 cover mainly the western Pacific and eastern Pacific Ocean respectively. Taking the area weighted monthly mean values over sectors 1, 2 and 3 covering the whole earth has also created a hemispheric zonal index, called sector 4.

The ratio $I'=I_z / I_m$ defines the general character of the circulation. Cases where $I' > 1$ may be called meridional circulation while the cases where $I' < 1$ may be called zonal circulation. On this basis, using daily indices of I_z and I_m, the frequency (number of days) of zonal circulation (F_z) over all the four sectors is also found out for all the months for each year. The strength of zonal index, meridional index and the ratio of the two are expressed as percentage anomaly (ΔI_z), (ΔI_m), ($\Delta I'$) and frequency of zonal index as percentage anomaly (ΔF_z) from their respective monthly means of 19 years period *i.e.* 1971-89. Successive season means of anomaly of zonal index and its frequency were formed from the monthly means by simple arithmetic averaging.

TABLE 1

Correlation Coefficient (CC × 100) between the zonal index circulation (I_z) and frequency (F_z) parameters and monsoon onset dates over Kerala for different months and seasons. Numbers in brackets indicate the sectors. Number 4 indicates the northern hemisphere

Months/	Onset dates	
Seasons	I_z	F_z
Oct(-)	48^{5}(4)	53^{5}(3), 54^{2}(4)
Jan(-)		49^{5}(2)
SON(-)	48^{5}(3), 46^{5}(4)	64^{1}(3), 50^{5}(4)
OND(-)	57^{2}(4)	46^{5}(1), 58^{2}(3), 54^{2}(4)
NDJ(-)	49^{5}(2)	48^{5}(2)

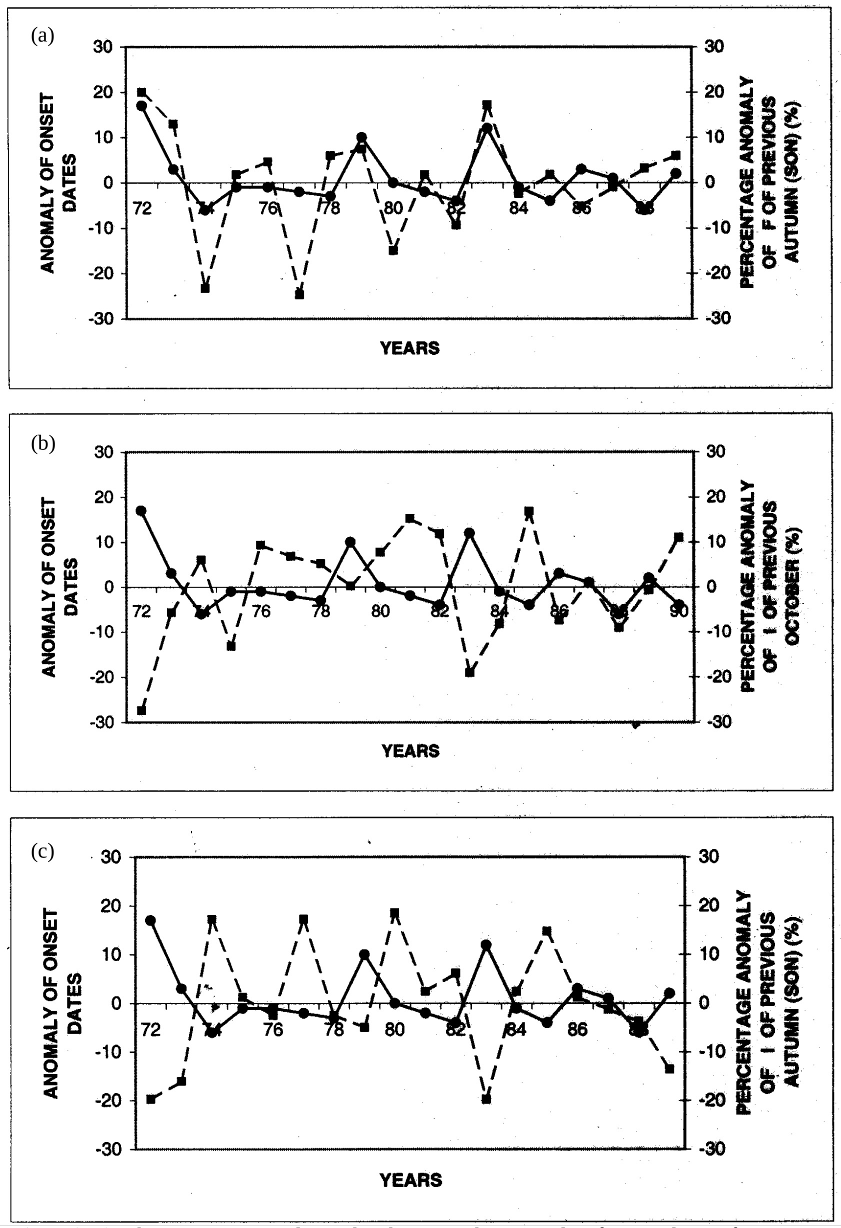
The superscripts 1,2 and 5 stand for 1%, 2% and 5% significant levels respectively. The signs (-) in parenthesis indicate antecedent months/seasons

3. Results and analysis

The results of analysis of teleconnection between mid-latitude circulation indices *viz.* I_z, I_m and I' monsoon onset dates over Kerala are presented in this section.

3.1. *Monsoon onset dates over India and zonal index*

Table 1 shows that previous October, autumn (SON), OND, NDJ seasons I_z and F_z have strong positive correlation coefficient (CC) with the monsoon onset dates over India. Out of all these antecedent parameters, the previous autumn (SON) season F_z over sector 3 has the highest absolute value of CC of 0.64 at a significant level of 1 per cent with the onset dates of monsoon. Fig. 2(a) shows the interannual variation of sector 3 previous September to October (SON) season zonal index percentage anomaly and monsoon onset dates anomaly for the years 1971 to 1989. Fig. 2(a) clearly shows the positive relationship. In other words, an above (below), normal strength of frequency of zonal index during previous autumn (SON) season over sector 3 is associated with late (early) onset of the succeeding monsoon season rainfall. Thus, frequency of zonal index of previous



Figs. 2(a-c). The year-to-year relationship between the anomaly of onset dates of monsoon (ΔP-days) and percentage anomaly of (a) zonal index (ΔI_z) of previous autumn season (SON) over sector 3 (b) meridional index (ΔI_m) of previous October over sector 3 (c) perturbation of zonal flow ($\Delta I'$) of previous autumn season (SON) over sector 3. (ΔP – solid line, ΔI_z, ΔI_m, $\Delta I'$ – dashed line)

autumn (SON) season can be used as a predictor of onset dates of monsoon over India explaining 41 percent variability.

3.2. *Monsoon onset dates and meridional index*

Table 2 shows that meridional index of previous October over sector 3 and hemispheric; previous December over sector 1, 3 and hemisphere; previous January over sector 3; previous autumn (SON) season over sector 1, 3 and hemisphere; previous OND season over sector 1, 3 and hemisphere; previous NDJ season over sector 3 and hemisphere and previous winter (DJF) season over sector 3 and hemisphere all have strong negative CCs with the onset dates of monsoon over Kerala. Out of all these parameters, the meridional indices

TABLE 2

Correlation Coefficient (CC × 100) between the meridional index circulation (I_m) and monsoon onset dates over Kerala for different months and seasons. Numbers in brackets indicate the sectors. Number 4 indicates the northern hemisphere

Months/Seasons	Onset dates
Oct(-)	-70^{1}(3), -68^{1}(4)
Dec(-)	-55^{2}(1), -54^{2}(3), -58^{2}(4)
Jan(-)	-53^{2}(3)
SON(-)	-48^{5}(1), -57^{2}(3), -56^{2}(4)
OND(-)	-56^{2}(1), -62^{1}(3), -63^{1}(4)
NDJ(-)	-59^{1}(3),-55^{2}(4)
DJF(-)	-64^{1}(3), -56^{2}(4)

The superscripts 1,2 and 5 stand for 1%, 2% and 5% significant levels respectively. The signs (-) in parenthesis indicate antecedent months/seasons

TABLE 3

Correlation Coefficient (CC × 100) between the I′ and monsoon onset dates over Kerala for different months and seasons. Numbers in brackets indicate the sectors. Number 4 indicates the northern hemisphere

Months/Seasons	Onset dates
Oct(-)	-54^{2}(3), -60^{1}(4)
Nov(-)	-52^{5}(1), -53^{5}(4)
Jan(-)	-51^{5}(1)
SON(-)	-52^{5}(1), -70^{1}(3), -71^{1}(4)
OND(-)	-56^{2}(1), -48^{5}(2), -59^{1}(3), -69^{1}(4)
NDJ(-)	-50^{5}(2)
DJF(-)	-51^{5}(2)
MAM-DJF	48^{5}(2)
Nov(+)	50^{5}(3)

The superscripts 1,2 and 5 stand for 1%, 2% and 5% significant levels respectively. The signs (-) and (+) in parenthesis indicate antecedent and succeeding months/seasons respectively

of previous October over sector 3 has very high absolute magnitude of CCs of 0.70 at a significance level of 1 per cent with the onset dates of monsoon. The interannual variations of meridional index percentage anomaly and monsoon onset dates anomaly for the years 1971 to 1989 are depicted in Fig. 2(b). It clearly shows the strong negative association. In other words, an above (below), normal strength of meridional index during previous October or winter season over sector 3 is associated with an early (late) onset of the succeeding monsoon rainfall. Thus, meridional index of previous October over sector 3 can be used as predictor of onset dates of monsoon over Kerala explaining 49 per cent variability of onset dates of monsoon over Kerala. The association in October may help the prediction of onset of Indian monsoon as early as in November.

3.3. *Monsoon onset dates over India and I′*

It is found from Table 3 that onset dates over India is associated with October, November, January, autumn (SON), OND, NDJ and winter (DJF) seasons I′. It is also teleconnected with tendency parameter (MAM-DJF) of I′ over sector 2. Out of these parameters the previous autumn (SON) season I′ over hemisphere has the highest CC value of –0.71 (significant at 1 per cent level) with onset dates over Kerala. Fig. 2(c) shows the interannual variation of previous September to October (SON) season I′ over hemisphere percentage anomaly and monsoon onset dates anomaly for the years 1971 to 1989. Fig. 2(c) clearly shows the remarkably inverse relationship. In other words, the high (low) I′ of previous autumn (SON) season is associated with late (early) onset dates over Kerala. This indicates that previous autumn (SON) I′ can be used as a predictor for onset dates of monsoon over Kerala.

The above CC's does not shows any significant changes when we remove the data of 1972. The value of CC's between onset dates over Kerala and frequency of zonal index (over sector 3) is found to be 0.62 (significant at 1 per cent level), with meridional index (over sector 3) is 0.69 (significant at 1 per cent level) and with I′ (over hemisphere) is 0.71 (significant at 1 per cent level) without inclusion of data of 1972.

3.4. *Possible physical mechanism between mid-latitudinal circulation indices and onset dates of Indian monsoon*

To understand the statistical relations discussed above, one must determine the physical process at work to track the steps between cause and effect. We propose here a mechanism to account for the mid-latitude/Indian monsoon onset dates.

Monsoon is essentially caused by the annual cycle of diabatic heating and cooling (Asnani and Mishra 1975). The summer heating causes an extensive low pressure area, frictional inflow and vertical motion which in the presence of the moisture causes monsoon rainfall. This annual cycle of diabatic heating and cooling is accompanied by an annual cycle in all the elements of global circulation including semi-permanent troughs and ridges lying in north-south direction. Deviation in normal heating of the tropical atmosphere have a great effect not only in monsoon circulation patterns and rainfall during individual years but also on all elements of global circulation from year to year and season to season. For example, anomalies in tropical heating create anomalies in different components of monsoon *e.g.* lagging/leading behind of the ITCZ / near equatorial trough over the Bay of Bengal and Arabian Sea away from their normal pattern, location and intensity of Tibetan High etc., which in turn cause anomalies in the rising branches of the Hadley and Walker circulation over the monsoon region. This is one of the major causes of the interannual variation of the monsoon rainfall and its onset dates. One important cause of the anomalous heating of the tropical atmosphere is the anomalies in the meridional transport of sensible heat from the tropical region to the extra tropical region (Asnani and Awade 1978).

Pisharoty (1981) proposed a hypothesis linking poleward transport of heat and the activity of monsoon. This hypothesis suggests that an active (subdued) monsoon over southeast Asia is preceded by below (above) normal transport of heat during the preceding winter and spring months. In other words, Indian summer monsoon may be conceived of a delayed response to the inadequacy of the poleward transport of heat during the preceding winter and spring seasons.

Our study essentially corroborates Pisharoty's hypothesis, although the physical link between the meridional circulation and monsoon rainfall/onset dates is likely to be complex and may arise through more than one physical effect. One effect seems to be the presence of deep troughs in mid-troposphere over middle latitudes in winter and spring which have significant relation to the corresponding strength of meridional circulation. Significant meridional exchanges of sensible heat, momentum and moisture etc. between the tropical and extratropical regions are caused by these semi-permanent troughs and ridges lying in near north-south direction along with the migratory system of each season (Asnani and Awade, 1978). Anomalies in heat exchanges between tropics and extra-tropics cause anomalies in temperature gradient between tropics and extra-tropics. In association with excess heat going from the tropics to middle latitudes the temperature gradient between the tropical and extra-tropical region is reduced, zonal westerly flows in the middle latitudes become one of low zonal index while meridional flow becomes one of high meridional index. As proposed by Pisharoty (1981), a high (low) meridional index situation and / or a low (high) zonal index situation during previous winter / spring should therefore be followed by bad (good) monsoon, and / or delayed (early) onset of Indian monsoon. In other words, a negative correlation should exist between monsoon onset dates and zonal indices during previous winter (spring). Our analysis, infact, shows significant negative correlation coefficients -0.70 between Indian monsoon onset dates and winter meridional index of previous October over sector 3 and that our analysis also shows a significant positive correlation coefficient of 0.64 between Indian monsoon onset dates and winter zonal index of previous autumn season (SON-) over sector 3.

The above mechanism leads one to speculate that antecedent variations in the mid latitude annual variation of the Indian monsoon onset dates, and has some predictive value.

4. Conclusions

(*i*) Strong and significant direct relationship exists between previous autumn (SON) season frequency of zonal index over sector 160° E to 45° W and onset dates of monsoon over Kerala. This shows that previous autumn (SON) season frequency of zonal index over sector 160° E to 45° W has some potential to be used as a predictor of onset dates of Indian monsoon.

(*ii*) Significant negative relationship are observed between the meridional circulation indices of previous October over sector 160° E to 45° W and onset dates of summer monsoon over India indicates that they can be used as a predictors of onset of monsoon over Kerala.

(*iii*) Strong negative teleconnection with I′ of previous autumn (SON) season over hemisphere and onset dates of monsoon indicates that it can be used as predictor of onset of monsoon over Kerala.

The present investigation has demonstrated that temporal variability in global scale mid latitude circulation parameters namely I_z, I_m and I′ are related to onset dates over India. The investigation has also isolated several antecedent parameters that have considerable potential to be used as predictors for the long-range prediction of onset dates of monsoon over Kerala. It has also confirmed the idea that one of the centers of action for the interannual variability of onset dates of monsoon over Kerala may probably lie over the mid-latitude region.

The limitations of the present study are the relatively small data set of 19 years. Although, this data set may be enough to draw a hypothesis, there is no additional data available to test the hypothesis and authors are fully aware of the potential danger of drawing any definite conclusions from such statistical relationships, although studies based on data of even lesser number of years have been reported elsewhere. Before one can use mid-latitude circulation index for prediction of onset dates over Kerala, the results as observed in this study need to be further investigation with larger set of data to verify the relationship.

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