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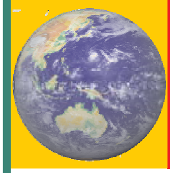

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NCC RESEARCH REPORT

Indian Summer Monsoon Onset: Variability and Prediction

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Abstract

A set of empirical models based on the principal component regression technique was developed for the operational forecasts of the date of monsoon onset over Kerala (MOK). Predictors for the models were derived over the Asia-pacific region associated with the MOK. Five Predictors during the second half of April only were used in the first model (Model-1) so that the forecasting of MOK can be prepared in the end of April it self. This model was developed to forecast the date of MOK in advance of around 15 days particularly in case of early onset that occurs in the middle of May. The second model (Model-2) used 4 additional predictors during the first half of May along with 2 predictors used in the Model-1 for the update forecast by 15th May. Both these models showed good skill in forecasting the date of MOK during the independent test period of 1997-2007. The root mean square error (RMSE) of the forecasts from both the models during the independent test period was about 4 days which was nearly half the RMSE of the forecasts from a climatology based model during the same period.

1. Introduction

The onset of the Indian summer monsoon is the most anxiously awaited weather singularity in the Indian subcontinent as it heralds the rainy season and marks the end of the hot summer. The onset of Indian summer monsoon represents significant transitions in the large scale atmospheric and oceanic circulation in the Indo-Pacific region. The onset of summer monsoon over Kerala (southern tip of India) is a crucial event and it marks the beginning of the rainy season for the country. There is no widely accepted definition of this monsoon transition. However, at the surface, monsoon onset is recognized as a rapid substantial and sustained increase in rainfall. The first rains of monsoon occur over Burma and Thailand in Mid May and subsequently extend to the northwest. Over India, monsoon onset occurs initially across the south peninsula in early June, when heavy rains lash south peninsula after the cross-equatorial low-level jet (LLJ) is established across the Somali coast into the near-equatorial Arabian Sea. This phenomenon is usually accompanied by the formation of a mid-troposphere shear zone across the Bay of Bengal to the south-east Arabian Sea in which a cyclonic vortex may be embedded. The northward progression of the monsoon is symptomatic of a large scale transition of a deep convection from the equatorial to continental regions (Rao 1976, Sikka and Gadgil 1980, Webster et al. 1998). By middle of July, monsoon covers the whole country.

Large scale changes occur in the circulation features associated with the onset phase of Indian monsoon (Pearce and Mohanty 1984, Ananthakrishnan et al. 1983, Ananthakrishnan and Soman 1988, Soman and Krishna Kumar 1993, Joseph et al. 1994, Joseph et al. 2006). At the date of monsoon onset, there is a band of deep convection (low OLR) in the east-west direction passing through southern tip of India, a maximum cloud zone as identified by Sikka and Gadgil (1980). Fig.1 shows the spatial structure of composite mean OLR during the onset phase. During the summer monsoon onset phase, major changes are also observed in the atmospheric wind flow at all levels. There is an appreciable acceleration of cross equatorial flow across the Somali coast and westerly zonal flow over the equatorial Indian Ocean (Fig.2). The westerly zonal flow extends up to 600 hpa. The relative humidity of the air also increases at least up to 500hpa (Rao 1976). At the upper tropospheric levels, the onset is generally associated with a northward shift in the subtropical westerly jet stream to the north of the Tibetan Plateau and the westward shift of the quasi-stationary trough at 500hpa, from about 90^{o}E to about 80^{o}E. Yin (1949) was the first to link the process of monsoon onset to the displacement of westerly troughs in the circumpolar westerlies and shift of the sub-tropical jet (STJ) to the north of the Himalayan periphery. A tropical easterly jet stream also appears over south India in association with the monsoon onset (Koteswaram 1958 & 1960). Murakami and Ding (1982) have suggested that the onset is related to the warming of the Eurasian region by diabatic heating. Thus the onset of the monsoon over India is linked to a combination of regional and planetary scale changes over the entire Indian monsoon region. There exists a variety in the linkages of the onset process with the seasonal developments of transitions in the regional and planetary-scale features. Pearce and Mohanty (1984) found that the period prior to monsoon onset consists of two main phases 1) a moisture buildup phase over the Arabian sea during which synoptic and mesoscale transient disturbances develop and b) a rapid intensification of the Arabian sea winds and a substantial increase in latent-heat release, essentially a large scale feedback process.

Soman and Krishna Kumar (1993) studied the climatological features of atmospheric circulation associated with the monsoon onset. The relative humidity builds up suddenly in the vertical a few days before the onset at the respective stations. The vertically integrated zonal moisture transport at individual stations over the peninsula increases sharply with respect to the south Kerala onset, with appropriate lag in time. The composite outgoing long wave radiation fields over the north Indian Ocean (Figure not shown) show rapid buildup of convective activity over the southeast Arabian Sea and east Bay of Bengal with the approach of the monsoon. Krishnamurti and Ramanthan (1982) examined observational aspects of the evolution of energy exchanges and differential heating during the GARP Monsoon Experiment MONEX.

2. Definition of Monsoon Onset over Kerala (MOK)

The onset of Asian monsoon can be considered as having two phases, one with a rainfall surge over South China Sea and the other with increased rainfall over India (Wang and Lin 2002). Onset of South China Sea Monsoon (SCSM) is the first transition of Asian summer monsoon (ASM) causing major changes in both convection and winds (Hsu et al.1999). The seasonal monsoon transition can occur in a variety of ways with abrupt, gradual or multiple transitions. Though at the surface, the monsoon transitions are first revealed by variability in rainfall, a variety of dynamic and thermodynamic precursors are known to exist (Ananthakrishnan and Soman 1991). There are number of techniques to identify the onset of Asian monsoon (Wang et al. 2004, Zeng and Lu 2004, Wang and Wu 1997, Tanaka 1992).

The India Meteorological Department (IMD) has determined the date of MOK operationally every year, for more than 100 years. On an operational mode, the date of MOK is based on the synoptic conditions as given by Forecasting Manual Unit (FMU) Report No. IV – 18.2 by Ananthakrishnan et al. (1968). On real time model, the declaration of date of MOK was based on rainfall (Ananthakrishnan et al. 1967). If after 10^{th} May, any five stations out of the following seven stations viz., Colombo, Minicoy, Thiruvananthapurm, Alapuzha, Kochi, Kozhikode, and Mangalore receive rainfall (1 mm in 24 hrs.) for two consecutive days, the MOK may be announced on the second day. Accompanying such rainfall, the lower tropospheric westerly wind over Kerala is strong and deep and the relative humidity of the air is high from the surface to at least 500 hpa (Rao 1976). IMD has been taking these factors into consideration in a subjective way to determine the onset date. Fasullo and Webster (2003) proposed a hydrological definition of Indian monsoon onset and withdrawal. To diagnose onset and withdrawal, vertically integrated moisture transport is used instead of rainfall. They argued that using rainfall over Kerala may be susceptible to “false” or “bogus” monsoon onsets, which are associated with propagating tropical intra-seasonal disturbances unrelated to the monsoon onset (Flatau et al. 2001). The disturbances are characterized by an enhancement of convection and westerly surface winds similar to the MOK but occurring over a smaller scale and lasting for a smaller duration (a week or less). Often bogus onsets are followed immediately by extended periods of weak winds and clear skies that result in heat waves and droughts in India. Flatau et al. (2003) and Joseph et al. (2006) discussed the bogus onset of 2002. A similar event happened in 2004 also associated with a severe cyclonic storm over Bay of Bengal. Joseph et al (2006) proposed a 3-tier strategy to determine the MOK objectively based on OLR and wind data in addition to rainfall realized around Kerala.

In 2006, India Meteorological Department adopted new criteria for declaring MOK operationally. These criteria use the information on rainfall and large scale circulation patterns as in Joseph at al. (2006). The criteria for declaring the date of MOK are based on rainfall, wind field and OLR. They are given below:

1. If after 10 May, 60% of the available 14 stations enlisted viz, Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Allapuzha, Kottayam, Kochin, Trissur, Kozhikode, Talassery, Cannur, Kasargode and Mangalore report rainfall of 2.5 mm or more for two consecutive days, the MOK may be declared on the second day, provided the following criteria are also satisfied in concurrence.
2. Depth of westerlies should be maintained up to 600 hpa, in the box equator to latitude 10^{o}N and longitude 55^{o}E to 80^{0}E. The zonal wind speed over the area bounded by lat 5-10^{0}N, longitude 70-80^{0}E should be of the order of 15-20 knots at 925 hpa. The source of data can be RSMC wind analysis / Satellite derived winds.
3. INSAT derived OLR value should be below 200 Wm^{-2} in the box confined by Lat 5-10^{0}N and Long 70-75^{0} E.

In these criteria, the emphasis has been given to the sharp increase in rainfall over Kerala. However, setting up of the large scale monsoon flow and extent of westerlies up to 600 hpa are also confirmed before declaring the monsoon onset over Kerala.

3. Scope and data

By April, general public as well as government officials become curious to know the arrival of monsoon over Kerala. The arrival of monsoon is crucial for farmers to plan their crop strategy during the season. A delay in the MOK does not necessarily mean a delay in monsoon onset over NW India. However, a delay in the MOK is generally associated with a delay in onset at least over Southern states including the city of Mumbai. In spite of its importance, there are not many studies attempting to predict the date of MOK. Reddy (1977) proposed the May 50 hpa zonal wind component over Singapore with westerlies presaging an early and easterlies a late onset date. Kung and Shariff (1980 and 1982) developed regression methods for forecasting the onset date in

Kerala based on April upper air patterns in the India-Australian region and Sea Surface Temperature (SST) around India in the pre-monsoon season. Rajeevan and Dubey (1995) developed a regression model for long range prediction of monsoon onset over Kerala using April mean surface temperature and winter snow cover over Eurasia.

In this study, we have examined the variability of the date of MOK and the associated regional circulation changes. An attempt has been made to analyze the relationship of the date of MOK with the oceanic and atmospheric variables around the Indo-Pacific region, with the ultimate aim of developing a prediction tool for the operational use.

For this study, the data of date of MOK was derived based on the IMD criteria adopted in 2006 as mentioned in the section 2. The time series of Indian date of MOK during the period 1971-2007 is shown in Fig.3. During the period 1971 to 2007, the average date of MOK was 1st June with a standard deviation of about 8 days. During this period, the extreme dates of onset over Kerala were 18th May 1990, and 19th June 1972.

The NCEP/NCAR (Kalnay et al. 1996) daily data of surface mean sea level pressure, outgoing long wave radiation (OLR) and zonal winds at 925hpa and 200hpa were obtained from the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA (http://www.cdc.noaa.gov/). The spatial resolution of these data is 2.5^{o}x2.5^{o} latitude X longitude. The other data used were daily minimum surface air temperatures of 6 stations (Deesa, Rajkot, Guna, Bikaner, Barmer and Akola) over Northwest India and daily rainfall data of all available rainguage stations in the latitude region of 8^{o}N-13^{o}N over south Peninsula obtained from IMD's National Data Center. All the data were used for the period 1971-2007.

4. Methodology

For identification of the predictors, daily data of wind, mean sea level pressure, surface air minimum temperature, rainfall over south India and OLR over the Asia-Pacific region were analyzed. The monsoon onset process over Kerala is influenced by both the intra-seasonal oscillations (ISOs) as well as large scale circulation patterns.

Hence in this study, the development of the model for forecasting of date of MOK has been designed on the basis of the predictors indicating the large scale circulation patterns and ISOs. We have derived data of the predictors averaged over two short periods 16-30 April and 1-15 May. For establishing the relationship of some of the climate variables such as mean sea level pressure, zonal wind, OLR etc. with MOK, we have prepared spatial maps of correlation of date of MOK with these climate fields. The correlation maps were prepared using data for the period 1975-2000. As seen in the Fig.3, the MOK has generally occurred after 15 May but in many years, the onset occurred before 31 May. Therefore, to predict the date of MOK around 15 days in advance, two prediction models have been developed. The first model (Model-1) uses the data up to 30 April and the second model (Model-2) makes use of data up to 15 May. With this, the first forecast can be made available by the end of April and the second forecast can be made available by 15 May. Forecast using Model-1 is particularly important in years when the MOK occurs in the middle of May. The Model-2 provides an update forecast, which will be of particular interest in years when the MOK occurs around the normal date or later.

The technique used here to develop the forecast models was the principal component regression (PCR). In this method, the principal components of the predictors are used in regression analysis to develop the prediction algorithm. The PCR technique is recommended when there is significant inter-correlation among the independent variables. The PCR model avoids the inter-correlation and helps to reduce the degrees of freedom by restricting the number of independent variables (Rao 1964). Principal Component-Regression (PCR) model has been used for the prediction of the seasonal (June-September) ISMR for the country as a whole based on predictors from the Indian Ocean only (Singh and Pai 1996). PCR model has also been used for the prediction of seasonal summer monsoon rainfall over two homogeneous regions of India based on predictors from various observed climatic fields (Rajeevan et al. 2000). The general mathematical formulation of PCR model is given below in brief.

A set of time series of 'm' inter-correlated standardised variables for 'n' years can be represented by (nXm) matrix, $\boldsymbol{Z} = [Z_{ij}: i=1,\ldots..,n;\ \ j=1,\ldots..,m]$. $\boldsymbol{Z}$ is transformed into $\boldsymbol{F}$ via the matrix transformation, $f_{ij}=Z_{ij}l_{ji}$, using principal component analysis (PCA). In matrix form above equation can be written as: $\boldsymbol{F} = \boldsymbol{ZL}$. Here $\boldsymbol{F}$ is the (nXm) matrix of PC scores each having zero mean and unit variance (i.e. the PC scores are standardized); **L** is (mXm) matrix of PC loadings. If we select any 'p' modes of the PC scores (p<m), we can write the PCR model as $\boldsymbol{R} = \boldsymbol{BF'} + \varepsilon$. Where ***R*** is the (nX1) predictand matrix, ***B*** is the (1Xp) matrix of regression coefficients, ***F'*** is the (nXp) matrix of selected PC scores and ε is the (nX1) error matrix.

For generating independent forecasts, a sliding but fixed training period was used. In this technique, a fixed window of training period is moved across the data period and the prediction is made for one year just following the training period. This means that the prediction model gets updated regularly with the addition of latest data and at the same time the model training period remains the same. Such regular updating of the prediction models is necessary for better predictions (Kung and Sharif 1982, McBride and Nicholls 1983, Nicholls 1984) as the time series of meteorological parameters are statistically non-stationary. Kaiser's criterion (Kaiser 1958) was used for retaining the first few PCs for further analysis. As per this criterion, PCs with eigen values equal to or more than 1 only are to be retained. Rationale behind this criterion is that the proportion of the variance explained by each of the retained PC should be at least equal to the contribution of variance (which is equal to 1) by each of the standardized variables used as the input. The retained PCs were then used for training the MR model. Using the PC loadings of the retained PCs, PC scores were calculated for the reference year and the same were then used for the prediction of ISMR for the reference year.

The skill of the PCR models is measured by calculating simple and well known model statistics such as Correlation coefficient between the actual and forecasted values and root mean square error (RMSE) of the model forecasts.

4. Results

4.1. Correlation Maps

The spatial maps of correlation coefficient (C.C.) between date of MOK and different climate variables from which some of the predictors were derived for the present study are shown in the Fig.4a to f. The climate variables considered for preparing the correlation maps are Outgoing Long wave Radiation (OLR), surface mean sea level pressure and zonal wind at 925hpa and 200hpa levels. In Fig.4a to f, the areas of positive (negative) C.C. significant at 5% significant level are shown shaded dark (light). In the Fig.4a, the significant positive C.C over the subtropical areas of Asia-Pacific region indicates below (above) normal surface mean sea level pressures over the region during earlier (later) than normal MOK years. Climatologically, during the second half of April, the surface pressure over the Asian subtropical region is low mainly due to intense solar land heating. Whereas over the Pacific region, there is a climatological sub tropical high. The intraseasonal oscillation leading to MOK is first noticed over the Pacific and its signal can be noticed over the subtropical northwest Pacific almost 20-25 days before MOK (Joseph et al. 2006). Thus when the surface pressure over subtropical Asia Pacific region is below normal during the second half of the April, it is indicative of influence of intraseasonal oscillation over the region and earlier than normal MOK. Associated with the changes in the surface pressure pattern, changes also occur in the flow pattern. As the monsoon approach, the easterly trade winds over the equatorial Indian Pacific region weaken and the westerly zonal winds set in. The significant negative C.C between zonal wind at 925hpa and MOK (Fig.4b) over this region indicate stronger (weaker) than normal westerly winds associated with earlier (later) than normal MOK. Similarly, the significant positive C.C. areas over the equatorial east Indian Ocean and neighboring Indonesian region (Fig.4c) indicate stronger (weaker) than normal climatological easterly winds at 200hpa associated with earlier (later) than normal MOK. The climtological low level westerly winds and upper level easterly winds over the equatorial east Indian Ocean during the second half of April is accompanied by climatological deep convection over the region. In fact the intraseasonal variability leading to MOK is more prominent in the convective pattern. This is actually reflected in the spatial map of C.C. between OLR and MOK date (Fig.4d), where significant positive C.C.s are observed in the latitude zone of 5^{o}N-15^{o}N extending from the east Indian Ocean to Philippines. The positive C.C. indicates below (above) normal OLR over the region associated with earlier (later) than normal MOK. The OLR anomalies are caused by the northward movement of the convective region associated with the intraseasonal oscillation. The significant C.C. areas observed in the spatial maps of C.C. of date of MOK with 925hpa zonal wind during 1-15th May (Fig.4e) and that with OLR during 1-15th May can also be explained as the link between the intra seasonal oscillation in these climate fields and the MOK event.

4.2. Predictor Data Set

Table-1 shows the details of the 9 predictors used for the two models. The geographical locations of the predictors are given in Fig.5. OLR, surface mean sea level pressure and zonal wind predictors were derived as the simple arithmetic average of the actual values over the respective geographical region whose domain is given in the fourth column of the Table-1. These geographical regions are derived from the correlation maps (Fig.4) and correspond to the areas where the C.C. between the respective climate variable and MOK was at least significant at 5% level. The time periods used for the averaging are given in the third column of the Table 1. In 1978, due to the problem in the satellite, OLR data was not available. Therefore, this data gap was filled using normal value (base period 1975-2000) of the OLR over the relevant geographical region.

Other predictors mentioned in the Table-1 are date of Pre Monsoon Rain Peak (PMRP) and surface air minimum temperature over Northwest India. The PMRP (Joseph and Pillai 1988, Joseph et al. 2006) is an event that occurs every years about 6-8 pentads earlier to the MOK, during which a cloud band passes through Kerala very similar to that occur during the monsoon onset phase with widespread rainfall over the extreme south Peninsula. The main difference between PMRP and MOK is that in association with the monsoon onset, a large area of deep convection can be seen over the south-east Arabian Sea. This feature is absent at PMRP and the large area of deep convection is instead seen over the south Bay of Bengal. Ramesh Kumar (2004) derived date of PMRP as the center date of the pentad with the maximum rainfall and that pertains to period between1st April to 10th May. For deriving date of PMRP, Ramesh Kumar (2004) used the rainfall derived from the Global Precipitation Climatology Project and in situ rain gauge data for the region bounded by 8^oN –13^oN and 70^oE-95^oE. In this study, the date of PMRP was derived from the daily rain gauge data averaged over the land region bounded between 8^oN -13^oN as the date corresponding to the centre of the first peak rainfall envelop over the region.

The land surface air minimum temperature over the Northwest India was computed as the average of surface air minimum temperatures of 6 surface observatories (Deesa, Rajkot, Guna, Bikaner, Barmer and Akola). The negative correlation between the minimum temperature index over Northwest India and date of MOK indicates above (below) normal heating of the region associated with earlier (later) than normal MOK.

All the predictor time series were normalized using 1975-2000 base period before used in the model development. As shown in the Table-1, all the predictors have significant (>95% level) correlation with the ISMR. The cross correlation among the 9 predictors is shown in the Table-2. As seen in this table, there is significant inter-correlation among some of the predictors. This is expected because the variations in most of the predictors are part of the evolution of the same physical mechanism leading to the monsoon onset. The first 5 predictors were used in the Model-1 and the last 6 predictors were used in the Model-2. As seen in the Table-1, all the 5 predictors used in the Model-1 pertain to second half of April.

4.3. <u>Performance of the PCR Models</u>

For forecasting the date of MOK each year, predictor data for the 22 years just prior to the reference year were used for training the models. For example, for forecasting of date of MOK in 2001, data for the period 1979-2000 was used for training the models. Similarly data for the period 1985 to 2006 were used for forecasting of date of MOK in 2007. Thus, with the available data, independent forecasts were prepared for the 11 year period (1997-2007) for each of the two models (Models 1 & 2). As mentioned in the previous section, due to the significant inter correlation among the predictors, PCA analysis was carried over each of the predictor sets. In case of Model -1, the PCA analysis of predictor series for each of the 11 independent forecast cases showed that eigen values of the only first two PCs were ≥1. Therefore, the first two PCs explaining about 86% of the total variability of the predictor set containing 5 predictors were retained for the regression analysis. In the case of Model-2 also the PCA analysis of predictor series resulted in the selection the first two PCs having eigen value ≥1. These 2 PCs together explained about 72% of the total variability of the predictor set (containing 6 predictors) and were used for the regression analysis. We found that any addition of other PCs having eigen value less than 1 does not make any improvement in the model performance. Fig.6 shows the performance of the forecast by Models 1 & 2 for the period 1997 to 2007. As seen in the Fig.6, both the model forecasts have shown good performance during the independent training period. During all the years both the models were able to correctly forecast whether the MOK was earlier or later to the normal date (1st June as computed from dates of MOK for the period 1971-2007). The root mean square errors of model forecasts during the independent test period of 11 years (1997-2007) for both the models was about 4 days (4.34 days for Model-1 and 4.30 days for Model-2) which is less than the standard deviation of the MOK (7 days). The C.C. between the actual and forecasted MOK for both the models was 0.78. During the years like 1997, 2001, 2003 & 2006 when the MOK was earlier or later than the normal MOK date by more than or equal to 5 days, the forecast from Model-2 was closer to the actual MOK date than the forecast from Model-1. On the other hand, during years like 1999, 2002 & 2005 the forecast from Model-1 was closer to the actual MOK date than the forecast from Model-2. Though the average difference between the forecasts from these two models during the period of 1997-2007 was 2.8 days, as a whole, the performance of both the models was nearly equal. The forecasts from the Models 1 & 2 were also compared with that of a climatology based model. The forecast from the climatology based model for each year was computed as the mean of the actual MOK values during the training period (i.e. 22 years prior to the reference forecast year). The RMSE of the climatology based model during the independent test period was 7.32, which is more than the RMSE of the forecasts from PCR models discussed in this study. Thus, it is clear that the PCR models developed in this study have performed better than the climatology based model.

5. Summary and Conclusions

The summer monsoon over the Indian subcontinent first arrives over Kerala situated at the southern tip of the Indian Peninsula around 1st June with a standard deviation of about 7 days. The arrival of the monsoon over the region is noticed by wide spread persistent and heavy rainfall replacing the occasional pre-monsoon rains. In some years the MOK occurs in the middle of the May itself. Therefore, for the operational forecasters need model which can provide forecast of the date MOK around 15days ahead of the event. This means a model that can forecast the event at least by the end of the April. Fortunately, researchers have noticed that the evolution of atmospheric and oceanic process associated with the MOK starts almost 30-40 days ahead of the event. In this study, efforts were made to make use of predictive signals available in the convective, thermal and circulation patterns over the Asia–Pacific region associated with the event to forecast the date of MOK well ahead of the event. For this purpose, two principal component regression (PCR) models using predictors were developed. Due to the possibility of occurrence of MOK in the middle of May itself, one model (Model-1) was constructed using the April predictors only so that the forecasting of MOK can be prepared in the end of April itself. The second model (Model-2) that can provide forecast for the date of MOK in the end of first half of May was prepared using 4 additional predictors pertaining to the first half of May along with 2 predictors used in the Model-1. Both the models showed good skill in the forecasting the date of MOK during the independent test period of 1997-2007. The RMSE of the forecasts from both the models during the independent test period was about 4 days which was comparatively very less compared to RMSE of the forecasts from a climatology based model (7.32) during the same period and standard deviation (8 days) of the MOK date. This study demonstrates that the forecasting of date of MOK with some accuracy can be made by the end of April itself. In case of possibility of late onset, the forecast can be updated by making use of predictive signals from May.

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Table-1: Details of the predictors used in the models (Model-1 & Model-2) for the prediction of date of MOK. First 5 predictors listed in this table were used in the Model-1 and last 6 predictors were used in the Model-2. All the correlations are significant at and above 95% significant level.

No	Name of Predictor	Temporal Domain	Geographical Domain	Correlation Coefficient(C.C.) 1975-2000
1	Minimum Surface air Temperature over NW India (P1)	16th to 30th April	1. Deesa 2. Rajkot 3. Guna 4. Bikaner 5. Akola 6. Barmer	-0.38
2	Surface Mean Sea Level Pressure over subtropical NW Pacific (P2)	16th to 30th April	20-30N,130E-160E	0.57
3	Zonal Wind at 925hpa over Northeast Indian Ocean (P3)	16th to 30th April	5N-10N, 80E-110E	-0.52
4	Zonal Wind at 200hpa over Indonesian Region (P4)	16th to 30th April	5S-5N, 90E-120E	0.48
5	OLR Over South China Sea (P5)	16th to 30th April	5N-15N, 100E-120E	0.40
6	Pre-Monsoon Rainfall Peak Date (P6)	Pre-monsoon April-May	South Peninsula (8N-13N, 74E-78E)	0.48
7	Minimum Surface air Temperature over NW India (P7)	1st to 15th May	1. Deesa 2. Rajkot 3. Guna 4. Bikaner 5. Akola 6. Barmer	-0.37
8	Zonal Wind at 925hpa over Equatorial South Indian Ocean (P8)	1st -15th May	10S-0, 80E-100E	0.52
9	OLR Over Southwest Pacific (P9)	1st to 15th May	30S-20S, 145E-160E	-0.53

<u>Table-2</u>: Inter correlation coefficient among the 9 predictors used for the forecasting of date of MOK. The inter correlation coefficient was computed using data for the period 1975-2000. The inter correlation coefficients between different predictors significant at and above 5% significant level are shown using bold letters.

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**
P1	1.00	-0.24	0.16	-0.22	-0.21	**-0.40**	**0.51**	-0.20	0.20
P2		1.00	**-0.75**	**0.55**	**0.69**	**0.46**	-0.16	0.25	**-0.58**
P3			1.00	**-0.75**	**-0.79**	-0.25	0.31	-0.27	**0.41**
P4				1.00	**0.66**	0.28	**-0.50**	**0.57**	**-0.52**
P5					1.00	0.24	-0.31	0.31	**-0.49**
P6						1.00	**-0.37**	**0.39**	-0.34
P7							1.00	-0.32	0.14
P8								1.00	**-0.53**
P9									1.00

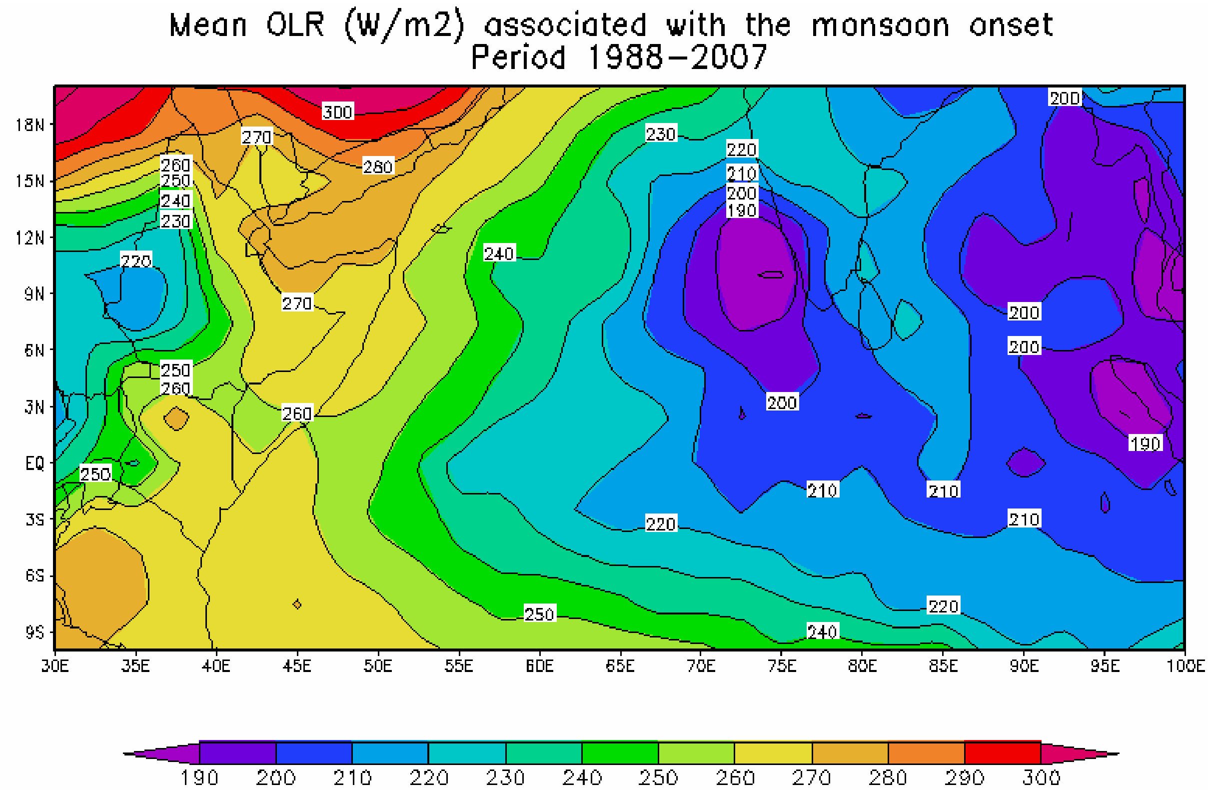

Fig.1. Composite mean OLR during the day of MOK. Period: 1988-2007. Unit: Wm^{-2}.

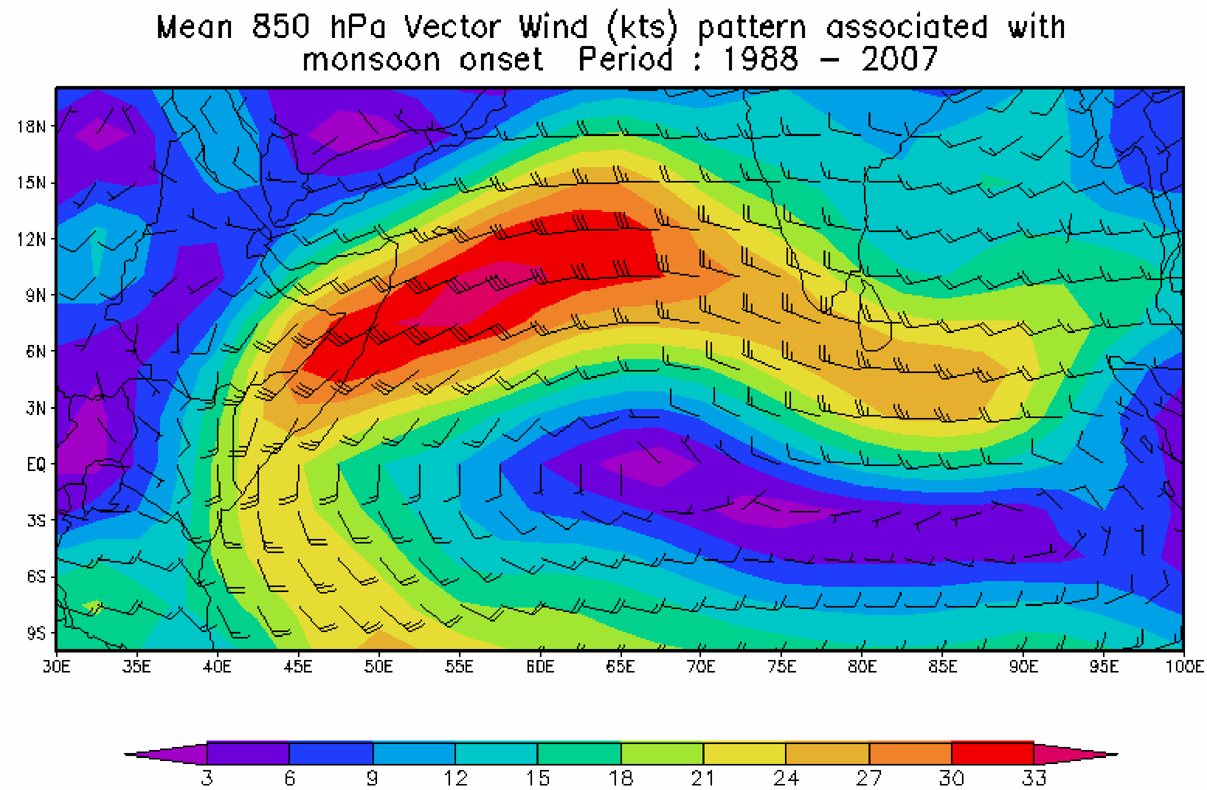

Fig.2. Composite mean 850hpa zonal winds over Indian Monsoon region during the day of MOK. Wind speed in Knots. Period of data: 1988-2007.

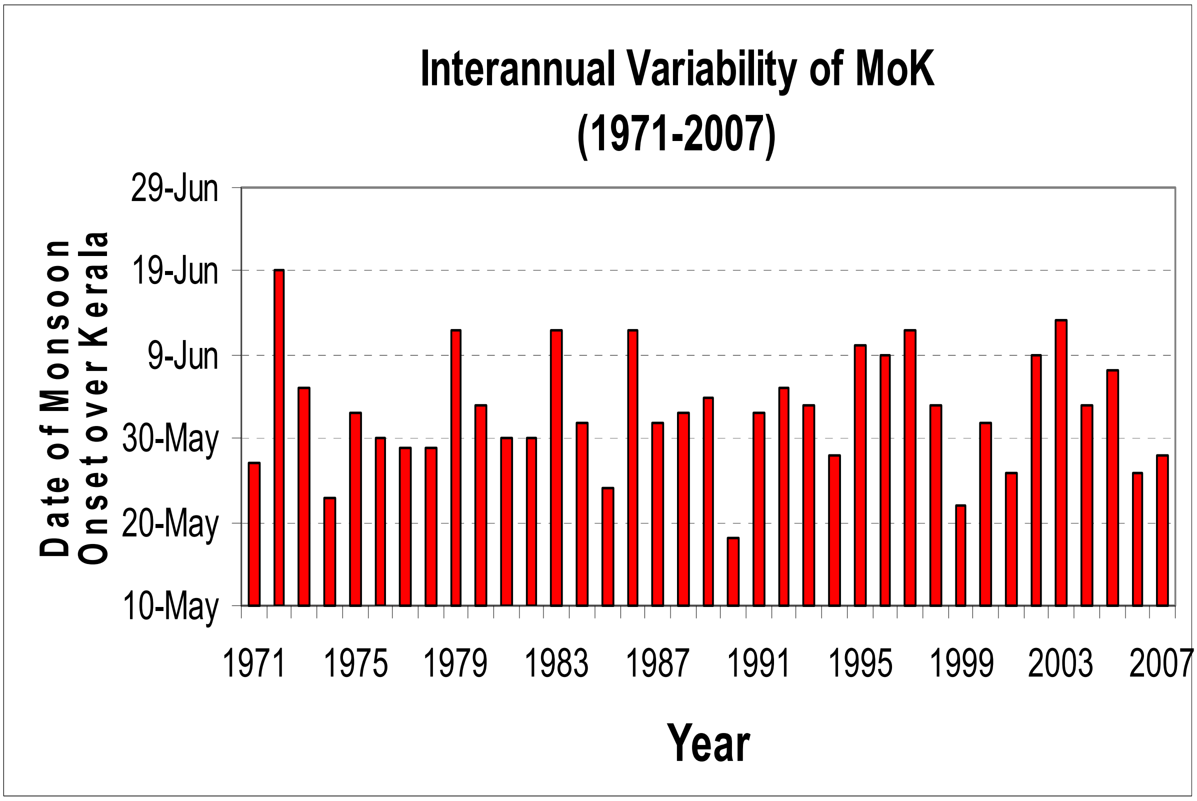

Fig.3. Interannual variation of date of MOK during the period 1971-2007. The average date of MOK is 1stJune and standard deviation is 8 days.

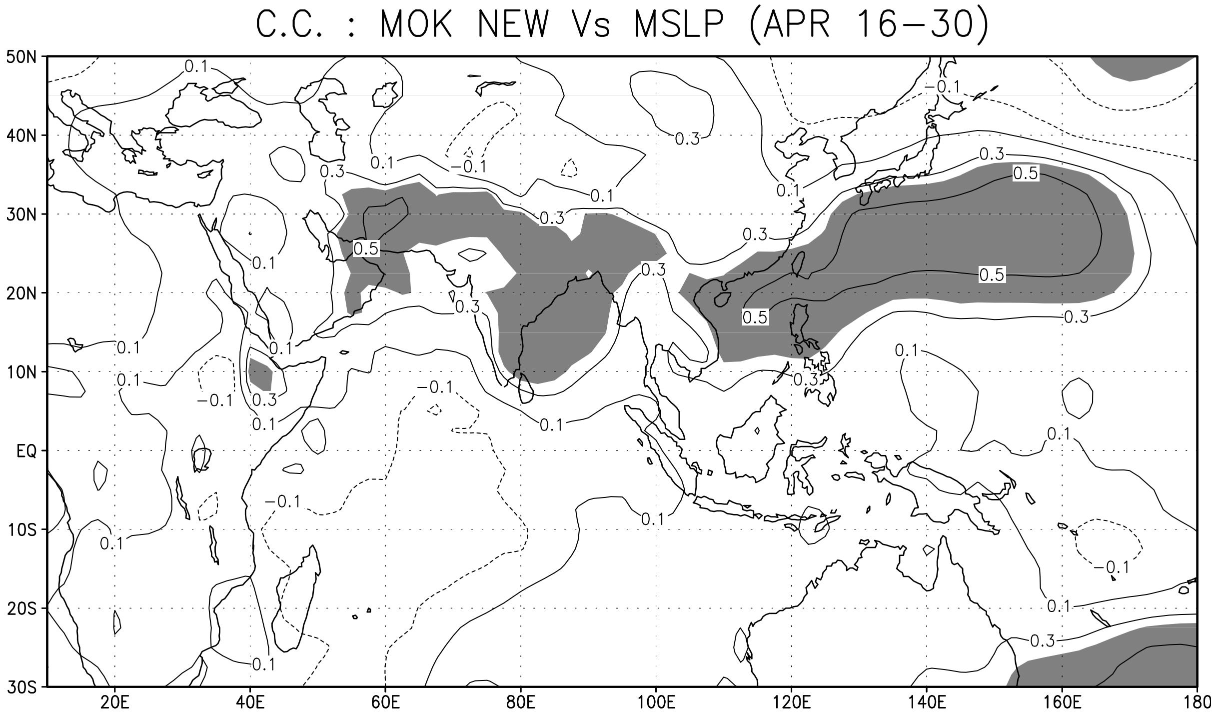

Fig.4a. Contour map of correlation coefficient (C.C.) between the surface mean sea level pressure (averaged over April 16 to 30) over Asia Pacific region and date of MOK. The C.C. was computed using data for the period 1975-2000. Solid (dotted) contours are used for positive (negative) C.C. The contour interval is 0.2. The areas of C.C. significant at and above the 95% significant level are shaded.

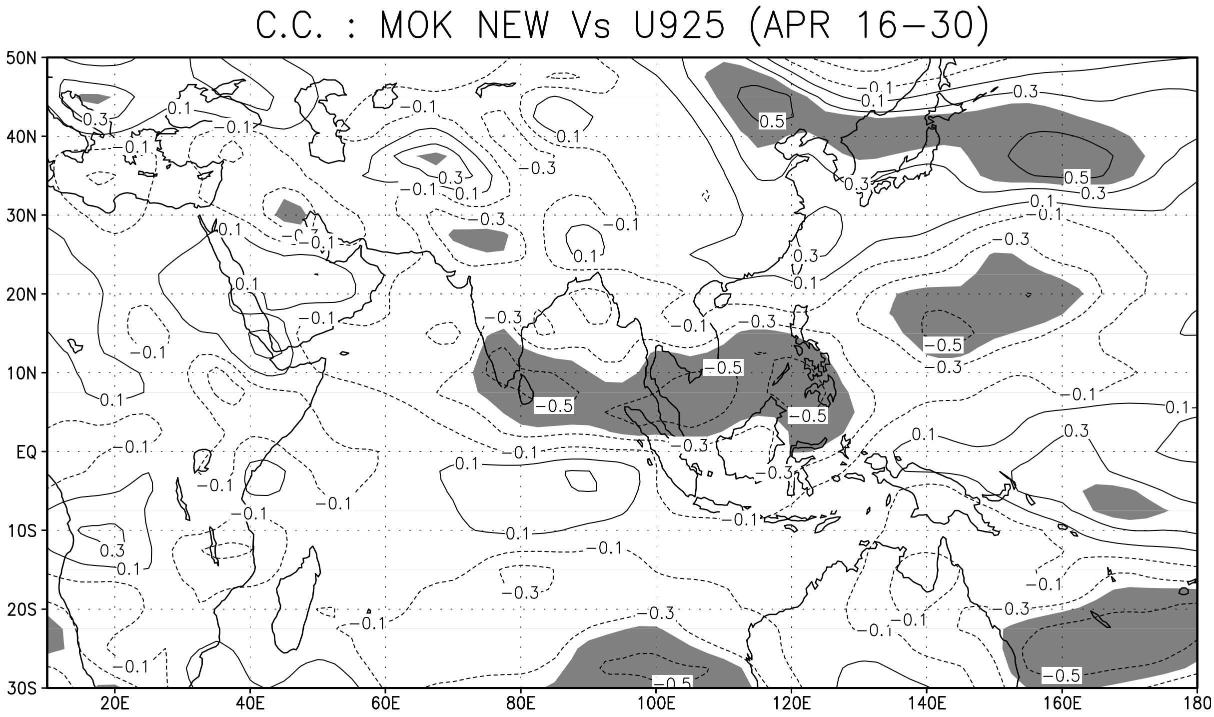

Fig.4b. Same as Fig.4a but for C.C. between Zonal wind at the 925hpa (averaged over April 16 to 30) and date of MOK.

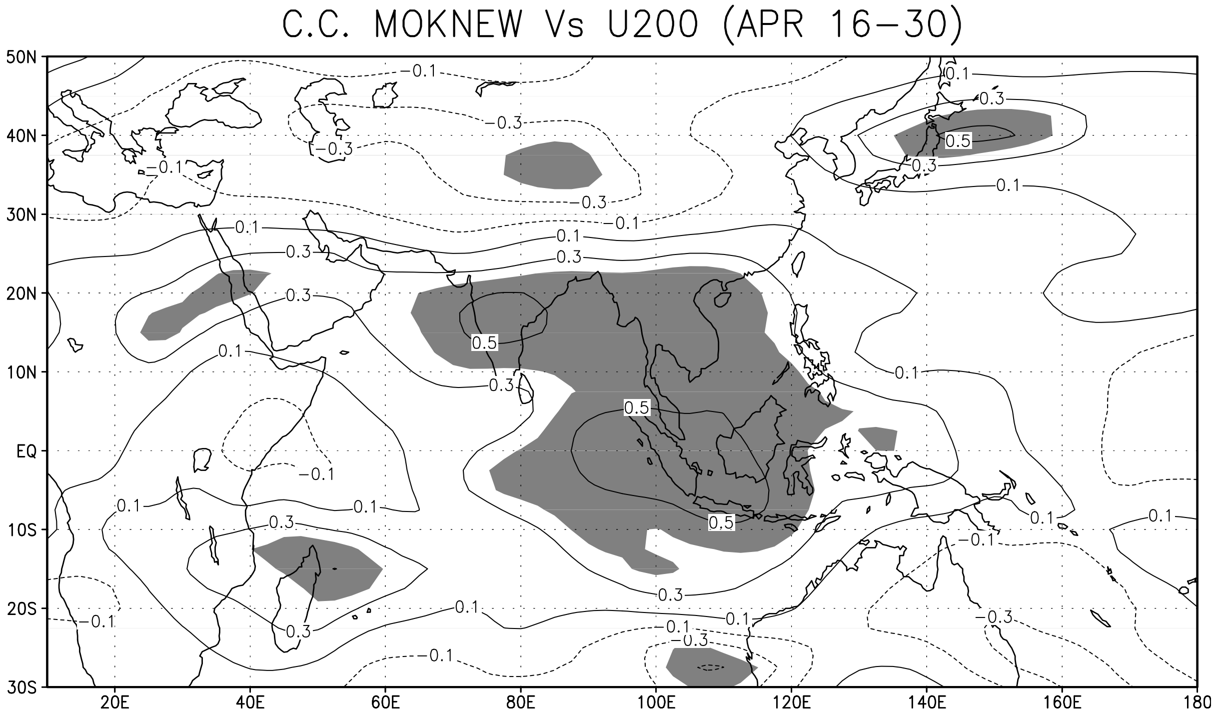

Fig.4c Same as Fig.4a but for C.C. between Zonal wind at the 200hpa (averaged over April 16 to 30) and date of MOK.

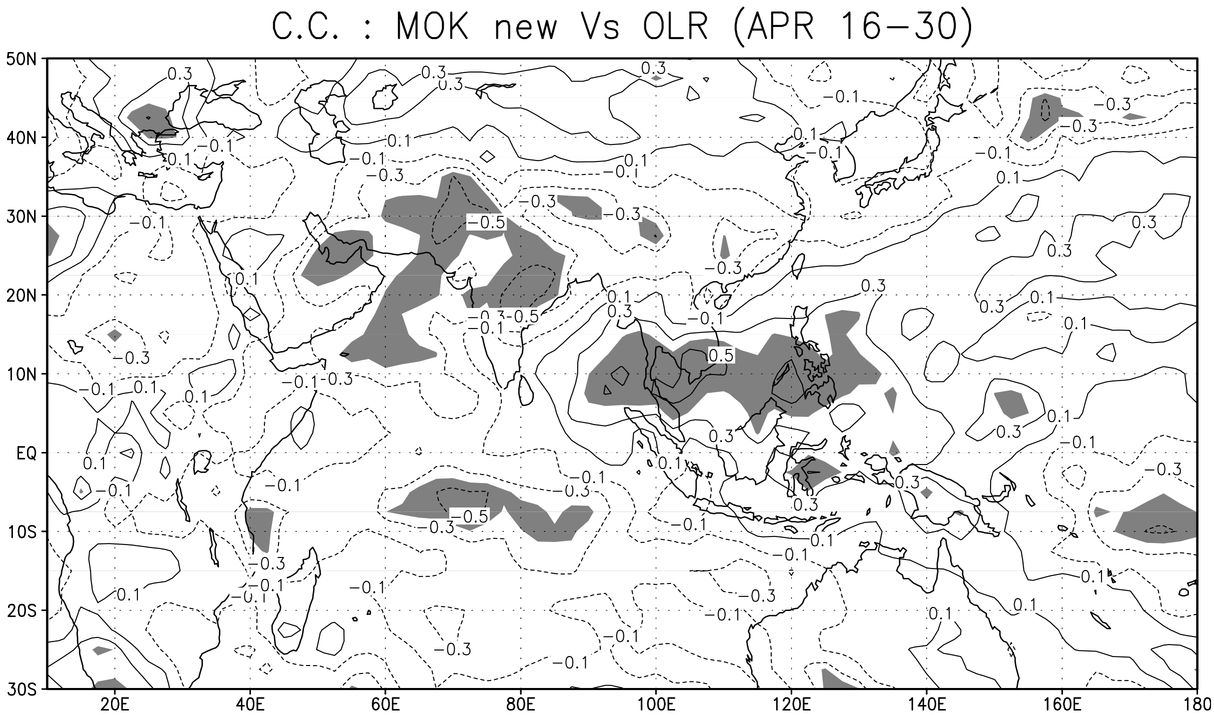

Fig.4d. Same as Fig.4a but for C.C. between outgoing long wave radiation (averaged over April 16 to 30) and date of MOK.

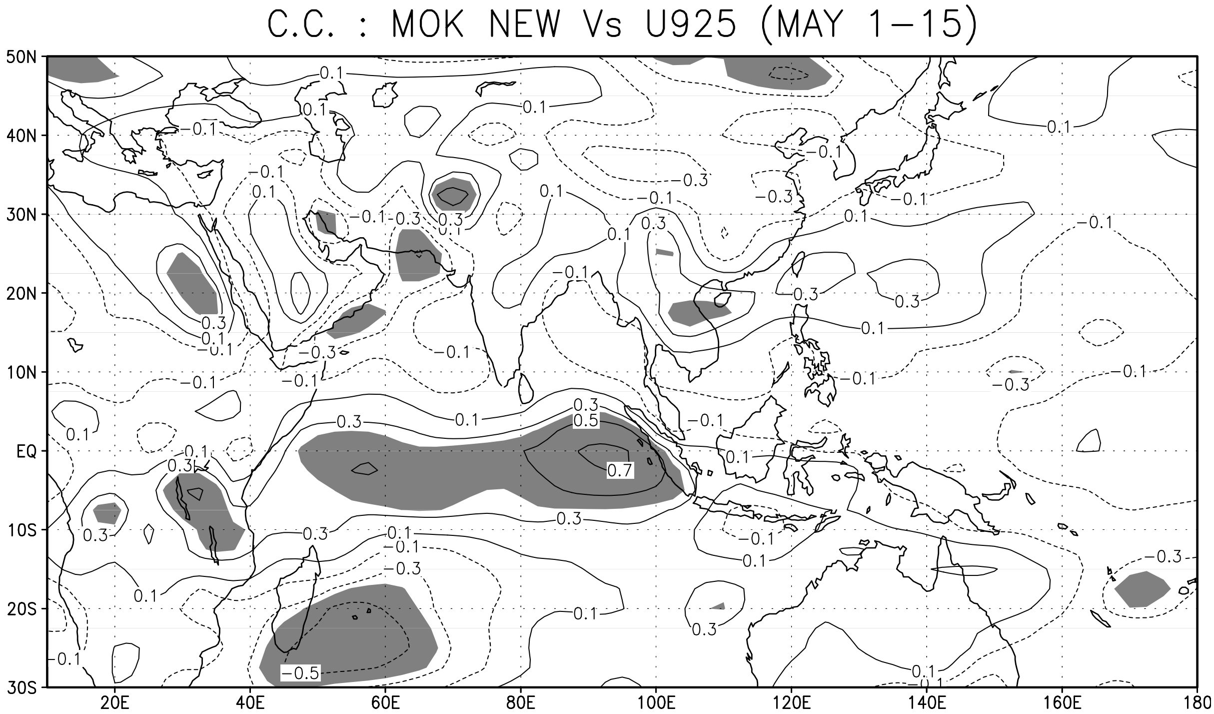

Fig.4e. Same as Fig.4a but for C.C between Zonal wind at the 925hpa (averaged over May 1 to 15) and date MOK.

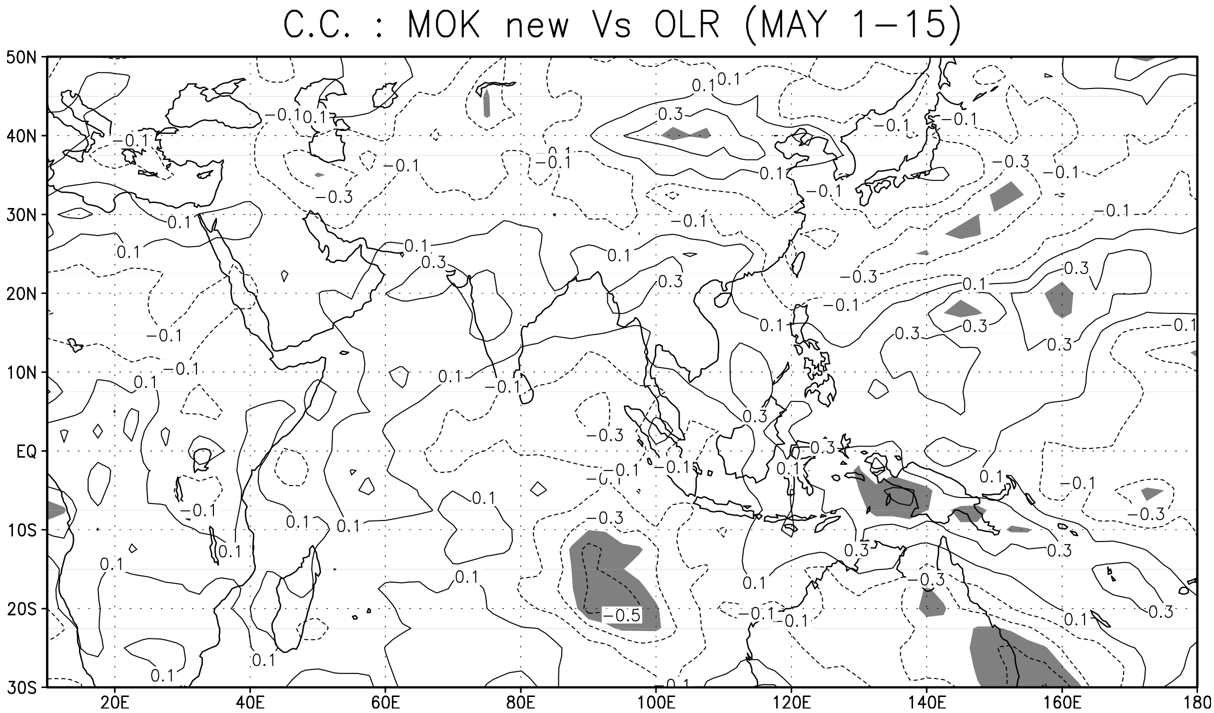

Fig.4f. Same as Fig.4a but for C.C between outgoing long wave radiation (averaged over May 1 to 15) and date of MOK.

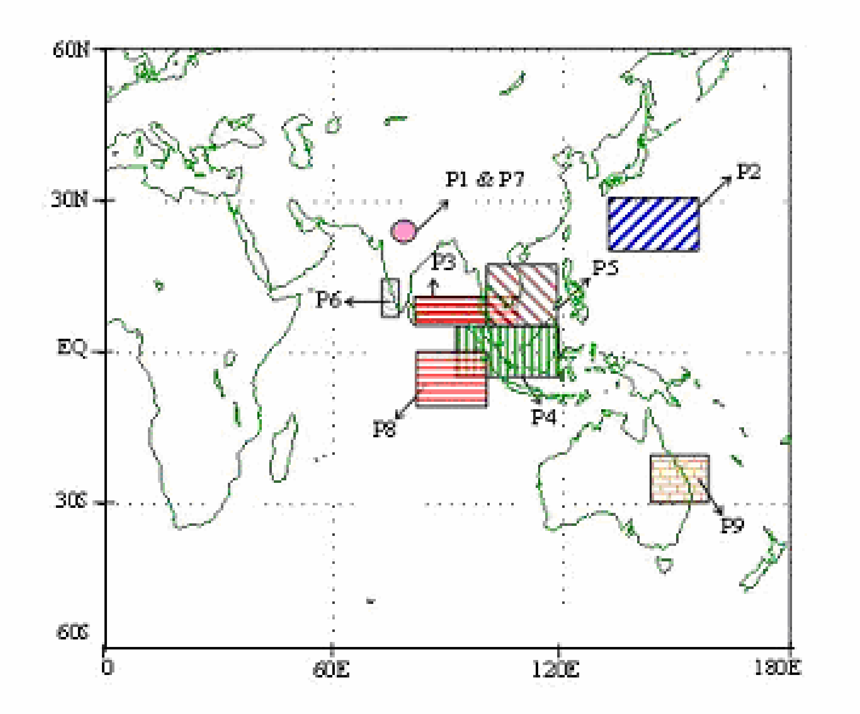

Fig.5. Geographical locations of the 9 predictors used in the two PCR models for the forecasting of date of MOK. The 9 predictors (P1 to P9) are listed in the Table-1.

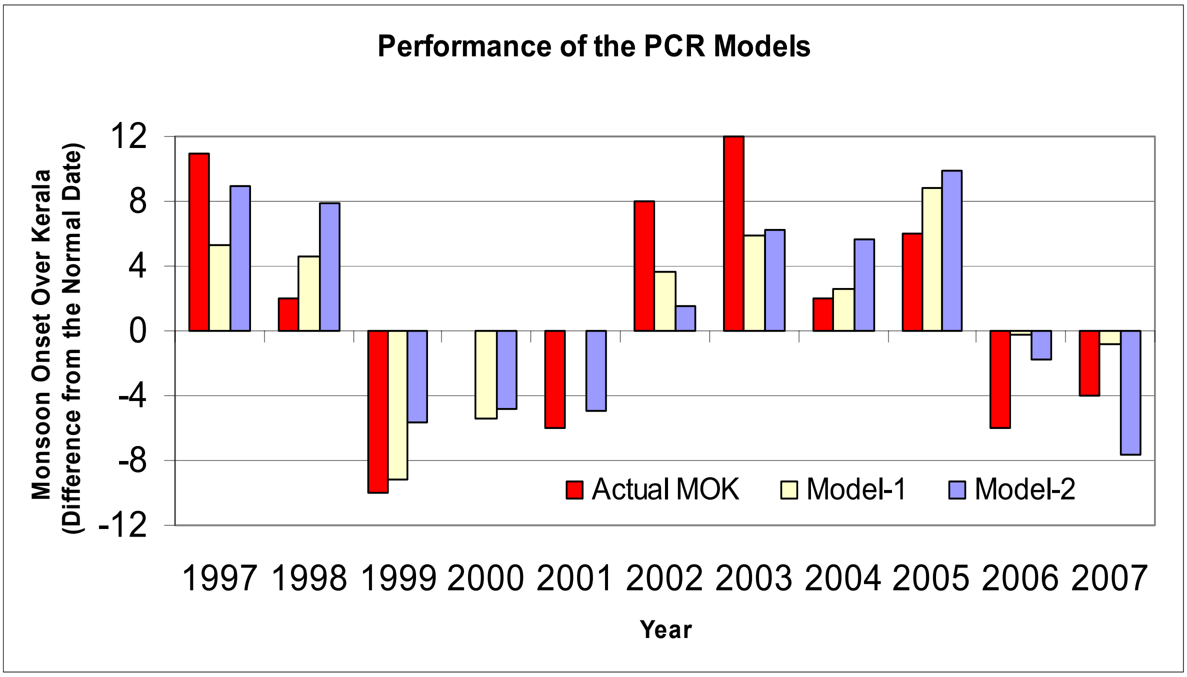

Fig.6. Actual dates of monsoon onset over Kerala (MOK) and forecasts from the two PCR models for the forecasting of date of MOK for the period 1997 to 2007.

N C C RESEARCH REPORTS

- 1) New statistical models for long range forecasting of southwest monsoon rainfall over India, M. Rajeevan, D. S. Pai and Anil Kumar Rohilla, Sept. 2005.

- 2) Trends in the rainfall pattern over India, P. Guhathakurta and M. Rajeevan, May 2006

- 3) Trends in Precipitation Extremes over India, U. R. Joshi and M. Rajeevan, October 2006