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Research Article

PREDICTION OF SUB-SEASONALITY OF INDIAN MONSOON THROUGH KINETIC ENERGY OF WAVE ZERO

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ABSTRACT

Analysis of sixty (1951-2010) years of daily Kinetic Energy of zonal waves derived from NCEP/NCAR u and v data and daily All India Monsoon Rainfall (AIMR) indicate that temporal variations of Kinetic Energy of wave zero (KE(0)) at 100 hPa have potential to predict the Intra-Seasonal Variations (ISV) of Indian Summer Monsoon one month in advance. The Principal Oscillation Patterns of KE (0) and AIMR are almost identical.

The prediction method presented in the study is simple and clear. Observe the temporal variation of KE (0) from mid-April and predict the variation of AIMR from June. In the present scenario, when none of the models (Statistical/Dynamical) in use in India are able to predict ISV, even the qualitative information like increase/decrease of rainfall during the next fortnight and that too one month in advance, is of immense importance to the farmers and planners and even to operational forecasters.

Key Words: *Kinetic Energy, Wave Zero, Indian Monsoon, Intra-Seasonal Variation*

INTRODUCTION

Saltzman (1957) derived equations governing the energetics of the large-scale of the atmospheric turbulence in the domain of wave number. Saltzman and Fleisher (1960) studied rate of transfer of kinetic energy between different scales of eddies and showed that the intermediate waves (wave numbers 5-10) were source of kinetic energy to long waves (wave numbers 1-4) and short waves (wave numbers 11-16). Saltzman (1970) summarized the results of several studies of energy interactions in the Fourier domain in extra-tropical regions. Krishnamurti and Kanamitsu (1981) examined upper tropospheric large scale circulation features for two contrasting monsoon years and showed the contrasting behaviour of wave number 3. Murakami (1981) studied the energetics of standing and transient scales and observed that standing waves are source of kinetic energy to transient waves. Awade and Bawiskar (1982) pointed out that drought monsoon activity is associated with large divergence of heat at subtropics and large convergence of heat at extra tropics. Bawiskar et al (1989) computed transport of momentum for contrasting monsoon years over India and showed that small scale disturbances are intense during normal monsoon years. Bawiskar and Singh (1992) examined the upper tropospheric energetics of the standing eddies during four contrasting monsoon years over India and found that wave number 2 is stronger during normal monsoon years as compared drought monsoon years. Bawiskar et al (1995) studied energetics of standing and transient eddies of upper and lower troposphere and pointed out that standing wave number 1 plays a very important role in the dynamics of the monsoon circulation in the lower troposphere. Bawiskar et al (1998) studied intra-seasonal variation of kinetic energy of lower tropospheric zonal waves and showed that wave 1 is dominated by 30-40 day and bi-weekly oscillations while short waves are dominated by weekly oscillations. Bawiskar et al (2002a) studied the energetics of zonal waves during Onset, Established and Withdrawal phases of monsoon and found that wave 0 over equatorial belt, waves 1 and 2 over tropical belt and waves 3-10 over extra-tropical belt influence the monsoon activity over India on intra-seasonal scale.

Most of the above mentioned studies are of diagnostic in nature. Bawiskar et al (2002b) were first to introduce a predictor based on the energetics of zonal waves by considering monthly global grid point data of ECMWF and showed that Northward (Southward) momentum transport by wave number zero in the lower troposphere over the latitudinal belt between 25°S and 5°N in the month of March leads to a good (drought) monsoon season (June-September) over India. Bawiskar et al (2005b) developed a simple regression model based on the lower tropospheric effective KE of zonal waves 1, 3 and 4 for the month of February. This model is giving better real time seasonal forecast.

Prediction of ISV was attempted by many workers. Von Storch and Xu (1990) made the first attempt to predict ISV by using Principal Oscillation Patterns (POPs) of equatorial 200 hPa velocity potential anomalies. They found a good correlation between time evolution of POP coefficients and area averaged Outgoing Longwave Radiation (OLR). Waliser et al (1999) used previous and present pentads of filtered OLR to predict future pentads of OLR. He found temporal correlations with observed band pass data set with lead time from 5-20 days, after which correlations dropped significantly with increasing lead time. Lo and Hendon (2000) developed an empirical model based on the assumption that the Madden Julian Oscillation (MJO) can be well represented by a pair of EOF's of OLR and three EOF's of stream function at 200 hPa. Goswami and Xavier (2003) constructed an empirical model based on the first four EOFs of 10-90 day filtered precipitation during monsoon season and first two Principal Components (PCs) of filtered surface pressure from NCEP/NCAR data. They found skill of prediction of monsoon breaks 18 days in advance. Webster and Hoyos (2004) used wavelet binding technique and linear regression scheme to forecast 5 day average rainfall variability. Bawiskar et al (2005a) observed that weakening (intensification) of lower tropospheric short waves (waves 3-10) over the extra tropics leads to active (weak) spell of rainfall during monsoon season. Dwivedi et al (2006) showed that the peak anomaly in the active regime can be used as a predictor for the duration of subsequent break spell. Dwivedi and Mittal (2007) used peak in the most dominant intrinsic mode functions of observed Indian monsoon Intra-Seasonal Oscillations (ISO) to forecast duration of active and weak spells.

The recent study of Bawiskar et al (2009) indicates that lower tropospheric ultra long waves hold a key to intra-seasonal variability of Indian monsoon. Picking up this thread, the authors have made an attempt to predict ISV of Indian monsoon through the temporal variation of the energetics of zonal waves.

The paper is organized as follows. In section 2 data and method are described. Results, prediction scheme and scope of the scheme are included in section 3. Section 4 gives concluding remarks.

MATERIALS AND METHODS

Daily global NCEP/NCAR wind (u & v) data at 10 tropospheric (1000 hPa - 100 hPa) levels for 60 years (1951-2010) are considered. Daily AIMR is taken from daily gridded rainfall data published by India Meteorological Department (Rajeevan et al., 2006).

Wind data are decomposed into spectrum of zonal waves and energetics of zonal waves are computed following Bawiskar et al (1995).

RESULTS AND DISCUSSION

Lag correlation technique is used to identify a parameter having potential to predict ISV of rainfall during monsoon season over India. Period of AIMR series is always taken from 1 June to 30 September (122 days). As per the lag, period of daily KE series is changed. For example, for lag 45, the period of daily KE series is taken from 17 April to 16 August (122 days). Correlation Coefficient (CC) $\geq$ abs (0.24) is significant at 99% level of significance.

Kinetic Energy of waves 0 to 10 are computed over 73 latitudes of the globe and at 10 tropospheric levels and for all the days of the year. As per the lag, 122 days of KE series are selected and correlated with fixed period of 122 days of AIMR. This analysis is carried out for individual years from 1951 to 2010. During the analysis we found that many waves have significant CCs at different lags but failed in consistency i.e. for some years the CCs were significant and for other years they were insignificant and or even changed the phase. The extensive analysis of all the waves proved to be fruitful. We could identify that KE (0) at 100 hPa around 20°N is only, the wave having consistent (i.e. for all the years) and significant CCs at various lags. The details are given in the next section.

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A new finding

Figure 1 gives interannual variations of CCs between daily KE (0) at 20°N and daily AIMR from lag 0 to lag 61. Significant CCs (95% level) are shaded. The belt of positive significant CCs can be seen from lag 0 to lag 20. There are gaps in the belt which indicate that CCs are not significant for the corresponding years. Change of phase takes place around lag 25. Belt of negative significant CCs extends up to lag 61. Around lag 45, the CCs are significant for all the sixty years.

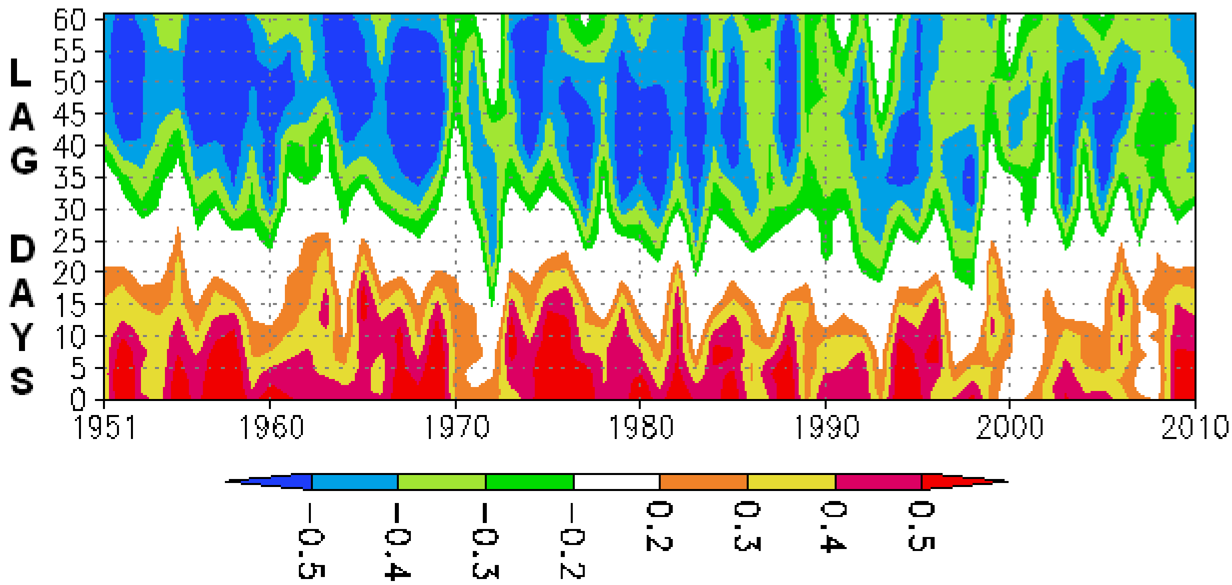


Figure 1: Inter annual variations of 0-61 day lag correlation coefficient between daily kinetic energy of wave 0 at 100 hPa around 20°N and daily All India Monsoon Rainfall.

Figure 2 gives interannual variations of CCs at lag 45 for two cases. Blue graph represents the CCs of original data (i.e. without filtering seasonality) and the red graph gives CCs after filtering seasonality. Filtering of seasonality reduces the strength of correlation but even then the variations are statistically significant in both the cases. This clearly indicates that the significant CCs are not only due to seasonality but the intra-seasonal variations have also major contribution. Hereafter, our discussion will be mainly related to the time series of KE (0) from 17 April to 16 August and time series of AIMR from 1 June to 30 September and for convenience, these two series will be referred to as K and R respectively.

Reason of significant correlation

What could be the reason of consistent significant correlation? Is it because of trendy nature of K and R or is it because of similarity in the temporal variations? Daily seasonal rainfall series are normally distributed (bell shaped) and trendless. To verify the other possibility, we have decided to examine the oscillation patterns of K and R for a period of 365 days of the year. For this purpose, we have considered daily climatology of K and R. To compare Principle Oscillation Patterns (POPs) of K and R, the seasonality (bell shaped nature) is filtered from both the series by using Inverse Fourier Transform. Normalised POPs of both the series are presented in figure 3. They are almost identical with some lag.

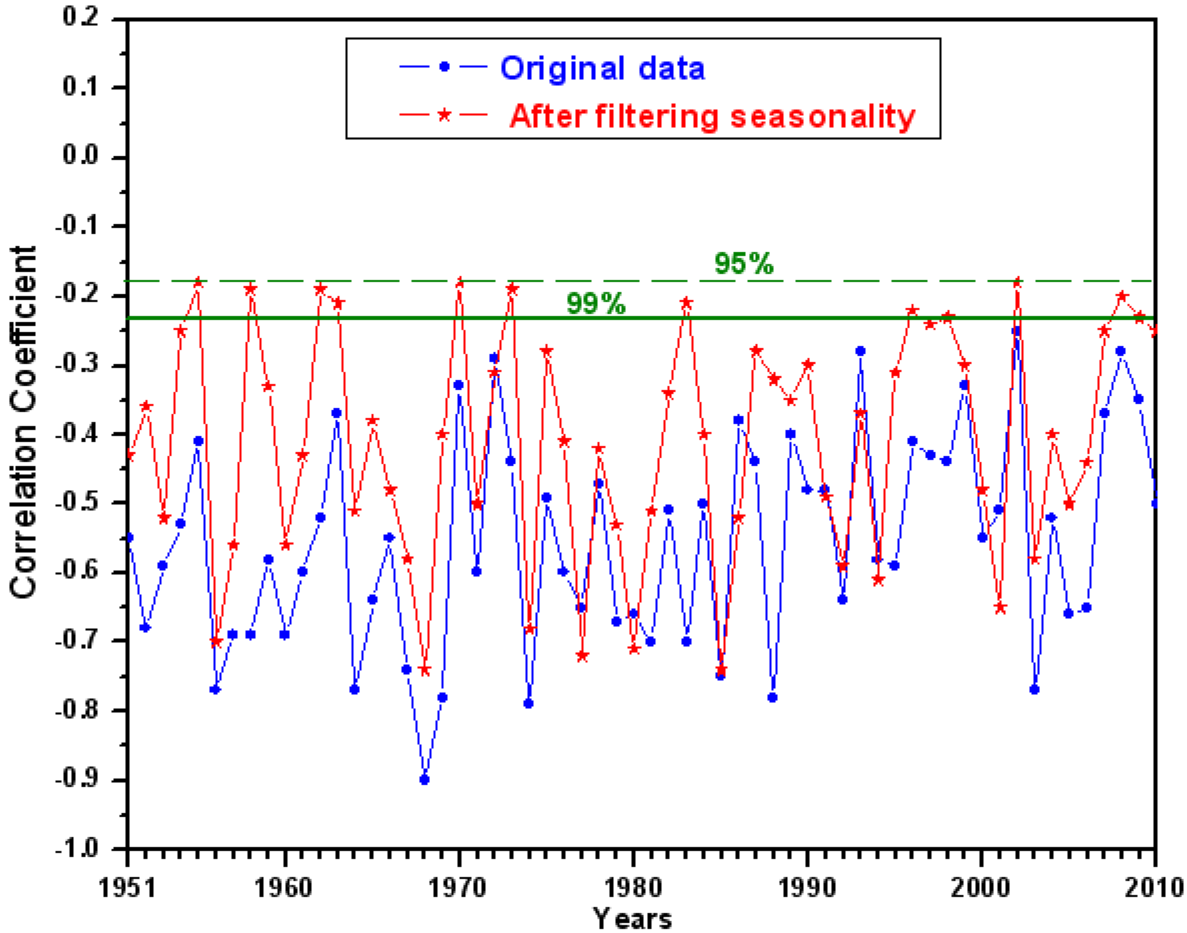


Figure 2: Inter annual variations of 45 day lag correlation coefficient between daily kinetic energy of wave 0 at 100 hPa around 20°N and daily All India Monsoon Rainfall.

Prediction

Here, we would like to make one thing clear that we are not trying to predict the quantitative rainfall but the temporal variation of the rainfall. It is already mentioned in the previous section that the significant CC between K and R is because of the similarity in POPs. This property, itself, has a potential to predict the variation of rainfall during the monsoon season. The analysis based on the above property is carried for various time scales and it is observed that the variation having period less than 10 days are not properly captured. The maximum skill is found for bi-weekly scale. Figure 4 gives bi-weekly temporal variations of predictor K and observed real time R for all the sixty years. Both the series are normalized and phase of K series is changed for comparison. Drought and Excess years are marked with letters D and E respectively. The most important aspect of the figure is that the variations of K series are available one month in advance as compared to the corresponding variation of R series. The figure clearly indicates that bi-weekly variations of more than one third of the years (which includes some drought and excess years as well) are captured with nearly 100% accuracy. There is not a single year when the method has failed. The success rate is always above 60%. Thus, there is no complicated formula for prediction, no regression model, no evolution of OLR or filtered rainfall and no decaying amplitude of prediction with the time but a simple

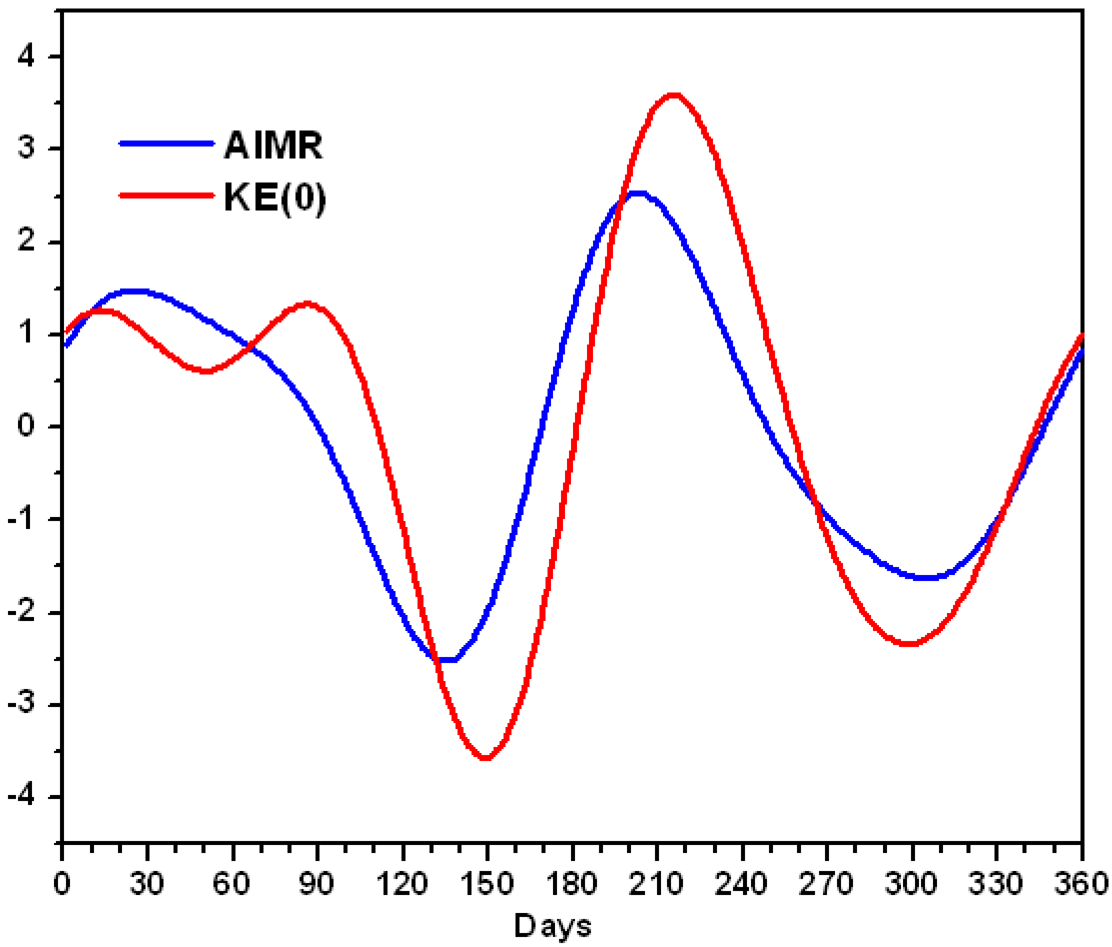
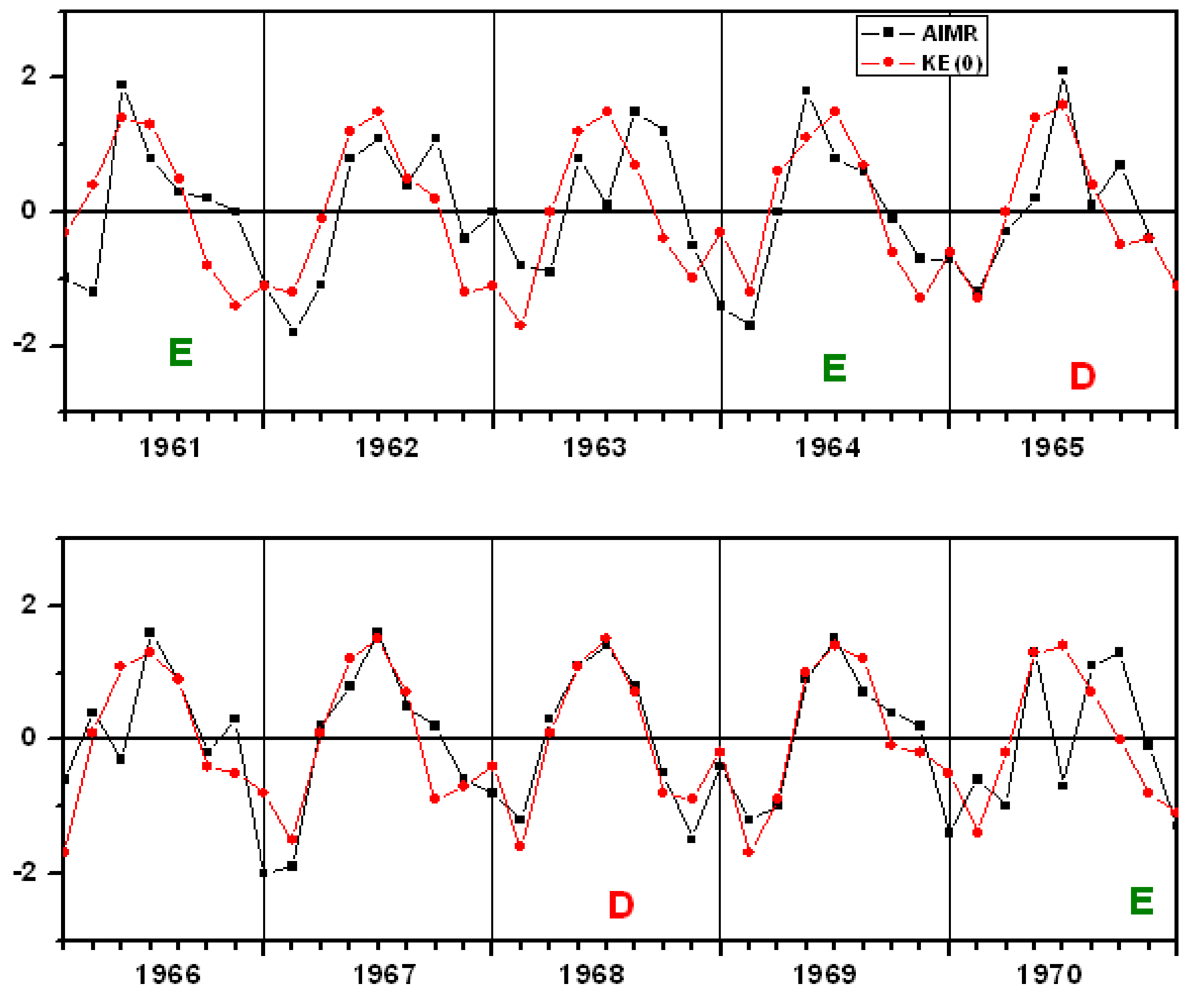


Figure 3

Figure 3: Principal Oscillation Pattern of daily kinetic energy of wave 0 at 100 hPa around 20°N and daily All India Monsoon Rainfall.



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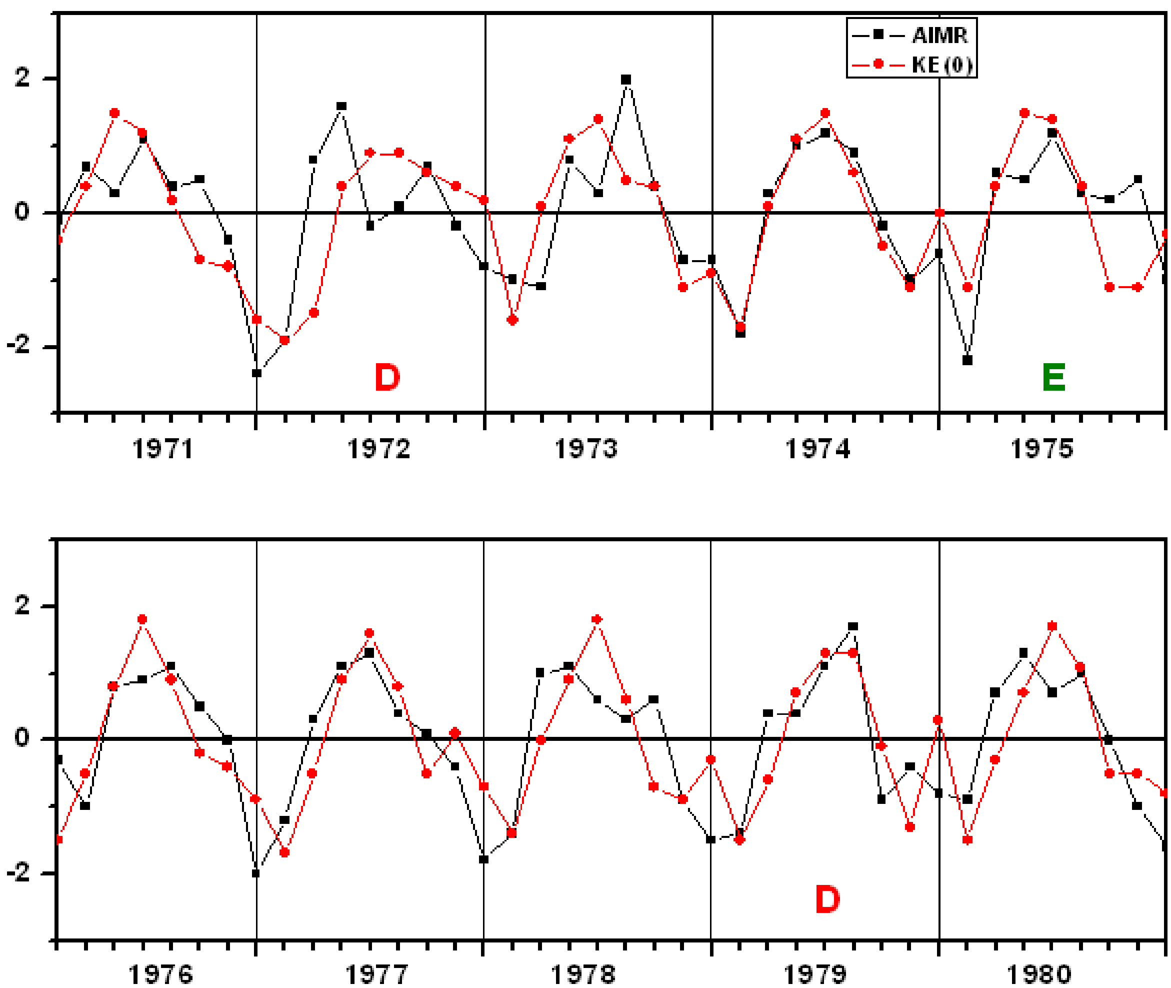

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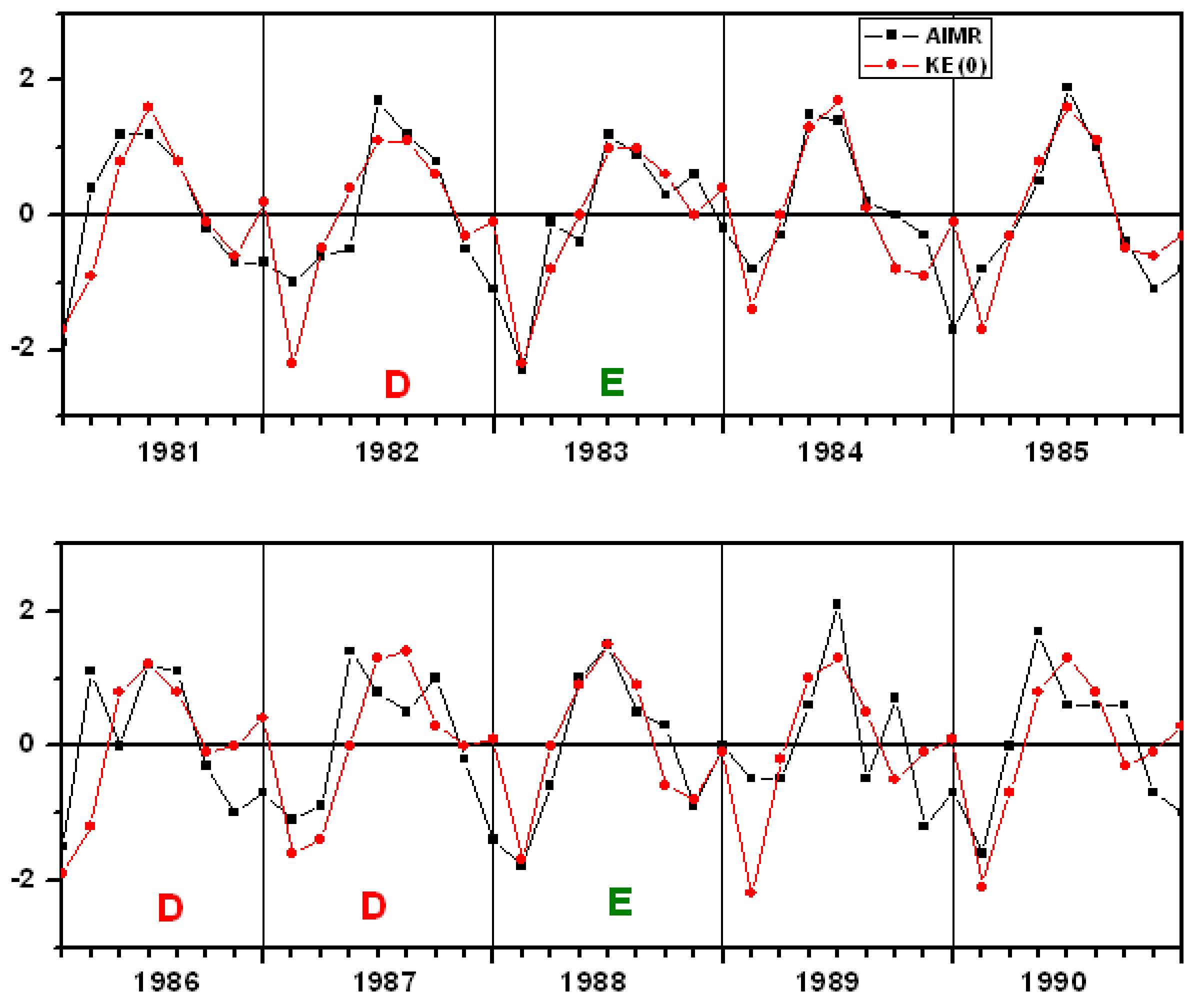

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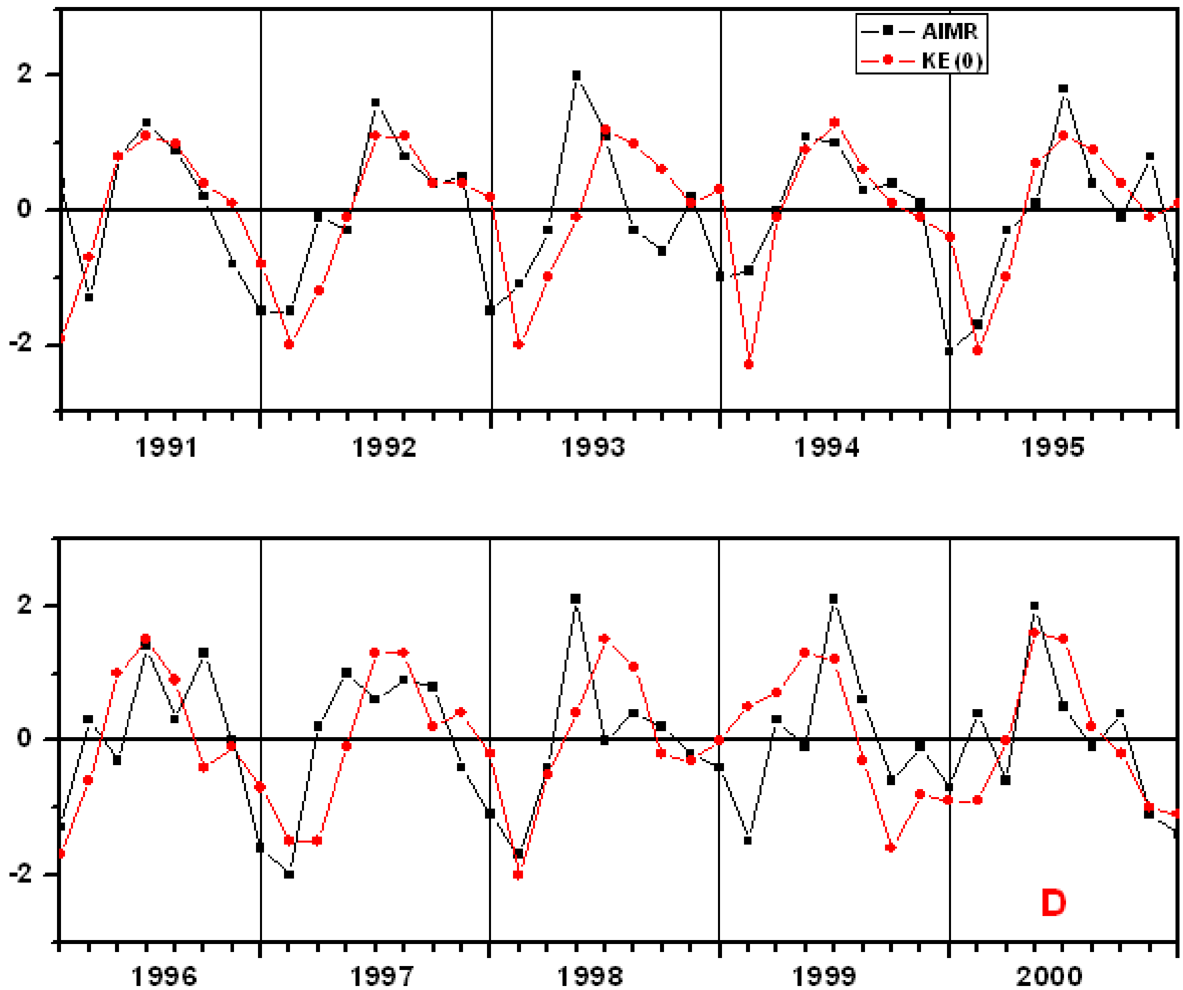

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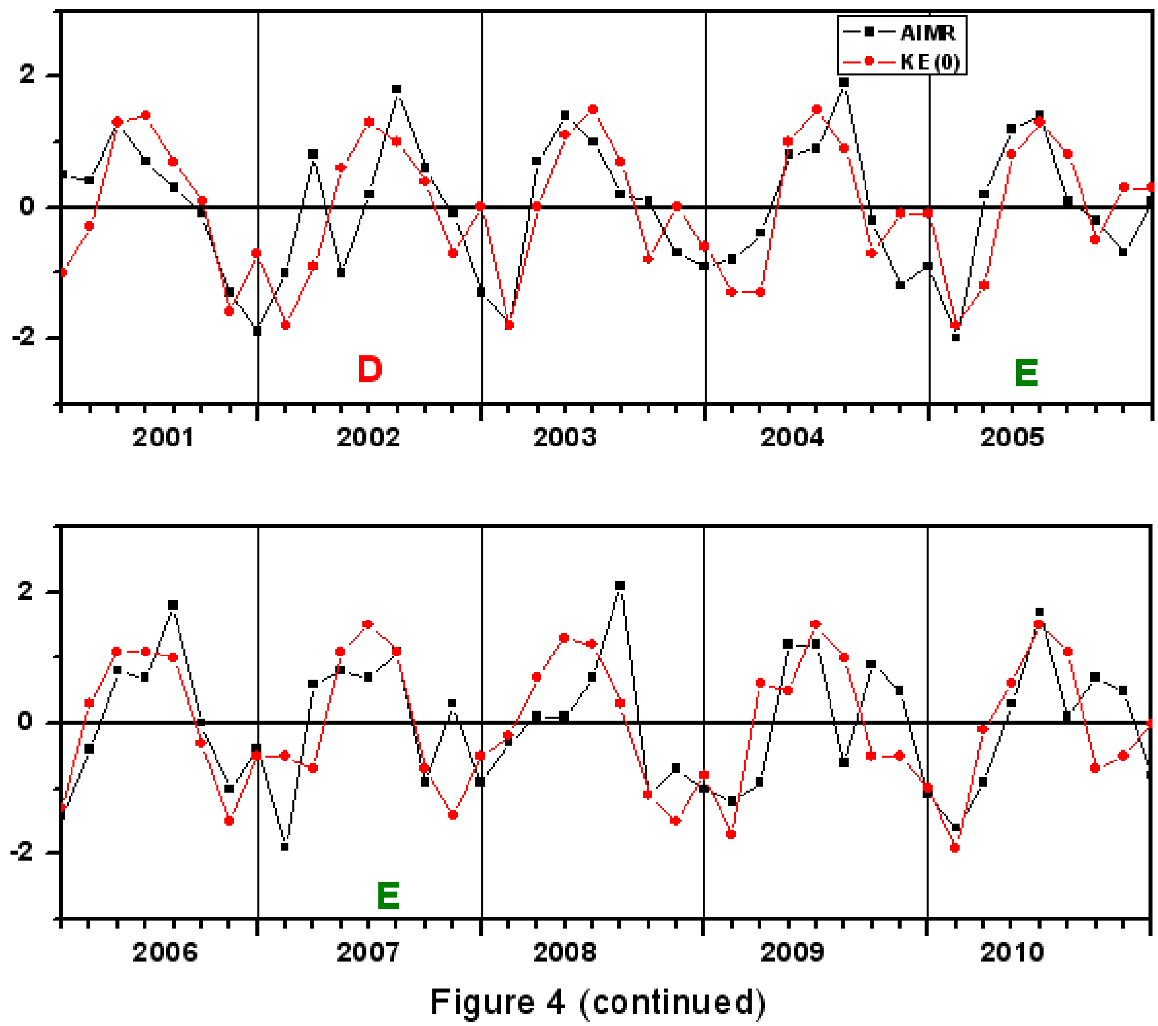

Figure 4: Comparison between normalised bi-weekly variations of AIMR and KE(0) for the years from 1951 to 2010. The phase of KE(0) is reversed.

scheme of prediction. **Observe the temporal variation of K from mid-April and predict the variation of R from June**.

Scope

A first step of introducing a simple scheme of prediction of ISV is being achieved through the study. In the next step, a linear regression model based on K and R series would be constructed for real time forecast of the variations of monsoon rainfall. The model will be further refined for smaller frequencies by incorporating the effect of the energetics of the adequate wave numbers. Even quantitative prediction is feasible.

Conclusion

The study clearly brings out that upper tropospheric KE (0) around 20°N has potential to predict the variation of monsoon rainfall. The reason behind the relation is that the POPs of K and R series are almost identical. This property has led to a simple scheme of prediction of bi-weekly variations of rainfall during monsoon season. In the present scenario, when none of the models (Statistical/Dynamical) in use in India are able to predict ISV, even the qualitative information like increase/decrease of rainfall activity during the next forthnight and that too one month in advance, is of immense utility to the farmers and the planners and even to the operational forecasters.

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