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Epochal changes in Indian monsoon-ENSO precursors

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Abstract. Precursors for the Indian monsoon are known to be highly epoch specific in their skills in predicting the monsoon on seasonal time scales. We show that the various precursors are correlated with the monsoon, only when they are correlated with ENSO, which happened in the recent period 1951 – 1990, but not in the 1990's and the period 1911-50. This accounts for the skill in monsoon prediction during 1951-90. We find that ENSO and its precursors tend toward higher amplitude and 3 – 5 year periods in the 1951 – 1990 epoch, and toward decreased amplitude and 5 – 7 year periods in the 1911 – 1950 epoch. We argue that the shift to lower frequency and amplitude in the earlier epoch diminished the association between the monsoon precursors and ENSO, leading to diminished skill in predicting the monsoon in that epoch. However, the simultaneous relationship between the monsoon and ENSO has been stable over the past 140 years, suggesting that the monsoon – ENSO teleconnections are robust once ENSO is established. Changes in the frequency of ENSO have implications for statistical prediction schemes for ENSO and the monsoon.

1. Introduction

Following the path pioneered by Sir Gilbert Walker (1918,1924) in the early twentieth century, several later studies (e.g. Pant and Parthasarathy, 1981; Rasmussen and Carpenter, 1983) have re-established a robust simultaneous relationship between interannual variability of Indian monsoon rainfall and the El Nino-Southern Oscillation (ENSO) phenomenon. However, in contrast to this simultaneous relationships with ENSO, inter-decadal changes in the relationship between monsoon rainfall and many predictors have been reported (see Krishna Kumar et al., 1995 for a summary).

Most of the predictors used in empirical prediction schemes for seasonal monsoon rainfall over India, have been shown to be manifestations of ENSO (Krishna Kumar et al., 1995). Principal component analysis on the set of monsoon predictors representing various facets of the ocean-atmosphere-land system covering the recent period 1951-80, shows that the dominant mode (explaining nearly half of the total variance) represents ENSO type variability and has a correlation of 0.8 with the monsoon rainfall. This accounts for the good skill in monsoon prediction that has been reported in recent decades. That said, other work (Trenberth and Hurrel, 1994; Kleeman and Power, 1988; Kestin et al., 1998) has shown interdecadal variations in the amplitude and period of ENSO. This suggests the possibility that the changes in the relationship between monsoon predictors and the monsoon and consequently, its predictive skills are related to changes in ENSO.

Several statistical schemes for ENSO prediction (Barnett et al.1988; and Barnston and Ropelewski, 1992) rely on the large-scale eastward propagation of global sea level pressure (SLP) fields from the Asian land mass through the Indian Ocean to the central Pacific a few seasons prior to ENSO events as identified by Barnett (1985) from his SLP analysis for the period 1951-1980. Since the ENSO signal was weaker in the earlier epoch (1911-50), the predictive SLP signal may have changed as well, with consequence for ENSO prediction schemes using SLP.

In this report, we examine the variability of ENSO and its precursor signal in SLP during the two epochs (1911-50 and 1951-90) and also the relationship between ENSO, monsoon and the predictors of monsoon.

2. Data

The study involves data for (i) all-India summer monsoon rainfall (June-September) during 1856-1997 (Parthasarathy et al., 1994 and Sontakke et al., 1993), (ii) monthly global SLP fields during 1911-1990 at a spatial resolution of 4°x4° (Kaplan et al., 1998a), (iii) SLP station data at Darwin and Bombay (1882-1994) and (iv) the eastern equatorial sea surface temperature (SST) anomalies (NINO3) for 1856-1997. NINO3 values were obtained from the grid point data of Kaplan et al. (1998b) for the era 1856-1949 and those during 1950-1997 are taken from CPC, Washington DC. The correlation between the two NINO3 series during the common period of 1951-90 is 0.97.

3. Results

It is well recognized that a major part of the interannual variability in the Indian summer monsoon rainfall related to ENSO and its simultaneous association is fairly robust. Fig. 1 shows the 21-year sliding correlation coefficients between monsoon rainfall and simultaneous (JJA) NINO3 SST anomalies during the last 142 years (1856-1997). The correlations are found to be strong and statistically significant throughout the entire record, with the sole exception of recent twenty years or so.

Among the set of monsoon predictors related to SLP and surface temperature during the pre-monsoon months, the winter to spring (MAM-DJF) tendency in SLP at Darwin and Bombay; minimum temperature in the west central Indian region during May; and northern hemisphere surface temperature during January and February have been found to be useful in the recent decades (see Parthasarathy et al. 1990,1991 and Krishna Kumar et al. 1997 for more details). To test our conjecture that the relationship between monsoon predictors and ENSO is crucial to the

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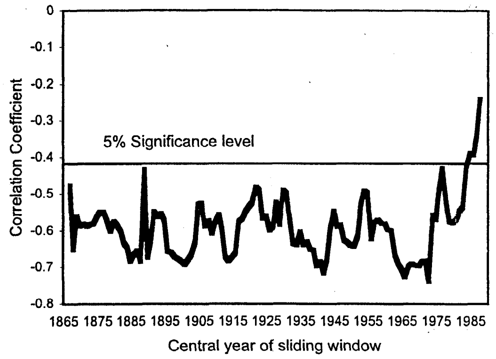

Figure 1: 21-year sliding correlations between Indian summer monsoon rainfall and NINO3 SST anomalies (JJA) during 1856-1997. The horizontal line shows the 5% significance level for the correlations.

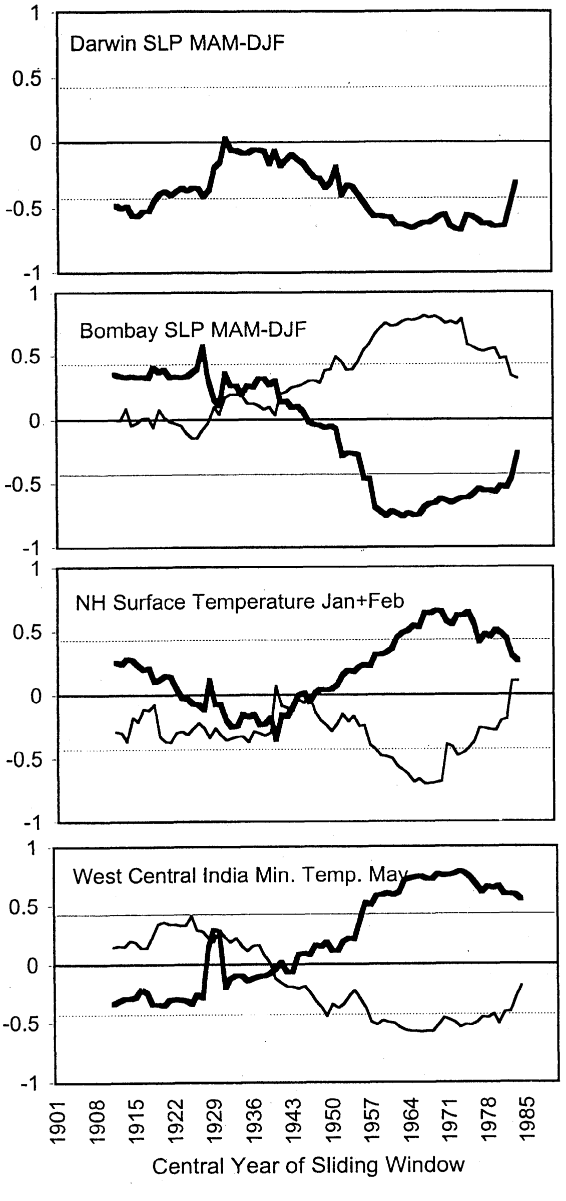

Figure 2: 21-year sliding correlations between (i) monsoon rainfall and predictors (thick line) and (ii) predictors and Darwin SLP MAM-DJF (thin line). The dashed lines (at ±0.42) indicate correlations significant at the 5% level (the y-axis in all panels is correlation co-efficient).

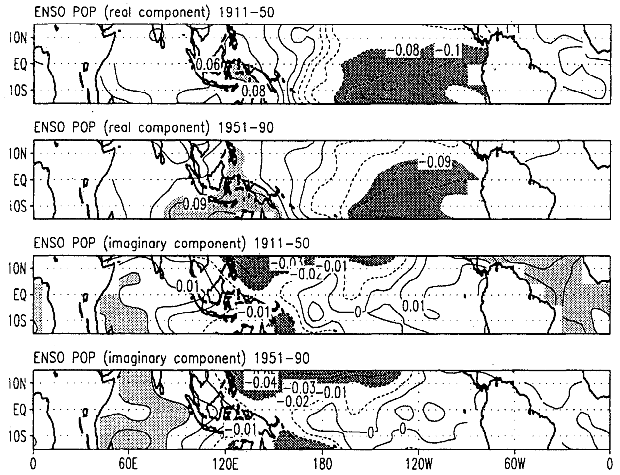

Figure 3: Real and imaginary components of ENSO POPs during 1911-1950 and 1951-1990.

relationship between the predictors and monsoon, we compute 21-year sliding correlations between (i) the predictors mentioned above and the monsoon rainfall (thick line in Fig. 2) and (ii) the predictors and the Darwin SLP tendency (MAM-DJF) (thin line in Fig. 2) during 1901-94 period. All the correlations are above the 95% significance level (correlation above 0.42) from the early 1950's until the late 1980's. Furthermore, note that the predictor – monsoon correlations are significant only when the predictors are strongly related to the winter to spring tendencies in the SLP at Darwin. Darwin SLP is one of the most often used indices for ENSO. Similar results are found when we correlate the predictors with winter to spring tendencies in NINO3 SSTs. These results also corroborate the findings of Parthasarathy et al. (1991), who show that the correlation between Bombay SLP tendency and the monsoon becomes dominant only when the former is significantly related to Darwin SLP tendency. Prior to the late 1920's, there was a brief period of about two decades when Darwin SLP tendency was significantly related to the monsoon (this was the time when Walker discovered the relationship). Note that the period of significant correlation and coherence among all the predictors, coincides with the period (1951-80) studied in Barnett (1985).

Global SLP fields have also been used to predict ENSO: Barnett et al., 1988 and Barnston and Ropelewski, 1992 use global SLP for a few seasons prior to the forecast time as ENSO predictors. The canonical loadings of the SLP fields during the four seasons prior to the peak period of the events shown in Barnston and Ropelewski (1992) confirms the propagating features identified earlier in Barnett (1985), and indicate the importance of SLP in the Indian Ocean sector as a predictor.

Recognizing the epochal nature of the predictor – monsoon relationship and predictor – ENSO relationships we now analyze the global SLP fields during the two epochs 1911-50 and 1951-90 to identify changes in ENSO characteristics. We determine the spatial propagation of signals from a Principal Oscillation Pattern (POP) analysis (Hasselmann, 1988), a technique which fits the time evolution of a dynamical system to a constant coefficient linear stochastic model. The eigenvectors of the modeled propagator matrix[1] are the modes of coherent time evolution within the model dynamical system. The eigenvalues give the period and decay time of the corresponding mode. The

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[1] This matrix relates dynamical fields at one time to those at a fixed time (here one month) later

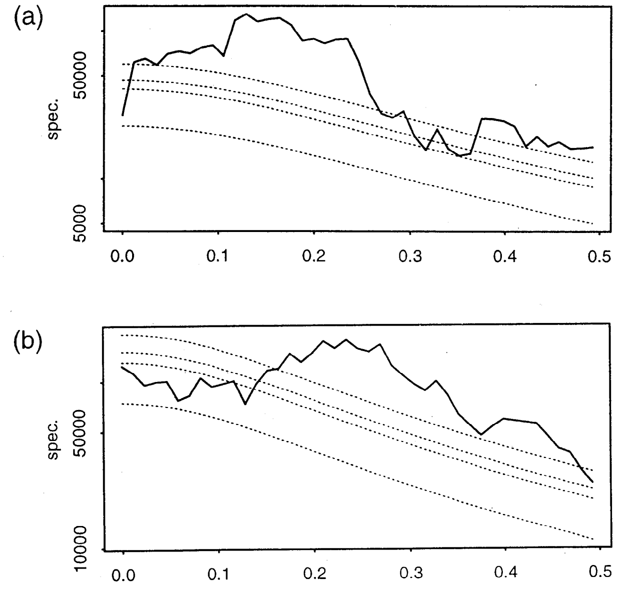

Figure 4: The spectra of the real component time series of the ENSO POP during (a) 1911-50 and (b) 1951-90.

eigenvectors, the POPs, are complex; in terms of propagation, the imaginary component of a POP leads the real component by one fourth of the POP period.

First, the monthly SLP data between 15°S to 15°N is smoothed with a 12-month filter. Simple moving averages were used but the results below are found to be insensitive to the moving window length of this smoothing. The data are next de-trended and a POP analysis is then performed separately for the two epochal periods: 1911-50 and 1951-90. The real and imaginary components of the easily identified ENSO POP for these two epochs are shown in Fig. 3. The spatial structure of the ENSO POP in both the epochs is quite similar with the exception of relatively weak loadings around Darwin in the earlier epoch compared to the recent period suggesting that this spatial shift may be enough to change the associated dynamical pattern. However, the strong similarity in the spatial structure might be expected in view of the dominance of the ENSO cycle in both periods. The aspect that differs between the epochs is the period of the oscillation: 84.5 months for the first and 41.8 months for the second. This can also be seen from the spectrum of the time component of the real part (or the ENSO pattern) for the two epochs shown in Fig. 4. The significant power is found to be in the 5 – 8 year period during the earlier epoch and 3 – 5 year period in the recent epoch. This suggests that the ENSO has roughly doubled in period. The decay times of the ENSO POP in the two epochs are nearly the same (29 and 31 months, respectively), so the ratio of decay time to period is much higher in the recent epoch, which indicates that the ENSO cycle was better defined and stronger. This is consistent with the variance of ENSO indices being greater in the later period (Trenberth and Shea 1987; Elliott and Angel, 1988). The precursor (imaginary) POP component, which leads the ENSO POP by one fourth of the period, shows a greater weight in the Indian Ocean during the later period. In both epochs the real and imaginary POP components correspond very well with EOFs 1 and 3 respectively (not shown here) of the SLP data. These two EOFs explain 55% of the variance in the first epoch and 73% in the second which demonstrates the dominance of the POP patterns. The spectra of the principal components of EOF1 in SLP in both epochs also resembled the spectra of real components shown in Fig. 4, providing verification from a different technique. The shifting of ENSO to a higher period during 1920-50 was also reported earlier

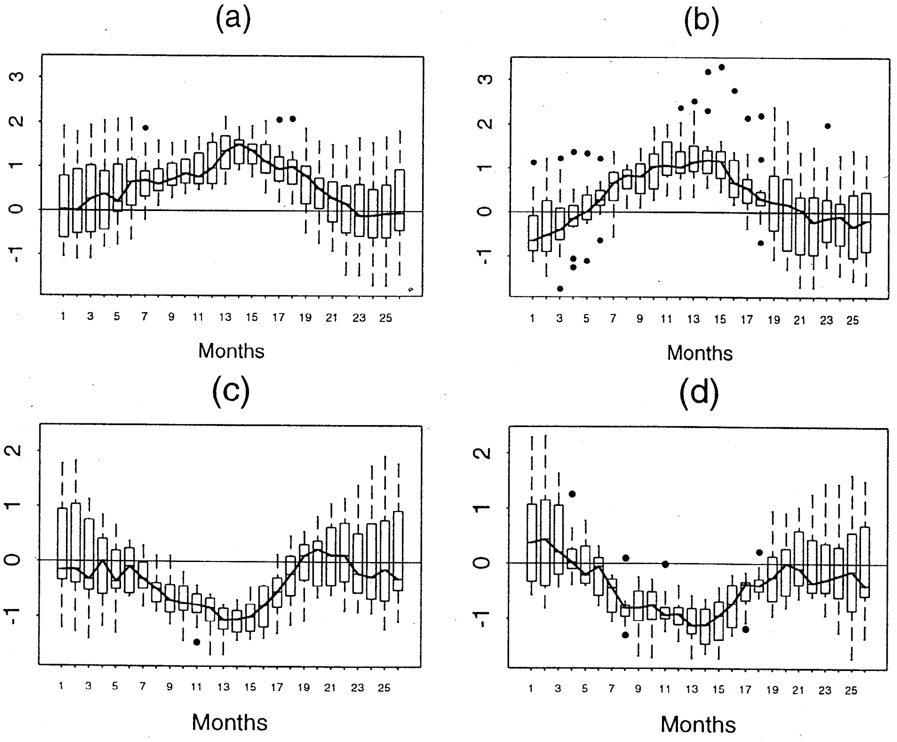

Figure 5: Box plots of NINO3 over a 25-month window; (a) warm events (1901-50); (b) warm events (1951-90); (c) cold events (1901-50) and (d) cold events (1951-90). Month 1 corresponds to December of the year prior to the event. The events were based on NINO3 anomalies exceeding ±0.75σ. The boxes correspond to 25 and 75 percentiles; the lines extend up to 5 and 95 percentiles and the dots indicate values beyond 5 and 95 percentile limits.

with the wavelet analyses on NINO3 and SOI data in Wang and Wang (1996) and Kestin et al. (1998).

In passing we remark that one can not conclude that different ENSO dynamics are at play in the two epochs. A chaotic (Zebiak and Cane, 1991) or stochastic (Moore and Kleeman, 1997; Kestin et al 1998) model of ENSO irregularity show strong decadal long fluctuations in the ENSO period.

The increase of the ENSO period during the earlier epoch would result if either (i) the events are separated by a longer interval or (ii) the duration of the events is longer. Examination of the characteristics of the time-evolution of warm and cold events during these two periods (Fig. 5) indicates that the events are generally longer in the earlier epoch compared to the recent. Also, as can be seen from Fig. 5, the swing (winter to spring) from one sign of the anomaly to another is very weak in the earlier epoch relative to the recent. As demonstrated in Fig. 2, the monsoon predictors are related to the swings in ENSO fields in the recent epoch as is their skill in predicting monsoon rainfall.

The increase of the ENSO period and the decrease in variance reduces correlations with various precursors in the earlier epoch. Also, the reduced Indian Ocean precursor amplitude together with an enhanced lead-time as a result of the increase in the ENSO period reduces the success of fixed time-lag precursors of the monsoon as well as of ENSO. The role of other climatic forcings from the mid-latitudes, such as, the Eurasian snow cover (Sankar Rao et al., 1996 and references there in), northern hemispheric circulation (Kripalani et al., 1997) should be investigated for improving the monsoon prediction, especially during epochs of weak monsoon-ENSO relationship.

4. Conclusions

1. Simultaneous correlation between ENSO and the monsoon is very robust over the past 140 years. The sole exception, the drop during the recent decades, obviously is of great interest, and perhaps a cause for concern.
2. Monsoon precursors/predictors are highly epoch specific.
3. POP analysis shows a robust ENSO spatial pattern involving eastward propagation of SLP signals which is not epoch specific.
4. The ENSO period as determined by the POP and other analyses is longer in the earlier part of the century compared to the recent (1950-present) epoch. In addition, the variance of ENSO as well as the precursors was significantly weaker in the earlier period. These two factors account for the epoch dependent nature of monsoon predictors.
5. The analysis hints at the potential limitations of statistical forecast models of monsoon and ENSO and suggests that the skills of such schemes need testing in different epochs in the light of variations in the ENSO cycle.

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