Interdecadal Change in Potential Predictability of the Indian Summer Monsoon

B N Goswami

Centre for Atmospheric and Oceanic Sciences, Indian Institute of Science, Bangalore, India 560 012

Abstract. A quantitative estimate using daily circulation data for 55 years reveals that the potential predictability of monthly mean summer monsoon climate (a ratio between 'external' and 'internal interannual variances) has decreased by almost a factor of two during the decades of 1980's and 1990's as compared to that during 1950's and 1960's associated with the major interdecadal transition of climate in mid-1970's . During the same period, however, the potential predictability of the summer climate over the central and eastern tropical Pacific has increased by a factor of two. The decrease in potential predictability of monsoon is partly due to a large decrease in 'external' variability during the recent decades as a result of interdecadal modulation of the mean monsoon circulation and partly due to 'internal' variability remaining relatively high. It is shown that the decrease in 'internal' variability due to decrease in intraseasonal activity during this period is rather small and can not compensate the decrease is 'external' variability resulting in significant decrease in monsoon predictability.

1. Introduction

Over the last couple of decades, the climate models have improved significantly in simulating the global climate [e.g., *Gates et al.*, 1999] and it has been shown that the tropical climate, in general, is much less sensitive to initial conditions and hence more predictable than the middle latitude climate [*Shukla*, 1981, 1998]. However, the Indian monsoon seems to be unique within the tropics with almost all climate models having serious systematic errors in simulating the seasonal mean rainfall and its interannual variability [*Sperber and Palmer*, 1996; *Gadgil and Sajani*, 1998; *Kang et al.*, 2002]. While prediction of seasonal rainfall in the Indian monsoon region is very important due to large area of rain-fed agriculture in this region, the skill of dynamical prediction of seasonal rainfall over this region is insignificant [*Wang et al.*, 2004; *Sperber et al.*, 2001]. Is the inability of the climate models to simulate and predict the interannual variability of the Indian monsoon due to deficiency of the models or due to some intrinsic limitations in predicting Indian summer monsoon (ISM) climate? Although model deficiencies have a role to play, there seems to be a more fundamental reason for the difficulty in predicting the ISM climate. It is shown in some recent studies [*Goswami*, 1998; *AjayaMohan and Goswami*, 2003] that the weak potential predictability of the ISM is partly due to the fact that the influence of the external low frequency interannual (LF) forcing such as the El Nino and Southern Oscillation (ENSO) is rather weak while the 'internal' LF variability generated by the vigorous intraseasonal oscillations (ISO) is relatively large over this region. Interdecadal variability of the ISM [*Kripalani and Kulkarni*, 1997; *Kripalani et al.*, 1997; *Mehta and Lau*, 1997] has been well known and is associated with global scale changes in the background circulation [*Krishnamurthy and Goswami*, 2000]. Interdecadal variability of the large scale circulation could influence the interannual variability of the ISM through influence on either or both the 'external' and the 'internal' component of LF variability. The potential predictability of monthly mean summer monsoon climate could , therefore, be modulated by interdecadal circulation variability. The correlation between ENSO and ISM has decreases to an insignificant level in recent years [*Kumar et al.*, 1999b, a; *Krishnamurthy and Goswami*, 2000]. As this is only a qualitative indication of the 'external' influence of ENSO on the ISM, by itself, it does not imply reduced predictability of the ISM. If the 'internal' variability (climate noise) also decreases proportionately, the ISM would remain predictable. No study, so far, has made a quantitative estimate of LF changes in the 'external' and the 'internal' components of ISM variability. Using three dimensional circulation data for 55 years, the present study quantifies the change in predictability of the ISM during this period and investigates whether the modulation of the 'external' or the 'internal' component by the large scale circulation is responsible for the change.

2. Data Used and Method of Analysis

NCEP/NCAR reanalysis has been used [*Kalnay et al.*, 1996; *Kistler et al.*, 2001] for the study. We obtained daily mean horizontal winds and vertical velocity at standard pressure levels and monthly mean sea surface temperature (SST) for the period 1948-2002 . Although reanalyzed precipitation may have some bias arising from inadequacy of physical parameterizations of the forecast model used in the reanalysis, only NCEP/NCAR reanalyzed precipitation can provide some insight regarding relationship between circulation and convective activity on interdecadal time scale. Therefore, daily mean reanalyzed precipitation for the period was also extracted. As the period between 1948 and 2002 contains a major transition of tropical interdecadal variability in the 1970s, we may expect the reanalysis data set to provide important insight regarding the three dimensional structure of the interdecadal variability.

To isolate the interdecadal component, monthly means were first created. Monthly anomalies were then calculated by removing the climatological mean annual cycle from the monthly means. The interdecadal variations at all levels were extracted using a harmonic filter. Low pass (LP) filtered field is reconstructed from all the harmonics with periods longer than 7 years . A 'residual' field representing

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interannual variability is obtained by subtracting the LP filtered field from the original monthly anomaly time series.

The potential predictability is defined as a ratio (F) between the 'external' and 'internal' interannual variances. The procedure for extracting the monthly mean 'external' and 'internal' anomalies is described in detail in *AjayaMohan and Goswami* [2003] and only a brief outline is presented here. The daily annual cycle of a given year of any field at any point is constructed as the sum of the annual mean and the first three harmonics of daily time series for the year. The slowly varying external forcing (such as those associated with the ENSO) modulates the annual cycle and makes it different from one year to another. The 'external' daily anomalies are thus defined as deviation of the daily annual cycle of an individual year from the climatological mean daily annual cycle. Monthly mean of daily 'external' anomalies provide monthly mean 'external anomalies. The deviation of the daily values of a given year from the annual cycle of that year represents the 'internal' anomalies essentially contributed by the ISO's. The 'internal' monthly anomaly is constructed from the monthly mean of daily 'internal' anomalies. In this manner, 'internal' and 'external' monthly anomalies for the summer monsoon months (June, July, August, September) for all the years were calculated. The procedure implicitly assumes independence between 'internal' and 'external' variability. To find variability of the potential predictability, a few fields such as zonal winds and relative vorticity at 850 hPa and vertical pressure velocity at 500 hP that are strongly associated with variability of the ISM were selected and F ratios were estimated using variances based on a 11-year (44 months) moving window.

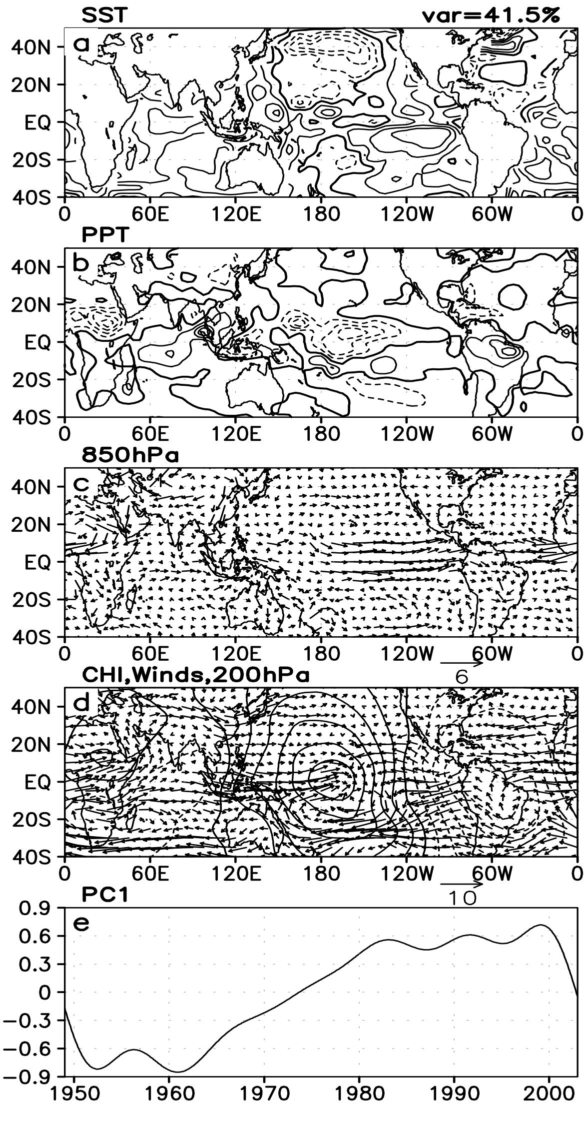

Figure 1. First combined EOF of LP filtered fields, (a) SST, contour interval 0.1K, (b) precipitation, contour interval 1.0 mm day^{-1}, (c) vector winds at 850 hPa, unit ms^{-1}, (d) vector winds (ms^{-1}) and velocity potential (contour) at 200 hPa, contour interval 1.0x10^{6} s^{-1}.(e) Time evolution of the PC1 , unit arbitrary. In (a), (b), and (c), the zero contour is thick.

3. Results

To gain some insight regarding the global spatial and vertical structure of the dominant interdecadal variability, a combined empirical orthogonal function (EOF) analysis

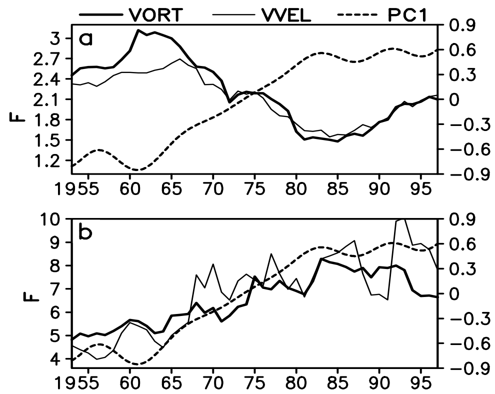

Figure 2. (a) Potential predictability index F, for vertical velocity at 500 hPa and relative vorticity at 850 hPa averaged over the Indian monsoon region (IMR) together with PC1 of the interdecadal mode. F for vertical velocity is multiplied by a constant factor of 1.25. (b) Same as in (a) but for F averaged over central and eastern equatorial Pacific (EqP).

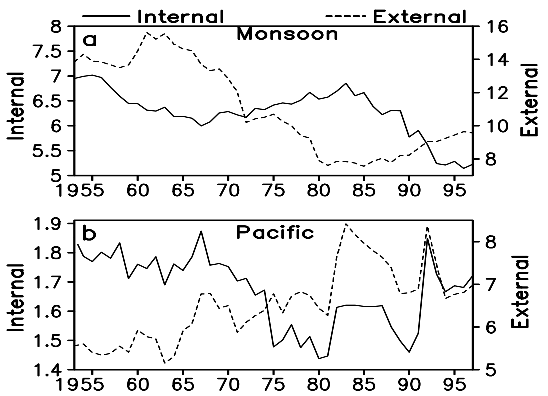

Figure 3. Changes in 'internal' and 'external' variances for relative vorticity at 850 hPa (in 1.0x10^{-12}s^{-2} averaged over (a) IMR and (b)EqPa.

was carried out using LP filtered SST, zonal and meridional winds at 850 hPa and at 200 hPa and velocity potential at 200 hPa. The EOF1 explaining 41.5 percent of the LP filtered variance is quite distinct from the other EOFs and could be considered a natural mode of oscillation representative of the multi-decadal amplitude modulation of the ENSO. Associated with the EOF1, the ENSO-like warming (cooling) of SST in the eastern tropical Pacific is in phase with SST over the tropical IO (Fig.1a). The spatial pattern of precipitation associated with interdecadal mode (Fig.1b) consists of enhancement of precipitation over two major regions namely, northern South America and eastern equatorial IO and Indonesia and decrease in precipitation over, central and eastern Pacific and central Africa. Consistent with the precipitation pattern, the wind patterns show low level convergence and upper level divergences over equatorial central America and northern South America and Indonesia while low level divergence is seen over equatorial eastern Africa and central Pacific around the dateline (Fig.1c,d). In the equatorial region, low level convergence (divergence) is always associated with upper level (200 hPa) divergence (convergence). The upper level velocity potential field of the interdecadal mode (Fig.1d) is consistent with the divergent circulation associated with the precipitation anomalies (Fig.1b). The precipitation pattern and the equatorial circulation are indicative of a three cell Walker circulation.

Strong association between variation of precipitation and low level winds and first baroclinic vertical structure of wind fields associated with it indicates that the interdecadal mode of variability is strongly convectively coupled. The following positive feedback between the atmosphere and the ocean may be envisaged for generating the interdecadal mode of variability. Enhanced precipitation over northern South America and Indonesia (Fig.1b) gives rise to low level convergence and weakens the easterlies in the eastern Pacific and south-eastern equatorial IO. Decrease of latent heat flux associated with the weakened mean winds leads to positive net heat flux to the ocean in the eastern Pacific and eastern IO leading to positive SST anomalies in these regions (Fig.1a). Higher SST in these regions further deepens the low pressures in the regions and further weakens the easterlies and leads to further increase in SST. However, the exact mechanism for controlling this positive feedback and leading to an oscillatory behavior is not quite clear.

The LF variation of potential predictability over the Indian monsoon region (IMR, 40°E-100°E, 10°N-35°N) is clearly associated with the interdecadal mode with correlation between the PC1 and F for relative vorticity at 850 hPa and vertical velocity at 500 hPa being -0.88 and -0.84 respectively (Fig.2a). The F value for relative vorticity (vertical velocity) between 1980 and 1990 is lower by about 50 % (40%) compared to its peak value between 1960 and 1965. In absolute sense, this decrease has made the Indian monsoon only marginally predictable during the last two decades. With 44 degrees of freedom for both the variances, the F values are significant at 5% level. The decrease is also considered highly significant as it represents more than 50% change of the mean value. In contrast, the potential predictability of the climate over the core ENSO region (equatorial Pacific,170°E-110°W, 10°S-10°N, EqP) has increased steadily with the F value during the decade of 1990's almost doubling that during the decade of 1950's. This LF variability of the potential predictability in the EqP is also strongly correlated with the evolution of the interdecadal mode with correlation between F of relative vorticity at 850 hPa and of vertical velocity at 500 hPa and PC1 being +0.89 and + 0.82 respectively. The F value over the IMR is always smaller than that over the EqP. As a result of the opposite LF variability of F over the IMR and over the EqP, the contrast between the potential predictability of the climate over the two regions has increased considerably during the recent decades. While the ratio between F over the EqP and that over the IMR was about 1.5 during 1960's it is about 4.5 during 1990's.

What is responsible for the significant decrease (increase) in the potential predictability over the IMR (EqP) region? This is investigated in Fig.3 where the LF variability of the 'internal' and 'external' variances over the two regions are shown. It is noteworthy that the 'external' variance over the IMR has decreased by a factor of two during the recent decades compared to its value during 1960's. However, the 'internal' variance has decreased only marginally (approximately by 25%). The decrease in the 'internal' variability over IMR is essentially due to a decrease in the ISO activity in the region during the recent decades (not shown). Thus, the significant decrease of potential predictability of the Indian monsoon in the recent decades is partly due to decrease of the 'external' variability as a result of modulation of the background circulation by the interdecadal oscillation and partly due to the 'internal' variability remaining high. On the other hand , the 'external' variance over the EqP has increased by almost a factor of two compared to its values during 1950's and 1960's. The large decrease in the 'external' variance over the IMR is consistent with the fact that the all Indian rainfall (AIR, JJAS precipitation over the indian continent) also shows significant decrease in interannual variance during the recent decades [*Kripalani et al.*,

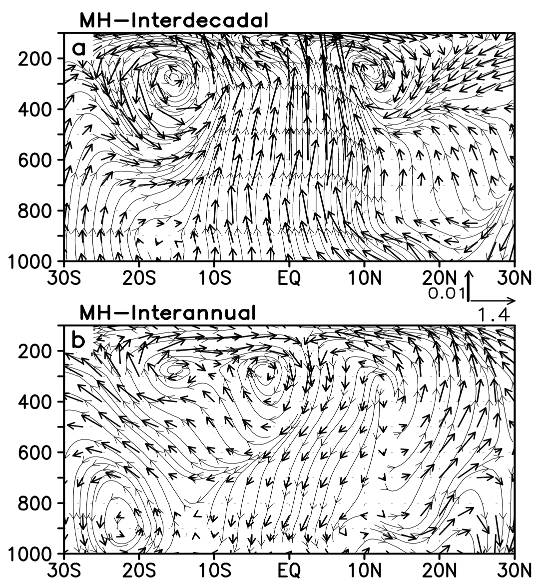

Figure 4. Monsoon Hadley (MH) depicted by latitude-height section of meridional winds (m s^{-1}) and negative of vertical pressure velocity (Pas^{-1}) averaged over 70°E-110°E at 12 vertical levels associated with (a) the interdecadal mode. Warm minus cold composite of LP filtered fields. (b) Strong minus weak ISM composite of residual (interannual) anomaly. Strong (weak) ISM composite was created by averaging JJAS anomalies for the years 1956, 1959, 1961, 1970, 1975, 1983, 1988, 1994 (1951, 1965, 1966, 1972, 1979, 1986, 1987).

2003; *Krishnamurthy and Goswami*, 2000]. It is also interesting to note that generally lower potential predictability over the IMR compared to that over the EqP is essentially due to the 'internal' variability in the former region being 3-4 times larger than that over the later region while the 'external' variability is larger only by a factor ranging from 1 to 2.

What kind of three dimensional circulation changes are associated with the interdecadal mode that result in the large change in the 'external' variability over the IMR? We can gain some insight on this question, from NCEP/NCAR reanalysis as the pre-1970's and post-1970's decades correspond to two opposite phases of the interdecadal oscillation. Using LP filtered winds at 12 vertical levels, warm (cold) interdecadal composite was created by averaging LP filtered fields between January 1952 and December 1965 (January 1982 and December 1995). The difference between warm and cold interdecadal composites of monsoon Hadley (MH) circulation is shown in Fig.4a. This is contrasted with the MH circulation associated with the residual interannual variability of the ISM (Fig.4b).The years used to construct the strong minus weak composite of the ISM are given in the caption of Fig.4b. The interdecadal MH circulation is characterized by significant deep ascending motion over the equatorial IO between 10°S and 10°N and upper level subsidence extending down to 500 hPa north of 10°N. The large scale persistent upper level subsidence inhibits convective activity over the ISM region leading to an overall decrease in monsoon rainfall and results in the negative correlation between interdecadal variability of the ENSO and the ISM [*Kripalani et al.*, 1997; *Mehta and Lau*, 1997; *Krishnamurthy and Goswami*, 2000]. As the Indian winter monsoon is associated with precipitation primarily over the southern tip of India extending to about 12°N, the winter convection (or rainfall) is facilitated by the enhanced upward motion in this region. Therefore, the Indian winter monsoon rainfall and ENSO are expected to be positively correlated on interdecadal time scale. This is indeed the case (not shown). A noteworthy point is that the amplitude of the interdecadal MH circulation is comparable to that associated with interannual variability of ISM. In fact, the upward motion between the equator and 15°N associated with the warm interdecadal phase is larger than the downward motion associated with a strong ISM and illustrates the possibility of significant modulation of the background flow by the interdecadal oscillation.

4. Discussion and Conclusions

The potential predictability of climate over the Indian monsoon region is generally lower than that over other parts of tropics due to significantly larger contribution of 'internal' variability to the interannual variability compared to that from 'external' variability. Modulation of the potential predictability of the Indian summer monsoon by the interdecadal oscillation adds significantly to the worsening problem of dynamical prediction of the Indian monsoon in the recent decades. It is shown that the potential predictability of the Indian summer monsoon during 1980's and 1990's has decreased by almost a factor of two compared to its values during 1950's and 1960's. The LF variation Indian monsoon predictability is shown to be closely linked with the evolution of the dominant interdecadal oscillation. The decrease in potential predictability is due partly to large reduction of the 'external' variability through modulation of background monsoon circulation and partly to only marginal decrease of the 'internal' variability . The 'internal' LF variability essentially arises from the statistics of the intraseasonal oscillations [*AjayaMohan and Goswami*, 2003]. It appears that the statistics of the intraseasonal oscillations is not strongly modulated by the background flow changes consistent with our assumption that the 'internal' LF variability is largely independent of the 'external' LF variability.

The interdecadal oscillation is expected to have certain amount of long range predictability due to its LF character and possibility of air-sea interaction associated with it. The strong modulation of potential predictability of the monsoon by the interdecadal oscillation indicates possibility of long range predictability of the changes in potential predictability of the Indian monsoon.

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Centre for Atmospheric and Oceanic Sciences, Indian Institute of Science, Bangalore 560 012,India; goswamy@caos.iisc.ernet.in

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