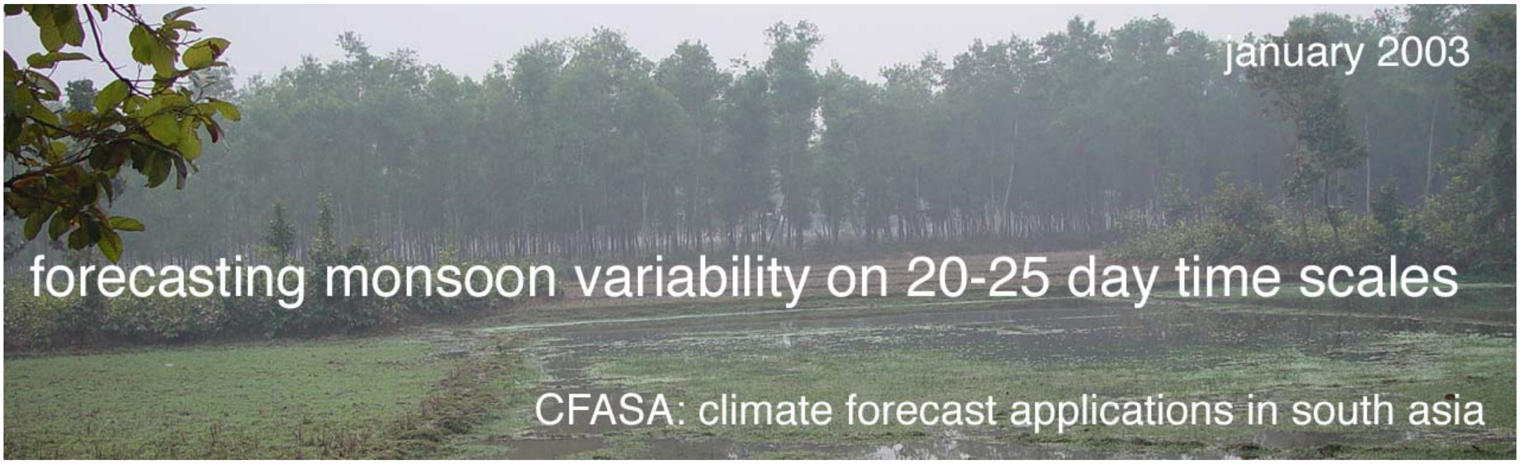

january 2003

forecasting monsoon variability on 20-25 day time scales

CFASA: climate forecast applications in south asia

One of the most important tasks in operational meteorology in the tropics is the forecasting of the timing and strength of the summer monsoon. Traditionally, there have been two major predictands: the seasonally averaged All-India Rainfall Index (AIRI) and the onset date of the monsoon (e.g., Parthasarthy et al. 1994, Webster et al. 1998). The former refers to a measure of the gross state of the monsoon over the entirety of India and the latter to the commencement of prolonged rainfall in the south of India. Predictors of these factors have rested heavily on the state of El Nino in the Pacific Ocean (e.g., Shukla and Paolina 1983). While each of these factors is important, there are a number of issues that may suggest that the question of monsoon prediction be readdressed:

- The AIRI is a gross broad-brush measure of the mean Indian monsoon rainfall. With an above average AIRI there may still be large regions of India that have below average rainfall (and vice versa). In general, an anomalous seasonal AIRI of either sign need not reflect substantial regions of drought or flood within India.
- The onset of the monsoon over south India is not correlated with the start of rainfall over broad reaches of India and, at best, weakly with large-scale ENSO indices (Fasullo and Webster 2002).
- Over a 120-year period, connections between the East Pacific sea-surface temperature and seasonal AIRI explain about 35% of monsoon rainfall variance. However, these large-scale ENSO-monsoon connections have proven to be statistically non-stationary with disappearing correlations during the early part of the last century (Troup 1965) and , more lately, during the last few decades (Kumar et al. 1999, Torrence and Webster 1999). For example, near normal monsoons accompanied the El Nino of the early 1990s. During 1997-98, when the strongest El Nino of the century occurred, the rainfalls were essentially normal (1997: -1% AIRI and 1998: + 5%AIRI. Yet, with the relatively weak 2002-03 El Nino, the AIRI for the summer of 2002 was one of the lowest on record. It was also not forecast by traditional means.

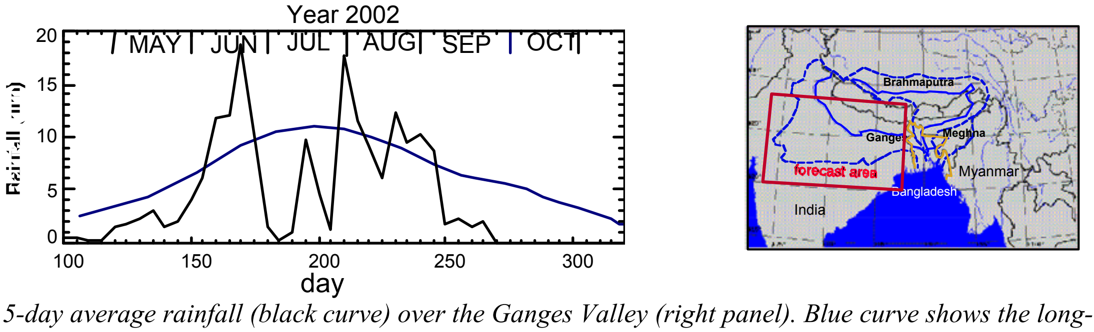

Figure 1: 5-day average rainfall (black curve) over the Ganges Valley (right panel). Blue curve shows the long-term average precipitation for the same region. Note that the drought of 2002, which resulted in an overall decrease of 19% of the seasonal AIRI, arose principally from a break in monsoon precipitation in July rather than a homogenous decrease of rainfall throughout the season.

Irrespective of recent failures of the monsoon-ENSO relationship, the question is whether or not a forecast of monsoon rainfall averaged spatially over the entire Indian subcontinent and temporally over the summer season is the most useful forecast for water management and agriculture purposes? Clearly, a useful forecast of the 2002 summer AIRI would have indicated a much below average rainfall. However, the failure of the monsoon resulted from a cessation of rains from late June through most of July and not from a general reduction of rainfall throughout the summer (Figure 1). Indeed, a forecast of the monsoon break 20 days in advance would have allowed most of the damage to agriculture to be avoided. A. R. Subbiah (Asian Disaster Preparedness Centre: ADPC Bangkok) notes that:

> *"The minimum length of a forecast which will allow a farming community to respond and take meaningful remedial actions against either flood or drought is about 10 days although a forecast period of 3 weeks would be optimal…*
> *Assuming that a three week prediction were available by the third week of June 2002 …. farmers could have been motivated to postpone agricultural operations, saving investments worth billions of dollars…water resource managers could have introduced water budgeting measures …. Similarly, the prediction of the revival of the monsoon in the second half of July would have motivated the planners and farmers to undertake contingency crop-planning…"* (Preliminary Assessment of the 2002 Indian Drought: ADPC, Bangkok, Thailand).

Whereas an indication of the overall seasonal deficiency of rainfall may have been useful, only a three-week forecast of the intraseasonal variability of the monsoon would have allowed substantial mitigation of the effects of the disastrous drought of 2002.

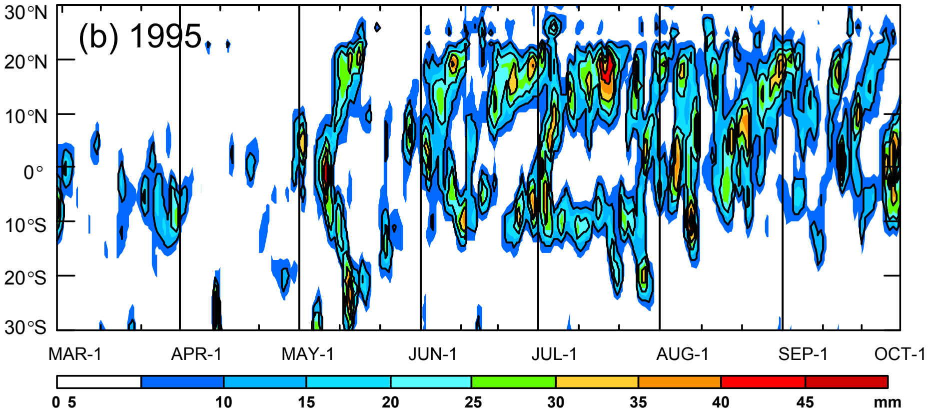

Figure 2: Satellite based MSU precipitation along 90°E as a function of time and latitude for the summer of 1995. The monsoon intraseasonal oscillations can be identified as the poleward bands of precipitation. The manifestation of these bands over South Asia are active and prolonged periods of precipitation. When the intraseasonal mode is occupies an equatorial position South Asia is in a break phase of the monsoon.

During the last few years a new paradigm has developed regarding the structure of the monsoon. This theory states that the basic instability of the monsoon is its intraseasonal variability through which the monsoon cycles through a series of wet (active periods) and dry (break periods) of the monsoon (Webster et al. 1998). Subsequent field studies (e.g., the Joint Air-Sea Monsoon Interaction Experiment: JASMINE, Webster et al. 2002), diagnostic and theoretical studies have shown that the monsoon intraseasonal variability is robust, large-scale (extending over the Indian Ocean basin), and low frequency (20-30 day) phenomena (Ferranti et al 1997, Lawrence and Webster 2002). Figure 2 shows a series intraseasonal oscillations commencing in the equatorial Indian Ocean and propagating slowly poleward.

The northward parts of this bifurcation become the active parts of the monsoon over South Asia (e.g., Lawrence and Webster 2002). Within this view, the basic instability of the monsoon system is the intraseasonal oscillation mode (Palmer 1994, Webster et al. 1998). Because of the importance of the mode to the monsoon climate,numerous attempts have been made to model and predict the mode numerically. However, simulation of the mode has remained an elusive (e.g., Sperber et al. 2000). With the absence of a numerical capability to predict this low-frequency monsoon variability, we have resorted to empirical prediction methods.

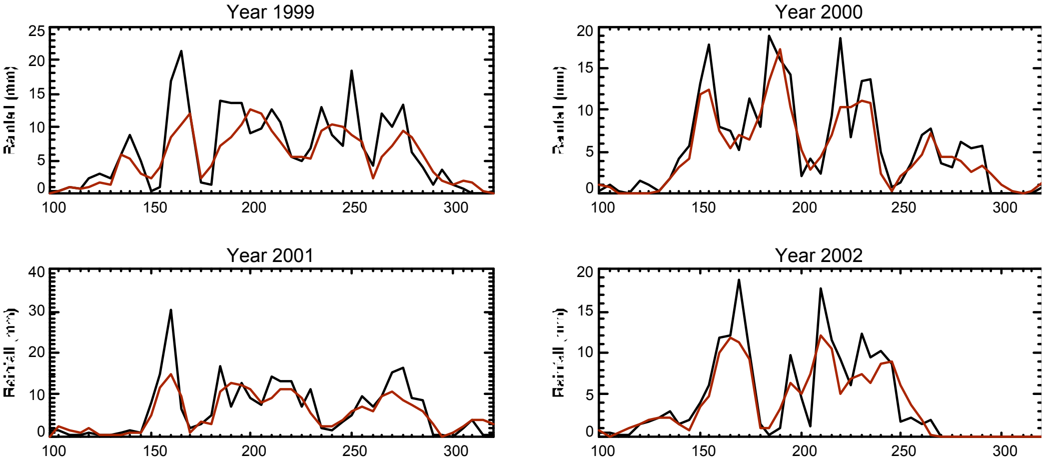

Figure 3: 20-day (5 pentad) forecasts (red curves) using the a priori wavelet-based empirical prediction scheme compared to GPCP satellite-based precipitation for the region shown in the map in Figure 1. The scheme predicts the phase of the oscillations remarkably well although tends to underestimate the magnitude of the wet periods.

Using the identification of the structure of monsoon intraseasonal variability gathered from diagnostic and modeling studies discussed above, a new *a priori* wavelet-based statistical model has been developed where the predictors are chosen as properties of the intraseasonal variability. The statistical scheme is based on the nonlinear scheme described by Poveda and Hoyas (1991). The scheme is termed "*a priori*" because the predictors are chosen from the physical features of the monsoon intraseasonal variability rather than chosen at random. The predictors are: precipitation over central equatorial Indian Ocean, precipitation over central India, sea-level pressure and soil moisture over central India, the intensity of the low-level Somalia Jet stream, the location of the upper tropospheric easterly jet stream, the SST over equatorial Indian Ocean, the upper tropospheric equatorial zonal wind, and surface winds over the equatorial Indian Ocean and the Arabian Sea. These predictors figure prominently in the composites of monsoon intraseasonal variability (Webster and Tomas 1999, Webster et al. 2002).

The predictand is the 5-day average rainfall over an area approximating the Ganges catchment region (Figure 1) determined from GPCP satellite-based precipitation. Examples of the empirical predictions are shown in Figure 2 for the summers of 1999-2000 (red curves) and are compared to GPCP satellite precipitation (black curve). In each of the examples, the forecasts determine accurately the amplitude and phase of the intraseasonal variability. For example, using this prediction scheme, the extent and duration of the 2002 drought would have been evident at the peak of the June rainfall (near day 170) and the eventual resumption of substantial rains by early July. The same technique has been used for the prediction of river discharge into Bangladesh with similarly accurate results.

We speculate that the use of such forecasts by planners may have a significant impact on agricultural and water resource practices in the monsoon regions. Currently, water resource management and cropping strategies are based on the climatological evolution of precipitation (dashed curve in Figure 1 1999 precipitation depiction). Similar to the "Green Revolution" of the 1960s, substantial increases in yield may be expected if the forecasts are properly assessed, disseminated and acted upon. To achieve this goal, there needs to be a strong interaction between scientists, government officials, policy makers and the user community. Optimization of impact requires the establishment of a set of common goals between these diverse groups. If these enactments were to occur, the impact of the intraseasonal forecasts may go beyond the substantial increase in yields. It may herald a truly "green" agricultural revolution as the use of pesticides and fertilizer would be used more efficiently and not increased as was necessary in the 1960s.

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