Overview

The Climate Forecast Applications in Bangladesh project (CFAB) has made considerable progress in the development of forecasting schemes for precipitation and flooding on short (1-10 days), medium (15-30 days) and long term (1-6 months). The schemes for the short- and long-term forecasts depend on the output of global forecast models. Medium range forecasting arises from the development of a new physically based Bayesian statistical method. All three schemes have been used with some success in the forecasting Ganges and Brahmaputra river discharge into Bangladesh. Coupled with detailed and existing forecast techniques used within Bangladesh, these discharge forecasts will prove extremely useful in agricultural planning, disaster mitigation and water resource management.

Agricultural experts have long held that forecasts on 15-30 day time scales are optimal. These forecasts would contain the largest variations in monsoon rainfall occurring in monsoon regions and allow for potential adjustments to agricultural planning (e.g., timing of planting and harvesting, crop choice, irrigation optimization) to be made. For example, 20-25 day forecasts would have reduced significantly the impact of the Indian mid-summer drought of 2002. Here we describe the forecast scheme and indicate its relevance to a large range of forecasting problems in the monsoon regions. The forecasting scheme and its application to real problems over a wider geographical domain forms the basis of a new project: Climate Forecasting Applications for Monsoons (CFAM).

(1) Monsoon Weather and Climate Variability

Significant climate variability exists in monsoon regions of South and East Asia that directly impact regional agricultural practices, health issues, water resource management, and the general welfare of a large percentage of the planet's population. There are four major time scales for climate variability:

- Weather events (1-5 days) such as tropical cyclones, storm surges, flash floods;
- Sub-seasonal (15-30 day) variability of monsoon rainfall as the monsoon waxes and wanes between active (wet) and break (dry) periods;
- Interannual (> 1 year) variability of monsoon rainfall; and,
- Long-term (decadal and centennial) that includes climate change and global warming.

Figure 1 shows rainfall variability for four summers (1999-2002) over the Ganges Valley (black curves). These years are very different but the largest variation in each takes place sub-seasonally with the monsoon oscillating between rainy ("active" periods of the monsoon) and dry ("break" periods) events. The timing of these events is critical for planting and harvesting of crops and the allocation of water for irrigation and industrial, urban, and hydropower usages. For example, in 2002, a delayed commencement of rains in early June, coupled with a severe monsoon break in late June and early July caused devastating crop losses over India. Even though the overall Indian seasonally averaged rainfall was 19% below average, greater problems occurred because of the timing, intensity and duration of the July drought rather than the overall seasonal deficiency.

(2) Need for Climate Forecasts on 20-25 day Time Scales

Before our current work, little progress had been made in the forecasting of the sub-seasonal peaks and valleys in rainfall in the monsoon regions, such as those seen in Figure 1. Most effort had been put into trying to forecast the seasonal rainfall averaged over vast regions such as India. The results have been mixed, however. Traditional methods using large-scale climate indicators such as the state of El Nino-Southern Oscillation (ENSO) have failed in recent times, even though there has been some success during a large portion of the last century. However, even if the traditional seasonal forecasts were more successful, one could argue about their utility when applied to real agricultural and water resource problems. For example:

- The sub-seasonal monsoon rainfall variations of the monsoon are far larger than the differences from year-to-year and the timing and magnitude of the sub-seasonal variation is critical for agriculture.
- Even if a forecast for an above or below average seasonal rainfall were accurate, it would not indicate which parts of the large scale area would be above average, normal or below average. Nor would it indicate when during the summer the active and break periods of the monsoon might occur.

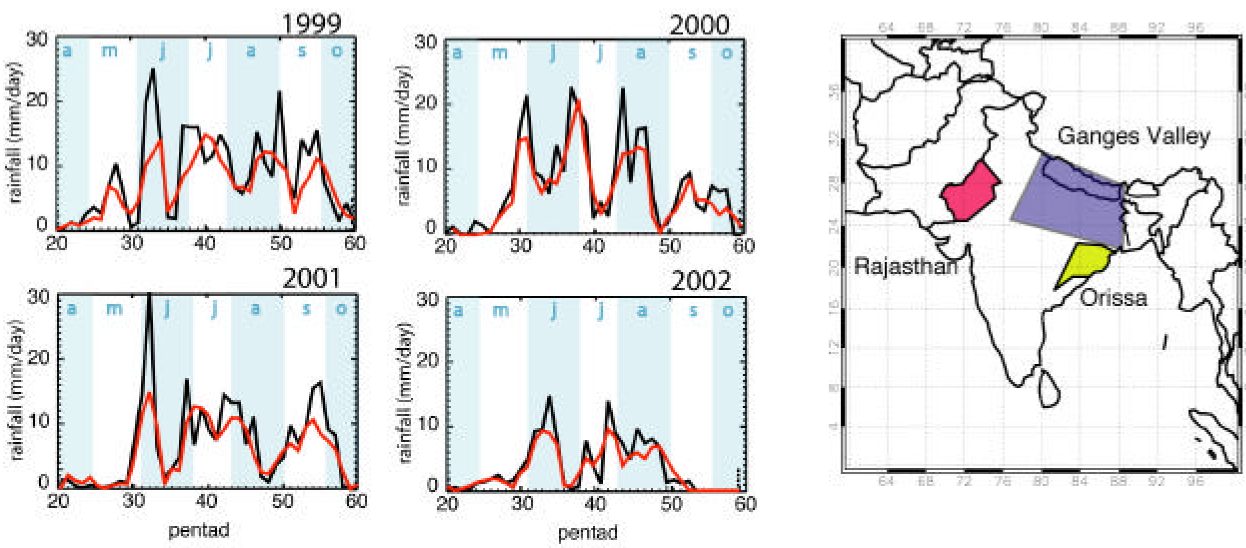


Figure 1: The 5-day average observed rainfall (mm/day: black curves) in the Ganges catchment (purple region: map) for the summers of the four years 1999-2000 plotted against pentad number (month shown on upper scale). Monsoon rainfall is characterized by a series of active (wet) and break (dry) periods lasting from 10-30 days. Red curves show the forecasts made 20 days ahead.

Of far greater utility are forecasts of the sub-seasonal variability if they had sufficient lead-time and were skillful. Indeed, a forecast of the July monsoon break 20 days in advance would have minimized the damage to agriculture during the 2002 monsoon. 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).

In summary, a perfect forecast of the seasonally averaged Indian summer rainfall of –19% would have been useful. But, since the devastation of agriculture 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), only a two to three-week forecast of the intraseasonal variability of the monsoon would have allowed substantial mitigation of the drought's adverse effects of the disastrous drought.

(3) A Forecasting Scheme for 20-25 day Variability: Exploiting New Understanding of Equatorial and Monsoon Climate

During the last few years a new understanding has developed regarding the nature of the variability of the monsoon on sub-seasonal and interannual times scales. This understanding has allowed a detailed morphology of the sub-seasonal monsoon variability to be described[#]. Through observational, diagnostic and modeling efforts the sub-seasonal variability has been shown to be a very large-scale phenomena occupying, at least, the entire Indian Ocean basin. Furthermore, the phenomena possess much the same evolution 2-4 times per summer and also year after year. Using the identification of the structure of monsoon intraseasonal variability gathered from many diagnostic and modeling studies, a new physically-based "*a priori*" Bayesian wavelet-based statistical model has been developed where the predictors are chosen as properties of the intraseasonal variability.[*] The scheme is termed "physically based" and "*a priori*" because the predictors are chosen from the physical features of the monsoon intraseasonal variability itself and not just randomly chosen predictors that are found to have strong correlations. The predictors are:

- Precipitation over central equatorial Indian Ocean and central India;
- Sea-level pressure over central India;
- Soil moisture over central India;
- Intensity of the low-level Somalia Jet stream, upper tropospheric equatorial zonal wind, surface winds over the equatorial Indian Ocean and the Arabian Sea and location and intensity of the upper tropospheric easterly jet stream;
- SST over equatorial Indian Ocean.

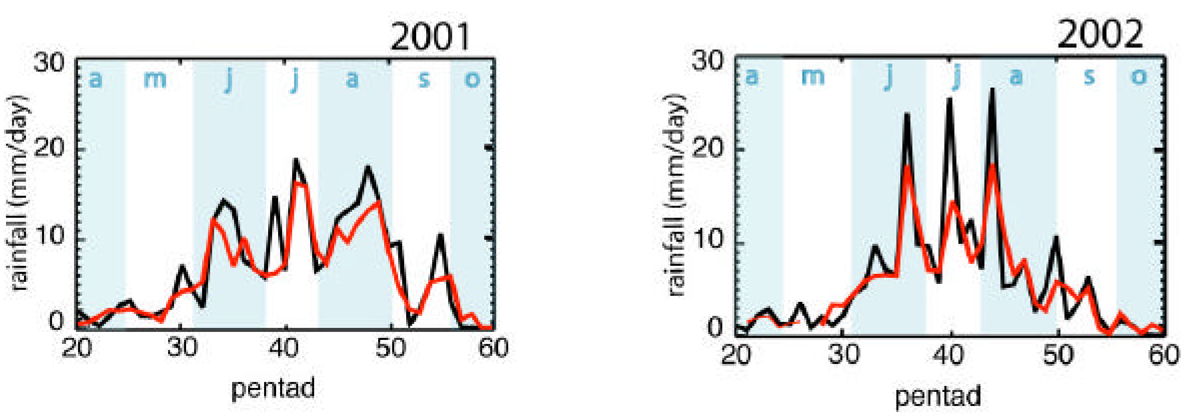


Figure 2: Five-day average observed rainfall in the Indian state of Orissa (yellow area on Figure 1 map) for the years 2001 and 2002 (black curves), and the 20-day forecast (red curves). Even though the area is much smaller than the Ganges Valley, considerable skill still exists. Similar forecasts were made for the much drier region of Rajasthan (red area on Figure 1 map). The 5-day average variance of the monsoon rainfall in Rajasthan (not shown) is also well captured.

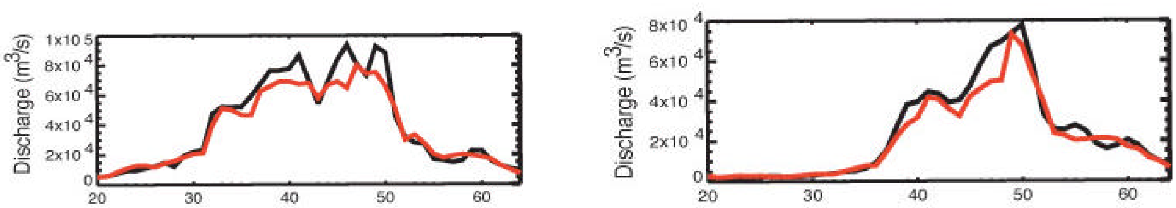
Wavelet analysis is applied to the predictand to determine the major bands in which variability resides. Four major bands are identified (<10 days, 10-40 days, semiannual and annual). The predictors are broken into the same bands and a linear regression technique is used to make the forecast. Each of these predictors is readily available in near real time so that timely forecasts are possible.

[#] Webster, P. J., T. Palmer, M. Yanai, R. Tomas, V. Magana, J. Shukla and A. Yasunari, 1998: Monsoons: Processes, predictability and the prospects for prediction. *J. Geophys. Res.*, 103, 14451-14,510.

[*] Hoyos, C. and Webster, P. J., 2003: 20-25-day forecasts of monsoon variability. Submitted to the *Bull. Amer. Meteor. Soc.*

(4) 20-25 Day Forecasts over Indian and Bangladesh

The quantity to be predicted (the predictand) is a quantity associated with the modulation of the monsoon on sub-seasonal time scale. One important 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 20-day predictions are shown in Figure 1 for the summers of 1999-2000 as red curves. 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 Ganges catchment area is a large geographical area. To test the techniques for a smaller region, 20-day forecasts were made for the summer of 2002 for the Indian States of Orissa and Rajasthan. Considerable skill still exists even for these smaller regions. The same technique has been used for the prediction of river discharge into Bangladesh with similarly accurate results. Examples of the forecasts for the Brahmaputra and Ganges are shown in Figure 3.



Brahmaputra (1998) Ganges (1998)

Figure 3: The observed 5-day average discharge of the Brahmaputra (left panel) and the Ganges (right panel) at the boundaries of Bangladesh for the year 1998 (black curves) compared to forecasts of the same fields 20 days ahead (red curves). 1998 was the year of extensive floods in Bangladesh where 60% of the country was under water for over 3 months.

(5) Utility and Scope of the Monsoon Forecasts

We anticipate that the scheme will be applicable wherever the slow physics of the sub-seasonal monsoon climate dominates such as in South and East Asia. North Australia and Indonesia are also candidate regions. We are confident that the discharge forecasting methodologies that produced Figure 4 will be useable in other catchment areas such as the Mekong. We are currently investigating the utility of the techniques to Equatorial Africa and the African monsoon regions.

We anticipate that the use of such forecasts by decision makers 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 (blue curves Figure 1). 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. At the same time, significant lead times in the forecasting of floods in Bangladesh can be expected. 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.

Finally, we note that the monsoon regions of the planet are arguably the most vulnerable over the next century in a warming world with a changing climate. We are of the strong opinion that a society that develops an infrastructure to adapt to, and take advantage of, short-term climate forecasts is a society that will be best equipped to accommodate climate changes associated with global warming.

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