ON THE 1994 INDIAN MONSOON RAINFALL ANOMALY

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Abstract:

In this study effort has been made to examine the diabetic heating anomaly for June to August during 1994. Moisture flux associated with southwesterly winds, that cause the west coast of India from the Arabian Sea, low level wind & relative vorticity field for the day 9^{th}, 11^{th}, 12^{th}, 13^{th} July, and vertical wind velocity at 500 hPa for 13^{th} July. The fact that the rainfall associates with just one event during 1994 monsoon contributed in the order of one standard deviation of rainfall, and this event was quite poorly predicted long range statistical forecast models have been developed to predict Indian rainfall on the basis of large scale indices of the atmospheric circulations in the preceding month.

However, one event (Monsoon low/depression) that would appear difficult to have been predicted so far ahead, has been identified, which appears to account for about 7.5% out of the observed 12% rainfall excess of 1994.

The result must be that the rainfall anomaly of the 1994 Indian summer monsoon was not predictable prior to the monsoon onset.

Introduction:

Indian Monsoon rainfall, that occurs during June to September, is critical for the agriculturally dominated Indian economy. Although the standard deviation of all-India rainfall is only 9.7% based on data for the last 124 years (see also Parthasarathy et al. 1990, Parthasarathy and Mooley, 1978), regional variations within India and pressures of increasing populations mean that rainfall deficiencies, when they do occur, can lead to serious consequences. Long-range statistical forecast models have been developed to predict Indian rainfall on the basis of large-scale indices of the atmospheric circulation in the preceding months – such as the Southern Oscillation Index. However one event, that would appear difficult to have been forecast so far ahead, has been identified which appears to account for about 7.5% out of the observed +12% rainfall excess of 1994.

Analysis of the 1994 monsoon:

The seasonal mean June-August column mean diabetic heating calculated from five years of ECMWF analyses (1990-94) is given in figure 1a. This heating comprises all diabetic processes such as latent heat release, sensible heating and radiation effects but is generally dominated by the latent heating and is thus can be used as a good estimate of precipitation. The zonal mean rainfall of the ITCZ is clearly evident north of the Equator at this time and within this, one can see the major rainfall regions of Central America and the southern Asia. 325 WM^{-2} over the North Bay of Bengal corresponds to about 11 mm day^{-1}, or perhaps a little more if one includes the effects of radioactive cooling. Elsewhere, one can see the radioactive cooling regions of the sub-tropical anticyclones. Figure 1b shows the diabetic heating anomaly for June to August during 1994. In terms of the Asian monsoon, this year was quite unusual with persistent rainfall overrun over the equatorial Indian Ocean. This is clear from infrared satellite pictures (not shown) and also in the anomaly diabetic heating. The diabetic heating anomaly field indicates that much of the 12% excess rainfall over India occurred in northwest India with, if anything, reduced rainfall over the southern peninsular. Bi-weekly mean column mean diabetic heating pictures for 1994, of which the mean for the first half of July is given in Figure 1c, show that the increased rainfall over northwest India occurred during July. Indeed, the excess diabetic heating over northwest India during July accounts for almost exactly the seasonal mean anomaly shown in figure 1b.

Figure 2 shows the daily percentage of normal all-India rainfall calculated operationally by the Indian Meteorological Department. The thicker line shows the seven-day running mean of the daily data. During July, one particularly strong peak in rainfall can be seen around 13 July during which the rainfall averaged over the whole country was more than 120% above normal. During July, the Indian monsoon is typically at its peak intensity. However, during July 1994, the monsoon was even more intense than normal, with the seven day running mean rainfall curve barely ever dropping below the 100% level.

Much of the monsoon precipitation is due to strong moisture fluxes associated with southwesterly winds that cross the west coast of India from the Arabian Sea (see for example Cadet and Reverdin 1981). Fig 3 shows the westerly moisture fluxes at 887 hPa which cross the 70°E meridian. From 9 July, this zonal moisture flux increases and the latitude of maximum flux moves south until 12 July. This increasing flux appears to be followed by the increase in Indian rainfall, which starts to intensify from about 10 or 11 July. The peak moisture flux seen on 13 July agrees well with the maximum in Indian rainfall intensity. After 13 or 14 July, both moisture flux and rainfall decrease.

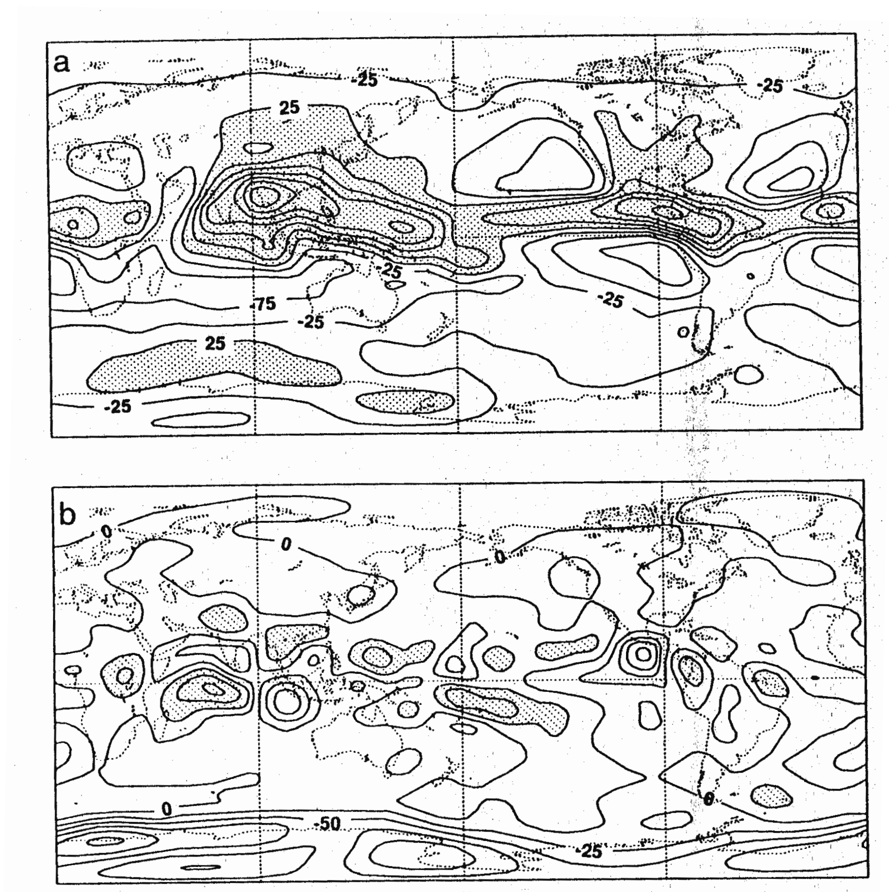
Figure 4 shows the low-level winds and relative vorticity field for the days 9, 11, 12, and 13 July. The increasing moisture fluxes at this time are more attributable to the increasing westerly winds than to changes in the low-level specific humidity field. These strengthening winds initially appear to be related to the depression seen over Pakistan 9n 9 July and this is confirmed by the fact that the maximum moisture fluxes on 9 July occur at about 21°N in figure 3. This depression weakens over the next couple of days, and the strengthening winds, whose latitude of maximum intensity moves south, appear to be increasingly related to the other depression over the North Bay of Bengal. By 12 July a depression begins to develop over northwestern India and this reaches full intensity by 13 July. The depression retains this intensity for about three days as it slowly tracks northwest towards Pakistan. Here it finally begins to decay.

Figure 5 shows the vertical wind velocity at 500 hPa for 13 July. There is strong ascent associated with the depression over northwestern India. If one assumes that adiabatic cooling due to ascent balances diabatic warming, Rodwell and Hoskins (1995), then an estimate of rainfall can be made. Over the three days of maximum intensity, the precipitation accounts for perhaps 7.5% of the total monsoon rainfall for the season. This is significant for seasonal forecasting of monsoon rainfall because the standard deviation of total rainfall is only itself about 9%. The moisture flux across the west coast of India was seen to start increasing about four days before the event, reaching its peak intensity simultaneously with that of the depression. Moisture fluxes across the west coast of India are essential for monsoon rainfall and fluctuations in moisture flux appear to be more related to fluctuations in the wind speed than to the humidity field. However, admittedly based only on the low-level wind fields, the three days forecast from the ECMWF, and even the one day forecast, appear to have failed to predict the strength of the westerly flow. Indeed, peak moisture fluxes in these forecasts, based on the observed humidity field, would have been about half what they actually were. In addition, the low-level wind fields for the forecasts show very little convergence in the region of the actual depression and, consistent with this, the vertical motion field would have been much weaker than actually observed.

The fact that the rainfall associated with just one event during the 1994 monsoon contributed in the order of one standard deviation of rainfall, and this event was quite poorly predicted even in a one day forecast would appear to suggest that GCMs forced with observed sea-surface temperatures would have had difficulty predicting even the sign of the monsoon rainfall abnormally one season in advance.

Long range statistical forecast models work on the assumption that indices of the large-scale atmospheric circulation set the overall conditions which determine, for example, the expected number of monsoon lows and depressions that will form and thus the total rainfall. However, the fact that such a short range GCM forecast could not predict the scale of this event based on the atmospheric conditions only a few days in advance may also imply that statistical models would have had difficulty making an accurate prediction of the seasonal rainfall total.

The conclusion must be that the rainfall anomaly of the 1994 Indian summer monsoon was not predictable prior to the monsoon onset.



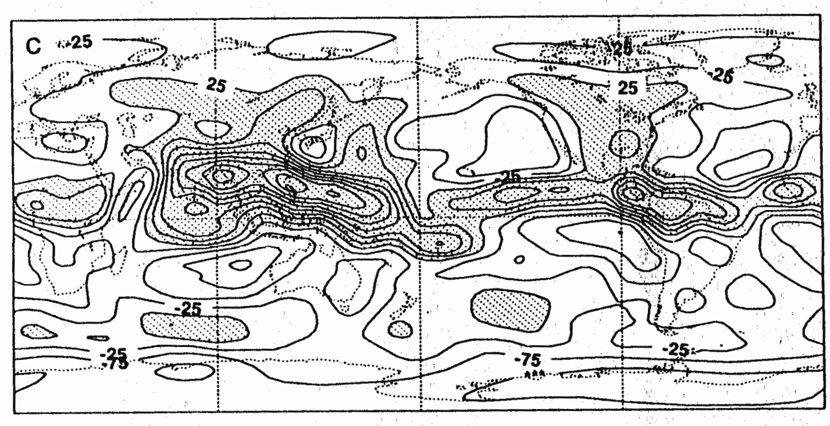


FIGURE-1 a,b & c.

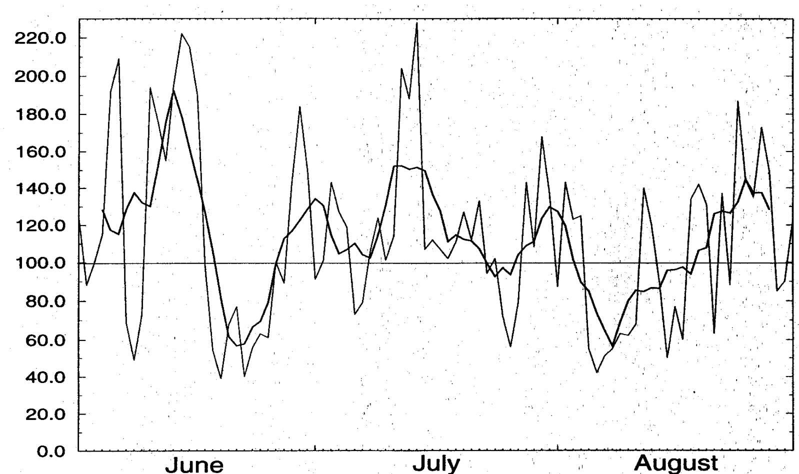


FIGURE-2

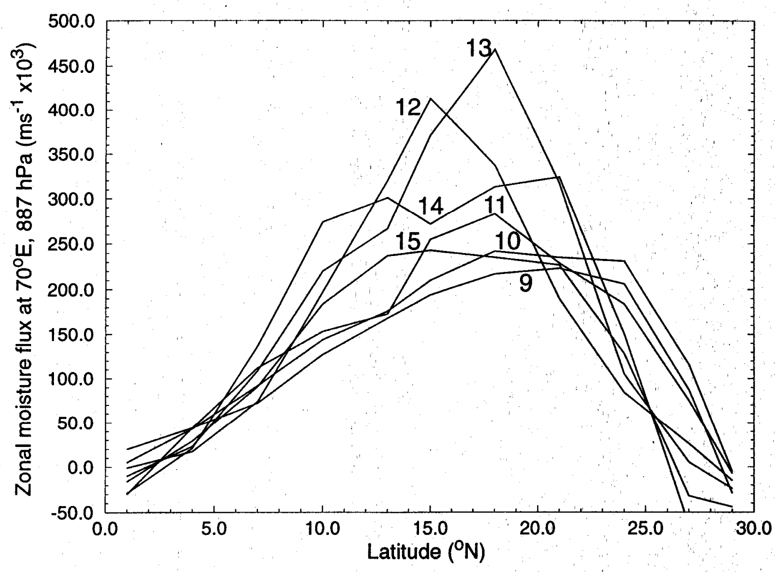


FIGURE -3

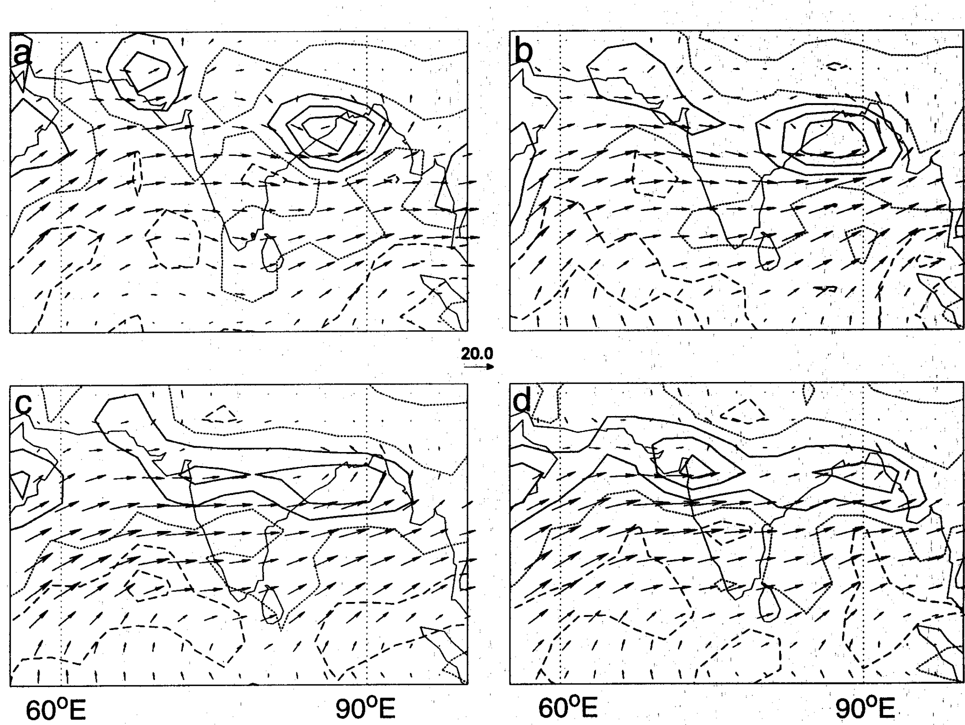


FIGURE - 4

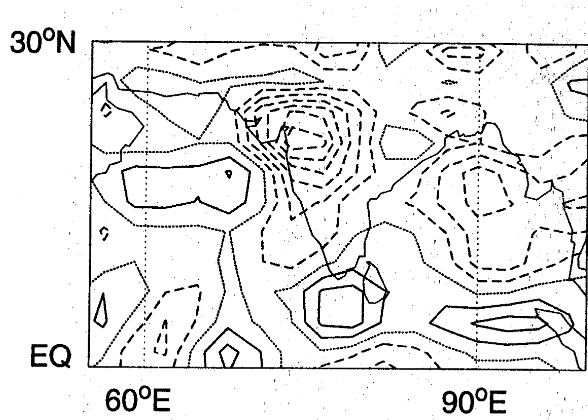


FIGURE - 5.

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