

LONG RANGE FORECASTING OF INDIAN MONSOONS



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THE SUN is the basic and the ultimate source of energy for the atmospheric motions giving rise to a variety of weather and climate fluctuations. Because the Earth is nearly spherical, and it revolves around the Sun and rotates on its own axis, the amount of solar energy that falls on any part of the surface of the Earth-atmosphere system varies with time of the day and a particular day of the year. The chemical composition of the atmosphere and the temperature distribution determine the rate at which the radiative processes heat or cool different parts of the Earth-atmosphere system. In general, the mean climate of the Earth is determined by an equilibrium among various physical processes which are directly or indirectly related to the size of the planet, the acceleration due to gravity and the distributions of ocean, land, and mountains on its surface.

The fact that the wind blows continuously means there must be a permanent source of kinetic energy to compensate for the continuous frictional dissipation. In this respect, the atmosphere can be considered as a heat engine in which the equatorial regions are being heated, and the polar regions are being cooled, thus producing energy to sustain the winds.

The description so far explains the mean climate of the Earth-atmosphere system. Why does weather change from day-to-day? This question leads us to a better formulation of the next question: why are monsoons different from one year to the other?

The causes of the day-to-day weather changes can be understood following the concepts of hydrodynamical instabilities of fluids, particularly the

instabilities of stratified and rotating fluids. The mean climate of the Earth's atmosphere is characterized by horizontal and vertical shears of wind, temperature and moisture. These shears are such that they permit growth of very small disturbances into large aperiodic fluctuations. The day-to-day changes in weather can be understood as manifestations of growth, decay and propagation of these unstable disturbances. This is also the main reason why weather changes cannot be predicted in great detail beyond a few weeks. The uncertainty in knowing the correct state of the atmosphere at any instant, and the growth rate of these instabilities, is large enough to make future predictions of the instantaneous state of the atmosphere useless after a finite amount of time.

During the past 40 years or so, meteorologists have been trying to determine the limits of weather predictability. Based on a variety of theoretical, observational and computer modelling studies it is now generally believed that:

1. The instantaneous large-scale (a few hundred kilometres) weather changes in the extratropical regions cannot be predicted beyond 2 to 4 weeks. (We consider the weather unpredictable beyond a period at which the prediction is not better than a randomly chosen weather map.)

2. The instantaneous large-scale weather changes in the tropical regions cannot be predicted beyond 3 to 7 days.

3. Monthly and seasonally averaged weather over large areas (a few thousand square kilometres) are predictable for the tropical regions compared to the extratropical regions.

The discovery of item 3 above has

given hope for long-range forecasting of Indian monsoon circulation and rainfall.

In contrast to the mechanisms of day-to-day weather changes, which are hydrodynamical instabilities, the changes in monthly and seasonally averaged weather (particularly the monsoons) are due to changes in the slowly varying boundary conditions at the Earth surface. The examples of these boundary conditions are sea surface temperature (SST), soil moisture and snow cover at the Earth's surface. Changes in these boundary conditions at the Earth surface can produce substantial changes in the atmospheric circulation and rainfall. For example, it has been found that during certain years the upper layers of the equatorial Pacific Ocean gets warmer by 1 to 2°C. This seemingly small change in ocean temperature (referred to as an El Niño episode — see p 64) produces quite large changes in the magnitude and the distribution of rainfall over the Pacific Ocean and the adjoining regions. It is also found that the changes in SST in the equatorial Pacific are significantly related to the Indian monsoon rainfall.

Fig 1 shows the monsoon season rainfall anomaly over India for 116 years (1871-1986) normalized by its standard deviation. Rainfall anomaly for any year is defined as the departure of rainfall for that year from the longterm mean rainfall. A value of one on the ordinate means that the rainfall was equal to its mean value (853 mm) plus one standard deviation (84 mm) or a total of 936 mm. A value of zero means that the rainfall was equal to the mean (853 mm), and a value of minus one means that the rainfall was the mean minus one stan-

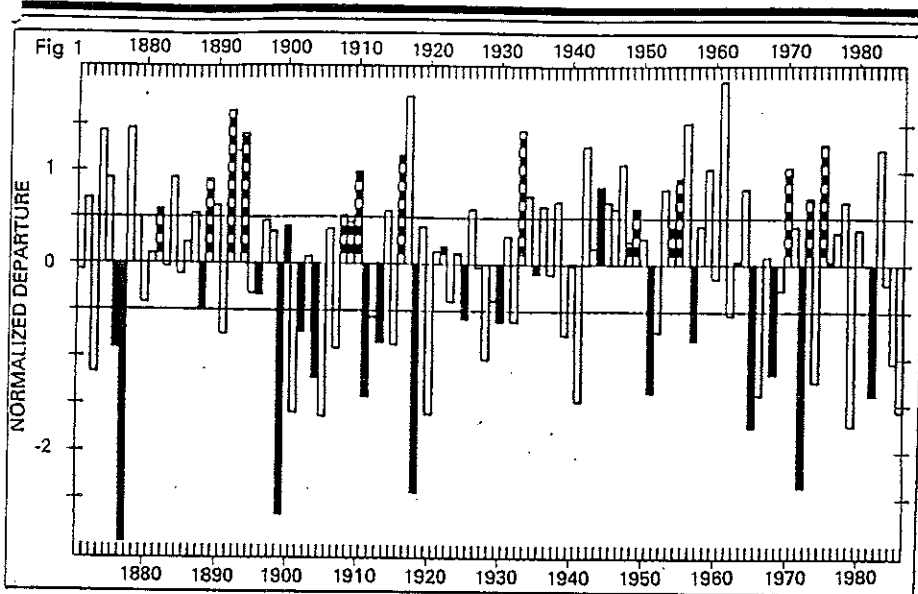


Fig 1 Indian summer monsoon rainfall anomaly (departure from longterm mean). Values of 1.0 and -1.0 mean rainfall was 84 mm above and below normal rainfall respectively. Zero line represents normal rainfall (= 853 mm). Solid and hatched bars denote warm and cold Pacific years

standard deviation or 768 mm. It is seen that there are no well-defined trends or periodicities in the rainfall series. The solid and hatched bars represent those years in which the sum of the Spring, Summer and Fall mean SST anomaly over the eastern equatorial Pacific and the change of SST anomaly from Spring to Fall was more than $+1^{\circ}\text{C}$ (less than -1°C). The years denoted by black and hatched bars will be referred to as the warm and

the cold Pacific years, respectively. It is remarkable that 20 out of 24 years denoted by black bars (warm Pacific years) have below normal rainfall and all the years denoted by hatched bars (cold Pacific years) have above normal rainfall over India. In fact, it is even more remarkable that most of the severe drought years are denoted by the black bars and only one year (1944) denoted by a black bar has a positive rainfall anomaly,

more than one half of the standard deviation. Likewise, most of the excessive rainfall years are denoted by the hatched bars.

Figs 2a and 2b show that the warm Pacific years are characterized by widespread droughts over India and cold Pacific years are characterized by widespread excessive monsoon rainfall over India. These observational results provide strong evidence of a significant relationship between equatorial Pacific SST anomalies and Indian monsoon rainfall anomalies.

Fig 3 shows the mean sea level pressure anomaly over Darwin (Australia) for the warm and the cold Pacific years. It is quite remarkable that the warm Pacific years (monsoon drought years) are also characterized by large positive anomalies of Darwin pressure and cold Pacific years (monsoon flood years) by large negative anomalies of Darwin pressure. It is also noteworthy that the tendency of Darwin pressure from the preceding winter to spring season is of opposite sign for the two cases.

Another example of an apparent relationship between Indian monsoon rainfall and snow cover over Eurasia is shown in Fig 3. It is found that the winter seasons with large snow cover over Eurasia are followed by monsoon seasons with deficient rainfall.

The existence of a significant relationship between the slowly varying

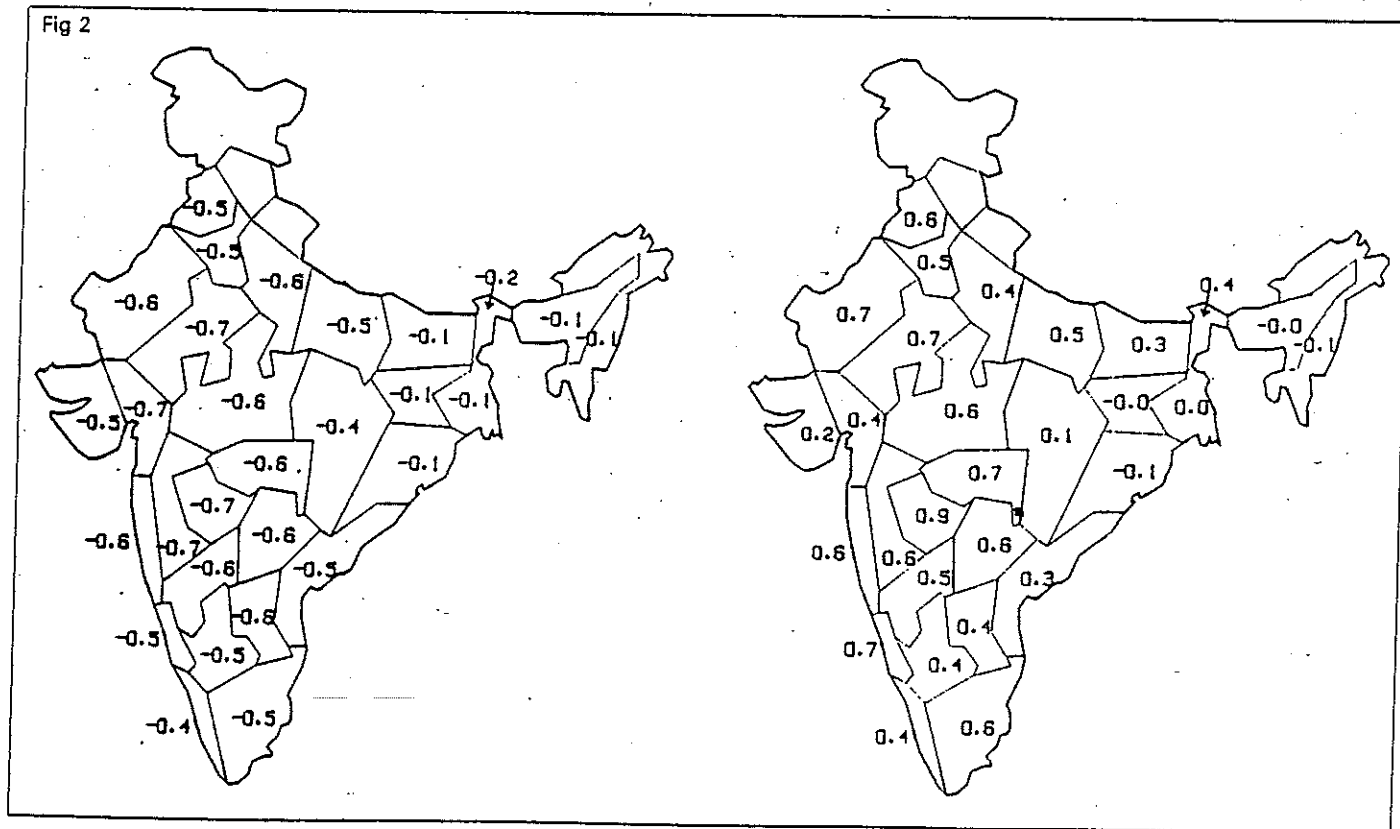
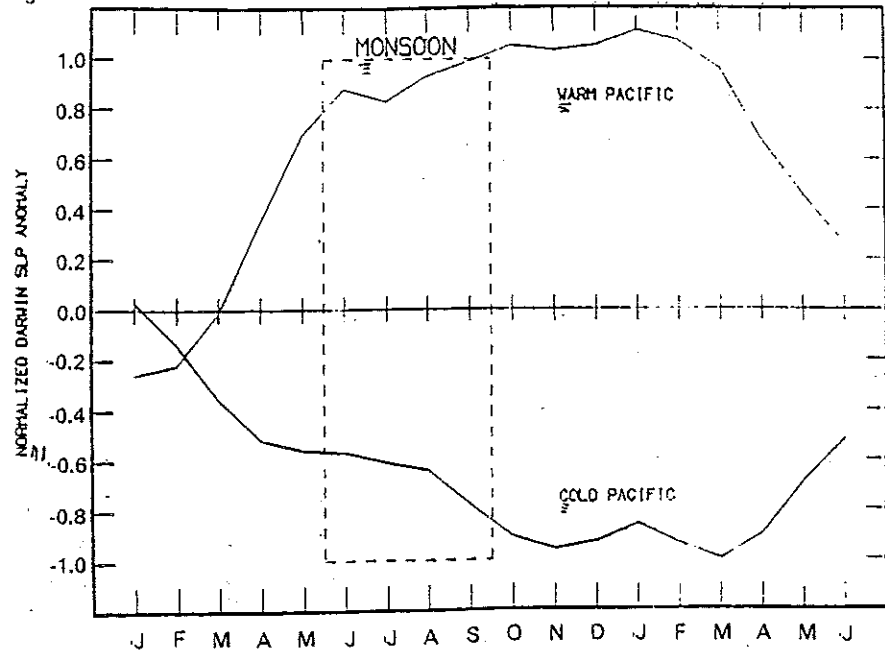


Fig 2 Rainfall anomaly (normalized) for Indian subdivisions averaged for years of (a) warm and (b) cold Pacific years

Fig 3



Sea level pressure anomaly at Darwin averaged for years with warm and cold Pacific respectively.

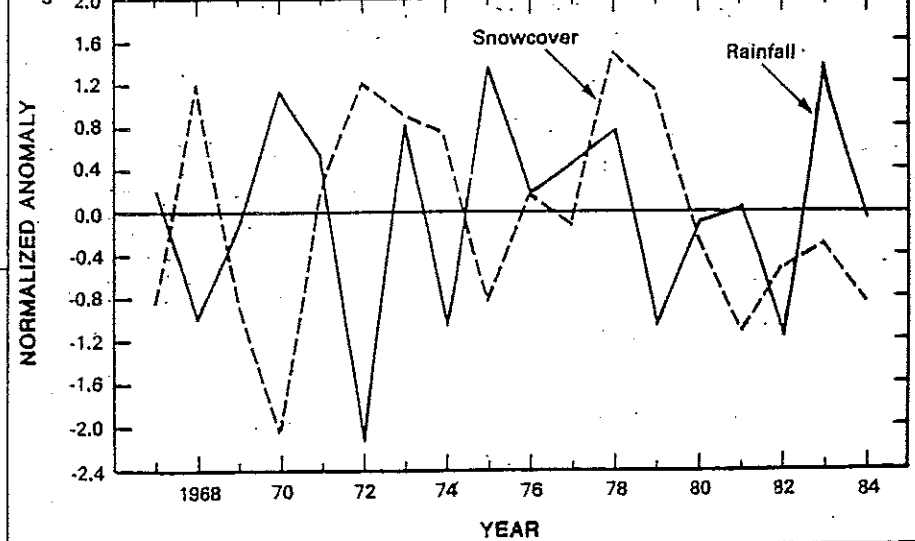
boundary conditions, global circulation and monsoon rainfall over India has given an observational basis and motivation to carry out computer modelling studies to simulate these relationships numerically, using complex and realistic mathematical models. Several empirical approaches are also being pursued to produce operational long-range forecasting of Indian monsoon rainfall.

Since the fluctuations of monsoon rainfall are of vital importance for agriculture, drinking water, and energy planning in India, numerous attempts have been made to develop empirical techniques to predict the

monsoon rainfall. These techniques are based on the premise that the global-scale changes have a sufficiently long time-scale such that a future state of the atmosphere can be predicted from the present or the immediate past state.

Fig 5 shows the results of verification of a simple regression model developed by D. A. Mooley and the author to predict seasonal mean monsoon rainfall over India. The two predictor parameters used in the regression equation are the tendency of the Darwin sea level pressure which represents a broader phenomenon called

Fig 4

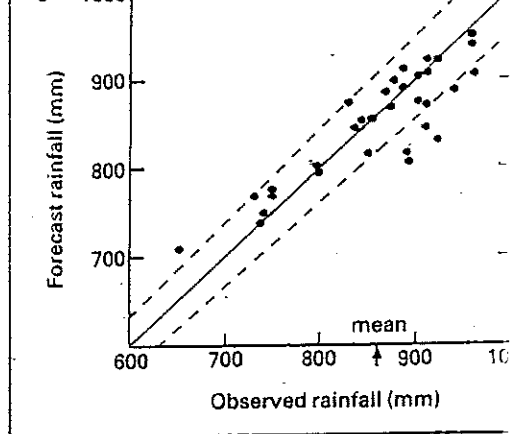


Indian monsoon rainfall anomaly (solid line) and Eurasian snow cover anomaly (dashed line).

the Southern Oscillation, and the latitudinal location of the 500 millibar ridge during April, which represents the mid-tropospheric circulation over India. The regression equation was developed using data of 30 independent years. In Fig 5 the two dotted lines represent ± 5 per cent of the actual rainfall. The root mean square error of predictions is about 36 mm which is only about 4 per cent of the mean rainfall and the prediction of droughts is especially better.

Although there is an upper limit of a few days to a few weeks for predicting instantaneous weather, there appears to be some potential for determining space and time-averaged circulation and rainfall. This potential appears to be particularly high for predicting seasonal mean monsoon rainfall averaged over large (1,000,000 km²) spatial scales. We have yet to find evidence for predicta-

Fig 5



Observed and forecast rainfall (mm) for 32 years of verification. The arrow indicates the longterm mean rainfall (853 mm). The dashed lines represent the $\pm 5\%$ of the solid line.

bility of monthly and seasonal rainfall over small regions ($\sim 100,000$ km²).



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