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# Vagaries of the summer monsoon rains

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## ABSTRACT

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Summer monsoonal rains are very important for the agriculture in our country. Fluctuations in monsoonal performance often create wide variations in crop production. In the present paper, the predictability of monsoon rains in the context of Professor Lorenz's recent work has been discussed. Variations in sea-surface temperature and snow cover and their impact on monsoonal rains are also discussed. Recent work on, the ENSO event and monsoons is described. The article covers the statistical methods for long range prediction of rains. The limitations of the current 16 parameter regression equation are mentioned. In conclusion the cost benefits, which can be assessed by methods based on probability are discussed.

**Key-words**— ENSO, ELNINO, Monsoonal rains, Monsoon prediction, India.

## सारांश

### ग्रीष्मकालीन मानसूनी वर्षा की उच्छृंखलता

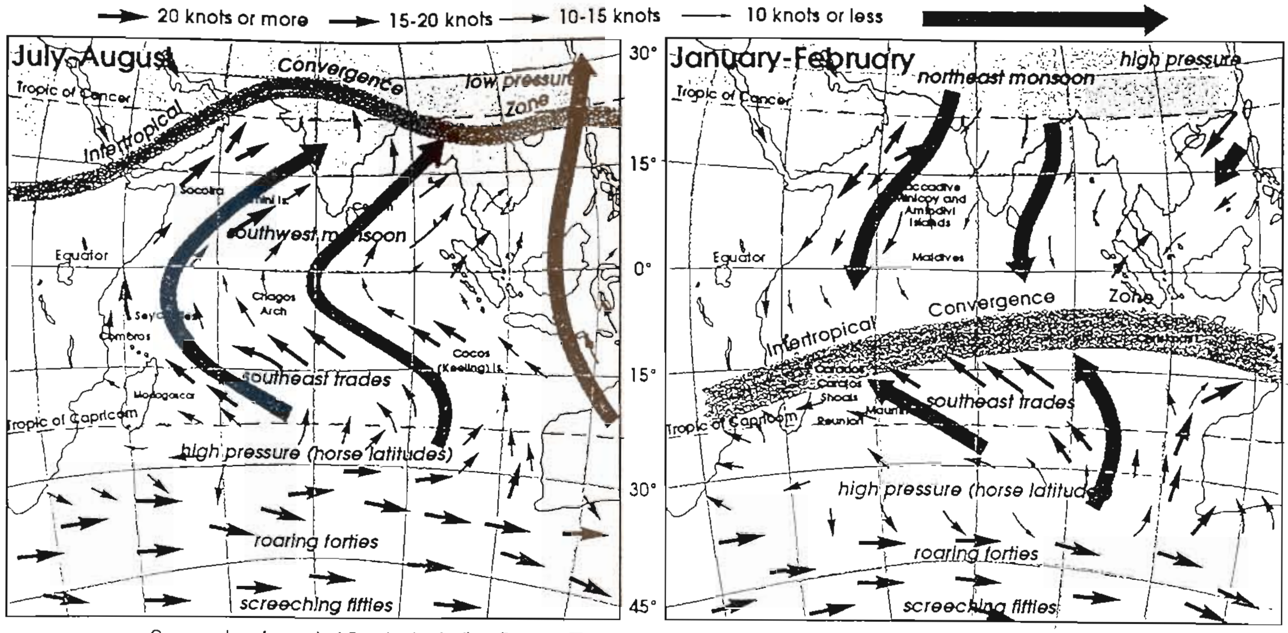
पी.के. दास

ग्रीष्मकालीन मानसूनी वर्षा हमारे देश की कृषि सम्बन्धी आवश्यकताओं के लिए अत्यन्त महत्वपूर्ण है। मानसून की अनियमितता प्रायः फसल उत्पादन में विचलन उत्पन्न कर देती है। प्रस्तुत शोध पत्र में प्रो. लॉरेन्ज़ के अर्वाचीन शोध के संदर्भ में मानसूनी वर्षा के पूर्वानुमान के विषय में चर्चा की गई है तथा समुद्र पृष्ठ के तापमान में विचलन तथा हिमाच्छादन के मानसूनी वर्षा पर पड़ने वाले प्रभाव पर भी प्रकाश डाला गया है। ई.एन.एस.ओ. घटना तथा मानसून के अद्यतन शोध कार्य का वर्णन भी इस शोध पत्र में किया गया है। आलेख में लम्बी परास की वर्षा के पूर्वानुमान के लिए सांख्यिकीय पद्धति का उपयोग किया गया है तथा इस आधार पर वर्तमान 16 प्राचल प्रतिक्रमण समीकरण की सीमाओं पर प्रकाश डाला गया है। निष्कर्ष स्वरूप इस शोध पत्र के अन्त में लागत लाभ की चर्चा की गई है, जिसे प्रायिकता की विधियों के आधार पर निर्धारित किया जा सकता है।

## INTRODUCTION

*I am grateful to the authorities of the Birbal Sahni Institute of Palaeobotany for inviting me to deliver the Sir Albert Charles Seward Memorial lecture. Sir Charles was an eminent scientist and Professor Birbal Sahni, his beloved student, was a very distinguished scientist of our country whose work helped our country to develop the science of Palaeobotany. I feel greatly honoured to speak on an occasion that is closely associated with the memories of two distinguished scientists.*

Monsoonal winds are indistinct print by differences in the response of land and ocean to solar radiation. The land responds much faster than the ocean and, as a consequence, broad currents of air blow towards the land from the ocean around the summer solstice. During the winter solstice this is reversed and the winds flow from the land towards the ocean. The former results in the summer monsoon while the latter is the winter monsoon (Das, 1995). The two monsoons are illustrated in Text-figures 1 and 2 and as shown in these two figures, both the monsoons are extensions of trade winds from (a) the southern hemisphere in summer and (b) the northern hemisphere in winter. The zone separating these two trade winds is referred to as the Inter Tropical Convergence Zone (ITCZ). For us the important question is their prediction. Can we predict, for example, their time of arrival in India, or their




Seasonal surface wind flow in the Indian Ocean. The thickness of the arrows are proportional to the force of the wind. From the *Indian Ocean Atlas*, 1976.

FIG. 1. FIG. 2.

Text-figure 1—Summer Monsoon Surface Winds.

Text-figure 2—Winter Monsoon Surface Winds.

performance in terms of rainfall ? As the summer monsoon is the larger system, we will focus our attention on this system. Unless otherwise stated, the monsoon will hereafter mean the summer monsoon.

## PROFESSOR LORENZ'S WORK ON PREDICTABILITY

Over three decades ago, Professor E.N. Lorenz, an eminent meteorologist at the Massachusetts Institute of Technology (MIT), was able to show that the upper limit of predictability for the atmosphere was about two weeks (Lorenz, 1993). In any dissipative system, such as the atmosphere, the solutions of the relevant system of equations can be represented by trajectories in phase space. The phase space is defined by the independent variables, that is, by X, Y and Z in a three dimensional cartesian system. The trajectories often remain confined in space, such as, a circle or an ellipse, which eventually, converges to a point. This is called an "attractor" for the system. Professor Lorenz showed that the equations for weather prediction possessed a set of two attractors and the trajectories in phase space tended to converge towards the first attractor and, later, towards the second attractor. This he defined as a system of "strange attractors" which implied, among other things, great sensitivity to the initial conditions with which we start computing the sequence of weather. Considering these aspects, Professor Lorenz estimated a maximum of about two weeks for short range weather prediction, if the best possible data were available to define the initial state. In reality, the maximum time for meaningful weather prediction today varies from 3 to 5 days.

Professor Lorenz was mainly concerned with short range prediction. A little after his work, Professor Jule Charney, another very eminent Professor of Meteorology at MIT put forth a new idea. He felt that there were certain types of weather systems that were driven by slow variations at the earth's surface. Examples of such variations were fluctuations in sea surface temperature (SST), snow cover and soil moisture. Longer range prediction of weather systems, which were dominated by a driving force of this nature was possible, felt Professor Charney. As we shall see this assertion was very relevant for long term prediction of monsoon rains (Charney & Shukla, 1981).

A question that is now of much interest is the possibility of an attractor for climate. The variability of climate, which is often seen in the sequence of ice ages and interglacial periods or in the formation of deserts over land which was once fertile, leads one to question whether an attractor does exist? More specifically, we need to know if we are moving towards a stabler climate in the years to come and the existence of an attractor will help us to answer these questions.

## THE EL NINO AND ENSO EVENTS

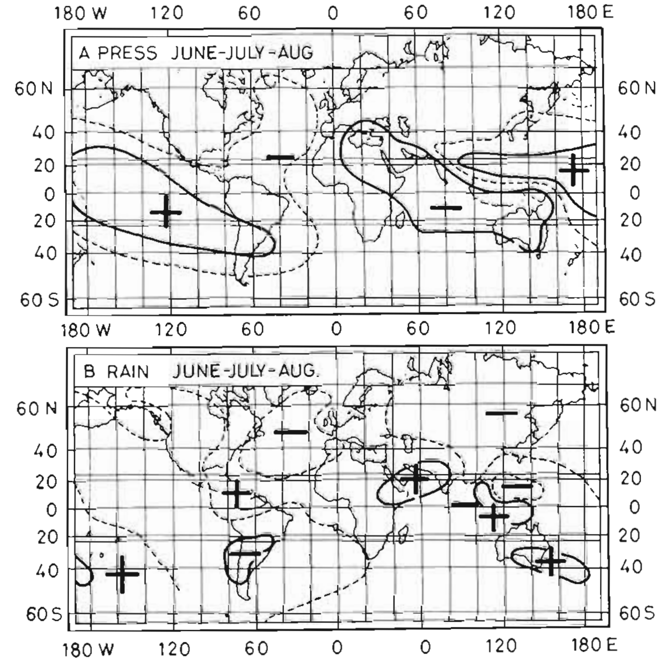
Professor Charney's ideas about climate changes forced by slow changes at the earth's surface have been substantiated by the recent discovery of a sudden change in sea surface temperature (SST). The "El Nino" refers to a sudden increase in SST in the coastal waters off Peru. El Nino is a Spanish word which means 'the male child', while a 'female child' is "La Nina". The abnormally high temperatures have disasterous effects on the Peruvian fisheries. The sudden appearance of warm waters off Peru was first reported in 1891 by Dr Luis Canenza who was the President of the Geographical Society of Peru. In normal or La Nina years, the coastal waters off Peru are cold because of strong upwelling, which brings up the colder waters from the deeper parts of the ocean. The upwelled water also bring up plankton on which the fishes thrive. But, once in a while the trade winds above the sea surface are weak and hence there is no upwelling or plankton for the fish, and warm water appears off the coast. The frequency of an El Nino varies from 2 to 7 years. As the El Nino appears around the time of Christmas, it is often referred to as the "Child Christ".

The sudden appearance of warm waters off Peru is closely linked to another important meteorological event that is referred to as the Southern Oscillation (SO). This was discovered by Sir Gilbert Walker in 1920—an eminent mathematician who noted a see saw pattern of fluctuations in pressure between the Pacific and the Indian Ocean. When the pressure was high over the southern Pacific, it was low over the Indian Ocean. But, once every few years there was a reversal. When this happened, higher pressures prevailed over the Indian Ocean and the pressures were low over the Southern Pacific. Sir Gilbert called this the Southern Oscillation (SO).

Later, Sir Gilbert discovered two more similar oscillations over the North Atlantic and the North Pacific Oceans. The North Atlantic Oscillation (NAO) was marked by periodic reversals in pressure between a centre of high pressure over Azores and a low pressure zone centred over Iceland. This oscillation is often associated with variations in temperature over Europe, especially in winter. The North Pacific Oscillation (NPO), on the other hand, is another see-saw pattern of pressure variations between a high pressure centre over northern Pacific and a low over the Alevtian Islands. It is closely linked to variations in temperature over North America.

Of these three oscillations the one that is important for India is the Southern Oscillation. As the rainfall varies inversely with surface pressure, so a poor or indifferent monsoon could be expected when surface pressures were higher over the Indian Ocean. On the other hand, low pressures over the Indian Ocean presage a good monsoon. A Southern Oscillation Index (SOI) is used for monsoon prediction. This is a measure of the difference in surface pressure between Tahiti, an island in French Polynesia, and Port Darwin in northern Australia. The former represents the Southern Pacific while the latter stands for the Indian Ocean. A negative value of SOI is indicative of a poor monsoon.

In the late fifties, Dr Jacob Bjerknes, who belonged to a family of great Norwegian meteorologists, noticed a coincidence between the Southern Oscillation and the El Nino. This was during the International Geophysical Year (IGY). This discovery made a great impact on meteorologists and oceanographers because it suggested "teleconnections" between meteorological events that were separated by great distances. A combination of the El Nino (EN) and the Southern Oscillation (SO) is now referred to as an ENSO event (Text-figure. 3). The exact mechanisms leading to an ENSO event are still being debated.




Text-figure 3—The Southern Oscillation during June, July and August, (a) pressures and (b) rainfall. Solid lines represent Correlation Co-efficients with the Southern Oscillation Index (SOI) (from Walker & Bliss, 1932).

Unfortunately, observations in India do not indicate a very well defined correspondence between a negative SOI, an ENSO event, and a deficient monsoon. A deficiency in monsoonal rainfall was associated with an ENSO event in only 60% of the cases. Table 1 presents seven cases when a rainfall deficiency was linked with an ENSO event.

Values of the Southern Oscillation Index (SOI) were ob-

**Table 1—Deficient monsoons linked with an ENSO event (1901-1960).**

| S.N. | Year | Monsoon rainfall as % of LPAV | SOI (mb) |
|---|---|---|---|
| 1. | 1905 | 83 | -5.0 |
| 2. | 1911 | 85 | -4.0 |
| 3. | 1918 | 75 | -5.0 |
| 4. | 1925 | 97 | -5.0 |
| 5. | 1939 | 91 | -4.9 |
| 6. | 1941 | 87 | -4.9 |
| 7. | 1957 | 98 | -2.5 |
| 8. | 1987 | 82 | -2.0 |

LPAV : Long period average value (Source : I.Met.D. records).

**Table 2—Non-concurrent ENSO and rainfall deficiency.**

| S.N. | Year | Monsoon rainfall as % of LPAV | SOI (mb) |
|---|---|---|---|
| 1. | 1951 | 81 | -2.5 |
| 2. | 1953 | 110 | -2.0 |
| 3. | 1965 | 82 | -2.0 |
| 4. | 1972 | 76 | -2.5 |
| 5. | 1982 | 85 | +2.2 |
| 6. | 1986 | 87 | -1.0 |

LPAV : Long period average value for the country as a whole.

tained from graphs provided by Hastenrath (1996). The SOI values shown above are departures from a mean value of -2.8 mb for the period 1951-1980. The interesting feature here is the large negative values of SOI for each ENSO event.

In Table 2 we present six cases of rainfall deficiency, with a negative SOI, that were not associated with an ENSO event.

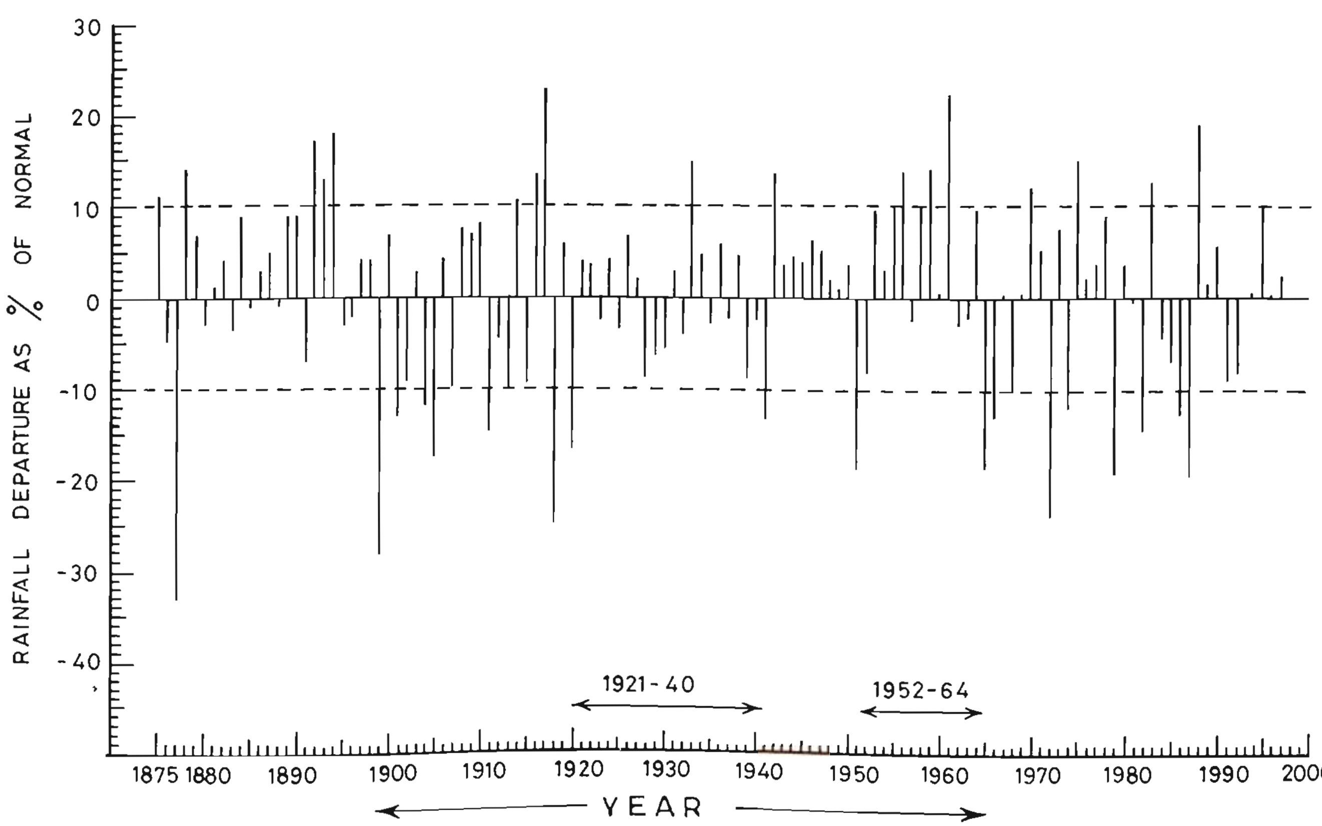
Compared to the values in Table 1, the SOI values in the above table are smaller, but negative SOI values do occur even when there is no ENSO event. Even when the monsoon is normal, as in 1953, a negative SOI can occur. But, as stated earlier, large negative values precede a deficient monsoon in about 60% cases.

How predictable is an ENSO event? With the help of atmosphere-ocean coupled models, it is now possible to predict the arrival of an El Nino several months ahead of the event. But, there is a sudden fall in predictability after 10 months. The reasons for the loss in predictability is not yet well understood (CLIVAR, WMO, 1992).

The irregular periodicity of the El Nino is another problem on which researches are currently in progress. Mathematical models have been able to show that the appearance of warm coastal waters is possible with a periodicity of 5 years over the eastern and central Pacific, but its appearance with a variable frequency is not well understood. We know that the El Nino appears with a weakening of the trade winds leading to the absence of coastal upwelling, but more research is needed to explain why the trade winds should suddenly weaken.

## GENERAL CHARACTERISTICS OF MONSOON RAINS

The time series of monsoon rainfall over the country as a whole from 1875 to 1996 is illustrated in Text-figure 4. A few interesting features of this figure are : (a) the period 1921 to




**Text-figure 4**—Time Series of Monsoon rainfall. Dotted lines indicate deviations of ±10% from mean. Another ±4% is added to account for moddemors.

1940 was one of normal rainfall, if one considers a departure within ±10% to be within the normal range of variability; (b) the years between 1986-1988 saw a period of rapid fluctuation from large deficiency to an excess or abundant rain and (c) the last 10 years, that is, from 1988 to 1998 have again been one of normal rainfall. The point that emerges is that the rainfall time series consists of fairly long periods of normal rainfall, with short periods of rapid fluctuations.

The average rainfall for the country is 851.3 mm, but during 1986, 1987 and 1988 it was 786, 707 and 1018 mm respectively, while 1987 was an El Nino year 1986 was not, but the SOI was negative in both years.

A factor which controls the overall deficiency or excess of rainfall is the timely arrival and withdrawal of the monsoon. In 1986 the monsoon arrival was delayed by 4-5 days over most parts of the country, but its date of withdrawal was normal. In 1987, the northward advance of the monoon was abnormally delayed. Some parts of northwest India received monsoonal rains after a delay of nearly one month. The net result was a rainfall deficiency of 18% for the country, but it was -46% for northwest India. These figures indicate the rapid variations of the monsoonal rains in both space and time. A detailed spectral analysis of these fluctuations has not yet been undertaken, but this could yield results of considerable interest.

## HIMALAYAN SNOW COVER AND THE MONSOON

Changes in Himalayan snow cover provide another example of low frequency changes at the earth's surface. It is one of the parameters currently used for long range prediction of summer rains over the country. Recent studies carried out by Groisman *et al.* (1994) suggest the existence of a negative correlation of –0.58 between the extent of snow cover and the Southern Oscillation Index (SOI). The correlation co-efficient is statistically significant. It implies that the snow cover is larger for years of rainfall deficiency. This has been observed for the prominent El Nino years in recent times.

Our data on the variation of snow cover on a time scale is not yet adequate. The impact of an increase in snow cover on the radiative balance of the earth-atmosphere system, especially on the formation of connective clouds over a snow covered region needs more research. The aerosol content of the atmosphere is yet another topic of interest, because clouds and aerosols represent two areas over which there is much uncertainty about their role in climate change.

## STATISTICAL METHODS FOR LONG RANGE PREDICTION

### Regression equations

Several statistical methods have been employed in the past to anticipate the performance of monsoonal rains, especially in the context of floods and droughts. Mention must be made of the pioneering work of Sir Gilbert Walker in the early part of this century. He developed regression equations with different predictors to compute the rainfall. His predictors were essentially independent of each other, and his forecasts were for (a) the northwestern sector of India and (b) the Indian peninsula. These two sectors were chosen because the variability of rainfall was largest over these two sectors. The variability of rainfall is measured by the ratio of standard deviation to the mean rainfall, which is expressed as a percentage. Of the early Indian scientists, we may mention the work of Professor P.C. Mahalanobis, who used a regression equation to forecast floods in Orissa (Das, 1995).

Currently, the prediction of summer monsoon rains (Y) is achieved by the following type of regression equation

$$Y = a_0 + \sum_{1}^{16} a_n (x_n)^{p_n} + R$$

Where $p_n$ is the power to which each predictor ($x_n$) is raised and R stands for the residual or the unexplained variance of the predictand (Y). The constants $a_0$ and $a_n$ are chosen in a manner which minimises R.

A wide variety of predictors are used. A detailed list of predictors is available in Das (1995), or in an article by Srivastava and Singh (1993). The predictors are antecedent features of the atmospheric circulation before the monsoon's arrival. They may be grouped under three heads : (a) pressures, (b) winds and temperatures and (c) snow cover and the Southern Oscillation Index (SOI).

According to me there are five reservations with this approach :

(a) The entire country cannot be used as a single unit for rainfall prediction, because the distribution of monsoonal rains is region specific. For example, the droughts over Orissa and parts of Rajasthan in 1998 could not be captured by a regression equation for the whole country. For this reason, Sir Gilbert Walker used regression equations only for northwest India and the peninsula, where the variability of rainfall was largest.

(b) The limits of tolerance are too large. For example, any rainfall deviation within ±10% of the mean value is within normal variation. In addition another ±4% of departures from normal are ignored because that is considered to be due to model errors. Thus, all variations within ±14% of the normal value are ignored. With such large tolerance the rainfall will be treated as normal on 75% of the rainfall time series. As mentioned earlier, the time series shows a prolonged spell of 19 years from 1921 to 1940 when the summer rains were normal (Sen Roy, 1990). This will not be the case if the tolerance limits were lowered.

(c) The predictors, especially pressures and temperatures, are not independent of each other. In developing a regression equation, the independence of the predictors should be ensured.

(d) The number of predictors is too large. Professor Lorenz (1956) had earlier pointed out that a large number of predictors could create difficulties because the influence of one could be off-set by others.

(e) The relative importance of each predictor could be assessed by computing how much of the total variance of Y is explained by each. If this was done, then the total number of predictors could be reduced by combining those which explain the largest variance of the predictand (Y).

Currently, experiments are in progress with other prediction models, especially autoregressive models (ARIMA). The results will be awaited with much interest.

## Probability Forecasts

A number of probability forecasts of rainfall are now being devised, but they are still in a research mode.

The methods hinge on the concepts of Principal Components (Preisendorfer, 1988). A vector space $X_{ij}$ is defined by

$$X_{ij} = \sum_{K=1}^{M} a_{kj}\, e_{kj}$$

Where the co-efficients $a_{kj}$ are the Principal Components and $e_{kj}$ are the normalised eigenvectors of the cross covariance matrix of $X_{ij}$. If the field is a time series of rainfall at different locations, then the Principal Components (PCs) tell us how much of the total variance is explained by each PC.

There are different procedures for finding out how much of the Principal Components consist of a "signal" and how much is "noise" (Steyaert *et al.*, 1977). In general, a PC to be treated as real must explain at least 5 to 10% of the variance of the raw time series. The selected PCs are then used to reconstruct a predicted rainfall pattern. As stated earlier, this along with other techniques are still in research mode, but they do point to the importance of long range prediction of monsoon rainfall in our country.

## SUMMARY AND CONCLUSIONS

The main conclusions of the present study may be summarised as follows :

(i) The total monsoon rainfall does show some correlation with the ENSO event. A rainfall deficiency is noted in about 60% of ENSO events.

(ii) There are occasions when a rainfall deficiency is not concurrent with an ENSO event.

(iii) The exact mechanism or mechanisms that lead to an ENSO event are not yet clear.

(iv) Long range predictions of monsoon rainfall with a regression equation, which uses 16 predictors and in which each predictor is raised to a power, has several limitations.

(v) Experiments with an autoregressive model with several leading indicators, or probablistic forecasts with Principal Components is suggested.

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