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# Potential for long-range regional precipitation prediction over India

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**सार** - भारतीय मानसून क्षेत्र में दीर्घावधि वर्षण के संभावित पूर्वानुमान की सामान्यतः अच्छी संभावना है जबकि उष्णकटिबंधी पट्टी के कारण जलवायु कोलाहल ( अर्थात दैनिक मौसम के उतार-चढ़ाव के कारण परिवर्तन) जलवायु संकेत ( अर्थात मासिक मौसमी माध्यों में प्रति वर्ष उतार चढ़ाव के कारण परिवर्तन ) की अपेक्षा न्यून है। छोटे स्थानिक मानों पर भारतीय उपमहाद्वीप के 1656 केन्द्रों में चार मौसमों के दौरान द.प. मानसून उप-मौसमों में होने वाली वर्षा की संभावनाओं का पता लगाने के लिए जलवायु कोलाहल से संबंधित अन्तःवार्षिक विभिन्नताओं के अनुपातों का परिकलन किया गया है।

मौसमी और अन्तरामौसमी स्तर पर द.प. मानसून की वर्षा का पूर्वानुमान लगाया जा सकता है। पश्चिमी समुद्री तट तथा भारत के दक्षिणी पश्चिमी भागों तथा भारत के उत्तरी पूर्वी भागों में वर्षा का सही पूर्वानुमान लगाया जा सकता है। जुलाई से सितंबर की अवधि में मानसून के सक्रिय होने के दौरान उत्तरी पश्चिमी भारत में अधिकतम दीर्घावधि पूर्वानुमान संभव है। पूर्वी प्रायद्वीपीय क्षेत्र में पूर्वानुमान की संभावना सामान्यतः न्यून पाई गई है जबकि उत्तरी मध्य भारत में यह सदा सामान्य रहती है। जनवरी से मई तक के महीनों के दौरान पश्चिमी विक्षोभों के कारण संभवतः उत्तरी अक्षाशों पर वर्षा का पूर्वानुमान लगाया जा सकता है। उत्तरी पूर्वी (उ.पू.) मानसून के कारण अक्तूबर से फरवरी तक के महीनों में दक्षिणी पूर्वी भारत और श्रीलंका में होने वाली वर्षा से दीर्घावधि पूर्वानुमान की सही संभावना का पता चलता है। इससे यह पता चलता है कि निकटतम समरूपी क्षेत्रों सहित देश के अलग - अलग केन्द्रों में पूर्वानुमान की संभावनाओं को देखते हुए एक स्थान से लेकर आंचलिक स्तर तक भारत में द.प. मानसून मौसमों, उपमौसमों तथा महीनों एवं अन्य मौसमों के दीर्घावधि वर्षण पूर्वानुमान की योजनाओं को कार्यान्वित करने का सही अवसर है।

**ABSTRACT.** The potential for long-range precipitation prediction over the Indian monsoon region is generally good where climate noise (*i.e.* variability due to daily weather fluctuations) is small as compared to the climate signal (*i.e.* variability due to year to year fluctuations in monthly/seasonal means) being in the tropical belt. In order to understand the potential on smaller spatial scales, the ratios of interannual variability to that associated with climate noise have been computed for precipitation of four seasons as well as SW monsoon sub-seasons/months over 1656 stations in the Indian subcontinent.

Precipitation in SW monsoon has been found potentially predictable on seasonal as well as intraseasonal scale. The west coast and contiguous northwest India, part of the 'northeast India are more predictable. Potential for long-range prediction over northwest India is highest during the active monsoon period from July to September. Over eastern peninsula potential for prediction is generally found low whereas over northcentral India it is always moderate. Over northern latitudes precipitation due to western disturbances during January to May is potentially predictable. Precipitation over southeast India and Sri Lanka during October to February due to northeast (NE) monsoon shows good potential for long-range prediction. It is manifested that long-range precipitation forecasting schemes for SW monsoon season, subseasons and months and for the other seasons over India on point to regional scale have good scope by taking into account the potential predictability at the individual stations as well as at contiguous resemblance areas over the country.

**Key words** – Long range prediction, Climate noise, Climate signal, Potential predictability, Seasonal and Subseasonal monsoon precipitation.

## 1. Introduction

Monthly or seasonal precipitation is the aggregate of daily precipitation over the month or the season. Interannual variance is typically computed by using these monthly or seasonal precipitation totals over at least 30 years or more. Thus interannual variance consists of two type of contributions. One is a variation resulting from the fact that the sums are made over a finite number of days of a process with daily variability but a constant mean. The second reflects possible changes from year to year in the mean. Daily variability due to weather fluctuations is theoretically predictable at most for, 7 to 14 days because of the sensitivity of dynamic forecasts to initial conditions. These fluctuations solely due to internal dynamics of the atmosphere, limit the prediction of the climate and are therefore called 'climate noise' (Leith, 1978). Month/season to month/season variance arises from the influences of the slowly changing external system on the internal system. The external system includes climatic components such as SST, large-scale phenomena ENSO, snow cover as well as external influences such as volcanic eruption, sun-earth geometry *etc*. This variance is supposed to be at least potentially predictable and is called climate signal. According to Madden (1981) climate signal can be further divided into two components, (*i*) currently predictable signal and (*ii*) potentially predictable fluctuations that are not now but because they are over and above climate noise may someday be predictable.

Actually, climate noise cannot be totally separated from climate signal as noise is also influenced by external system. But for practical purposes of estimating potentially predictable signals, climate signal and climate noise are treated as independent of each other and approximately separable components. The estimates of climate noise allow us to estimate the ratio of interannual variability to climate noise which is potentially predictable. Madden (1976) estimated climate noise of sea level pressure and Madden and Shea (1978) and Shea and Madden (1990) estimated climate noise for temperature. Precipitation is bi-modal process and Katz (1983) has developed a model fitting chain dependent processes for daily precipitation variability which depends on the assumption that the precipitation amounts on consecutive wet days are independent. Madden and Shea (1982), Singh and Kriplani (1986) have estimated climate noise for investigation of potential predictability or climate change by this model for North America and India respectively. Latter Katz and Perlange (1995) have generalised chain dependent process by including some dependence assuming that precipitation amounts are a randomly stopped, autoregressive process with a 1-day lag correlation. The latest study of potential predictability over New Zealand by Madden *et al.* (1999) and the present study are based on this model.

According to Leith (1978), there is evidence for useful climate predictability in equatorial and tropical regions where the noise level is small and the signal is large. Charney and Shukla (1981) indicate that a large part of low latitude variability is due to boundary anomalies in such quantities as SST, albedo and soil moisture which have longer time constants and therefore force slower changes in the atmosphere than those associated with flow instabilities.

From Blanford (1884) onwards attempts have been made to search predictors (signals) for long-range forecasting of the seasonal SW monsoon precipitation over India and to develop prediction models with latest mathematical / statistical techniques. Walker (Indian Meteorological Society, 1986) was the first who extensively studied correlation between Indian precipitation and global pressure, temperature, wind *etc*. He investigated three important planetary scale oscillations of which, the southern oscillation (SO), has been found important for long-range forecast of monsoon precipitation. Subsequent studies have shown that monsoon variability has physically consistent lag correlation with anomalies of numerous planetary scale parameters such as El-Nino, SO, Northern Hemispheric temperature and regional parameters such as April 500 hPa ridge along 75° E, Indian surface temperatures, Eurasian snow cover. Especially for agriculture and several other purposes precipitation forecasting over the country is needed on smaller spatial scales ultimately for each district. Also spatial precipitation variability is filtered out and signals on various spatial scales and sometimes of opposite signs are mixed up when long-range prediction for huge country as a whole is attempted. The monthly and seasonal scale interannual variance of precipitation over Indian subcontinent varies spatially. First Empirical Orthogonal Function (EOF) vector of seasonal monsoon precipitation over India (Bedi and Bindra, 1980; Sontakke and Singh, 1996) shows high positive loading over northwest India, low loading over south peninsula and negative loading over northeast India. Walker (1914), Shukla (1987), Parthasarathy and Yang (1995) have delineated the country into different regions by taking into consideration characteristics of the area averaged SW monsoon precipitation series of different meteorological subdivisions and combining them. Sontakke and Singh (1996) have identified six optimum number of regions based on fluctuation, cluster and EOF analyses of 306 station's SW monsoon precipitation for the period 1871-1984 to develop an effective system for precipitation studies.

Intention of the present study is to focus the long-range precipitation prediction potential ubiquitous over India. Singh and Kriplani (1986) have estimated potential predictability of July-August precipitation taking 19 years daily data spatially averaged over 33 subdivisions in India. But their approach is not sufficient because, (*i*) data length is not long enough for stable results, (*ii*) subdivisional unit is too large and being part of administrative unit not necessarily homogeneous for averaging daily data. Estimation of climate noise and F-ratios over subdivisions therefore do not serve the purpose of estimating potentially predictable areas, (*iii*) F-ratios are estimated only for July- August period, and (*iv*) Climate noise is estimated assuming that the precipitation amounts on consecutive wet days are independent.

This paper investigates scope for quantitative seasonal / monsoon intraseasonal long-range precipitation prediction over India on smaller spatial scales. It will be useful for identifying suitable regions for development of long-range precipitation prediction schemes as well as guideline for climate modelers. For this purpose, climate noise and potential for long-range prediction of precipitation on individual station level over the Indian subcontinent for seasons and monsoon months/subseasons have been estimated. Contour maps of potential predictability over the Indian subcontinent are presented for visualization and discussed.

## 2. Data

The daily precipitation data from 1596 Indian stations and 60 stations from Pakistan, Tibet, Bangladesh and Sri Lanka (Fig. 3) were used in this study. Indian stations were selected from total 4000 stations based upon length of record and the desire for representative spatial coverage. Indian data from 1901-70 for all the 1596 stations and from 1975-84 available for 511 stations out of total were from India Meteorological Department (IMD), Pune and Climate Prediction Center (CPC), Washington, DC. Data for 37 Indian stations and 60 stations from surrounding countries for the period 1979-84/93 were obtained from Global Telecommunication System (GTS). Generally, stations within India spanned more than 60-65 years of data and from surrounding countries spanned at most 14 years. For this reason, the emphasis in this study will be on India and results from surrounding countries should be viewed keeping in mind its limited data length. Shea and Sontakke (1995) provide more details on this dataset and also present various statistics on different time scales.

## 3. Estimating Climate Noise

Daily precipitation is a discontinuous process and consists of two components, one being the sequence of occurrences and the other being the intensity for time periods during which precipitation is occurring. Katz and Perlange (1995) have developed a two-state first-order Markov process probability model for daily precipitation variability. In this model the precipitation occurrence process is allowed to be correlated in time, and the precipitation intensities are allowed to have non-gaussian distribution. The variance of the daily precipitation over $T$ days is estimated as,

$$\sigma_T^2 = T\left[qp\sigma^2 + p(1-p)\frac{1+d}{1-d}\mu^2\right] \qquad (1)$$

$T$ = length of process (season or month),

$p$ = unconditional probability of wet days, (wet day=precipitation > 2.5 mm on a day),

$q$ = autocorrelation within sequences of wet days,

$\mu$ and $\sigma^2$ = mean and variance using wet days only,

$d$ = persistence parameter: $p11 - p01$,

$p11$ = probability of a wet day given the previous day was wet,

$p01$ = probability of a wet day given the previous day was dry

This model assumes that precipitation occurrence process constitutes a first order Markov chain and intensities to be independent. Klugman and Klugman (1981) have suggested procedures for calculating variance of the higher order Markov chain precipitation process. However, individual station's precipitation processes may not be of the same order and also variance formula becomes more complicated for higher order Markov chains, precipitation being dependent on consecutive wet days. Although a first order Markov model may not be appropriate for every individual station, Singh *et al.* (1981) have shown that overall it provides adequate description.

The daily precipitation data for each station was separated into four Indian seasons: winter (January + February), summer (March + April + May), SW monsoon (June + July + August + September), and NE monsoon (October + November + December); individual monsoon months June, July, August and September and SW monsoon subseasons JJA (June+July+August), JA (July+August), JAS (July+August+September`). Using Eqn. 1, estimates of climate noise were computed at a station for each time period for each data year. Next they were averaged or pooled over all the available years. This process was repeated for all the 1656 stations under consideration.

## 4. Potential Predictability

Total variance ($\sigma_A^2$) is assumed to be consisting of a potentially predictable 'climate signal' and an unpredictable component 'climate noise'. The total variance is,

$$\sigma_A^2 = \frac{1}{k-1}\sum_{i=1}^{k}(x_i - \bar{x})^2 \qquad (2)$$

where $x_i$ are the precipitation totals for the season or month under considerations and $\bar{x}$ is the mean over k years available. The ratio $\sigma_A^2/\sigma_T^2$ gives the F-ratio which is a measure of the potential for prediction.

The F-ratios have been calculated for each of the four seasons, the four monsoon months and JJA, JA, JAS subseasons for each of the stations. If F-ratio exceeds one

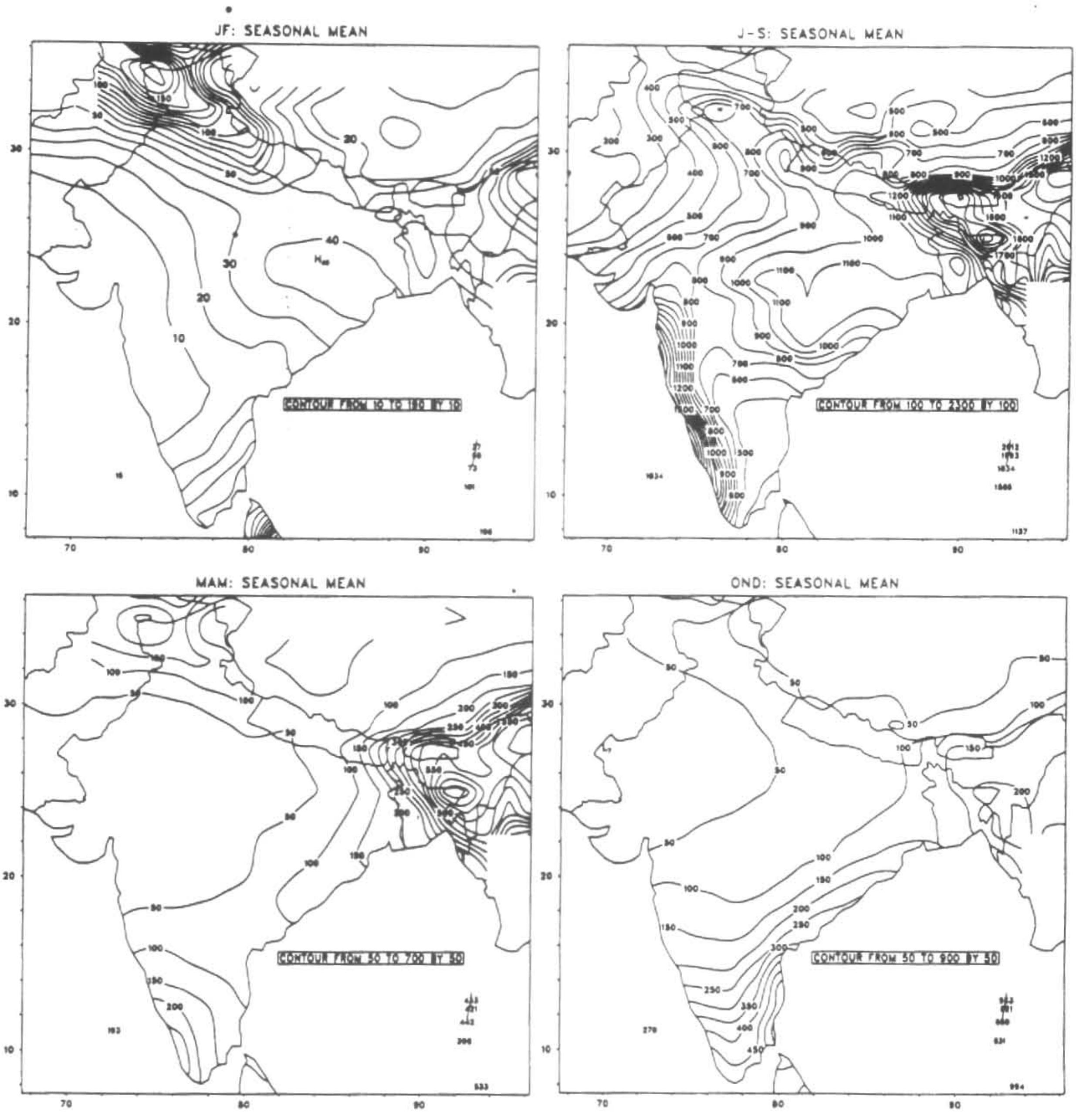


**Fig. 1.** Mean seasonal precipitation (mm) over India

over the station *i.e.* interannual variance exceeds noise then precipitation is potentially predictable. F-ratios of 1.25, 1.5, 2.0 and 3.0 indicate that it will be potentially possible to explain 20%, 33%, 50% and 66% of the total variance respectively.

## 5. Seasonal precipitation F-ratios

SW monsoon active over entire Indian subcontinent (Fig. 1) accounts for 70 to 90% of the annual total precipitation over most parts. SW monsoon seasonal F-ratios exceed one everywhere (Fig. 2) over the subcontinent. The higher F-ratios are along west coast and adjacent upper part (>1.75). F-ratios are also higher over upper Bangladesh and adjacent upper part of northeast India, Sikkim and Tibet. F-ratios are lower along southeast peninsula, northernmost India and eastern northeast India.

Precipitation activity in winter, summer and NE monsoon seasons is confined to particular areas and precipitation amount is very less than that of SW monsoon

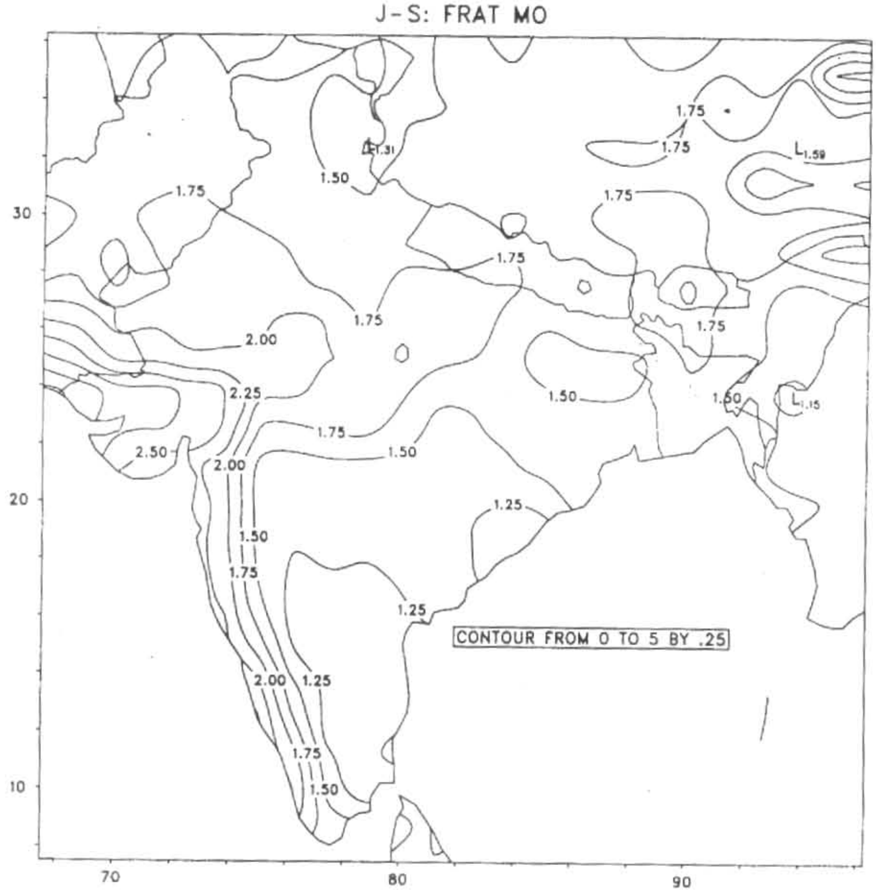


**Fig. 2.** Estimates of F-ratios for SW monsoon season precipitation over India

season. Exception is the southeastern subcontinent in NE monsoon season (Fig. 1). Therefore F-ratios during these seasons over those restricted areas of active precipitation are only described.

In winter, major precipitation area is northwest Indian subcontinent due to western disturbances (WD). Over northwest subcontinent in winter F-ratios exceed one and are greater than 1.5 at northern parts. Southeast subcontinent especially Sri Lanka gets precipitation due to remnant of NE monsoon in winter. F-ratios are high exceeding 2.75 over there. In summer major precipitation areas are northeast and southwest India mainly due to pre-monsoon thunderstorms. Over northeast India in summer F-ratios exceed one but are not very high (<1.5) and over some part of southwest India they are less than one. For NE monsoon season, F-ratios are good over southeast subcontinent ranging between 1.25 to 2.25. However, over upper east coast and northeast India F- ratios are less.

## 6. Monsoon subseasonal and monthly precipitation F-ratios

Total span of SW monsoon (June-September) decreases northwestwards and precipitation intensity varies spatially on intraseasonal scale (Fig. 3). Therefore F- ratios have been estimated for four monsoon months and subseasons JJA, JA, JAS.

In early June normally SW monsoon enters India from southwest coast and is in advancing phase (Rao, 1981). The onset and advance shows large interannual variability and therefore, precipitation is not consistent during the month. F- ratios also are not systematic though exceed one (Fig. 4). Over west coast and northeast India where SW monsoon is active during June, F-ratios are good. F-ratios are high over northwest subcontinent where precipitation of small amount is mainly due to western disturbances. By mid July, monsoon spreads over the

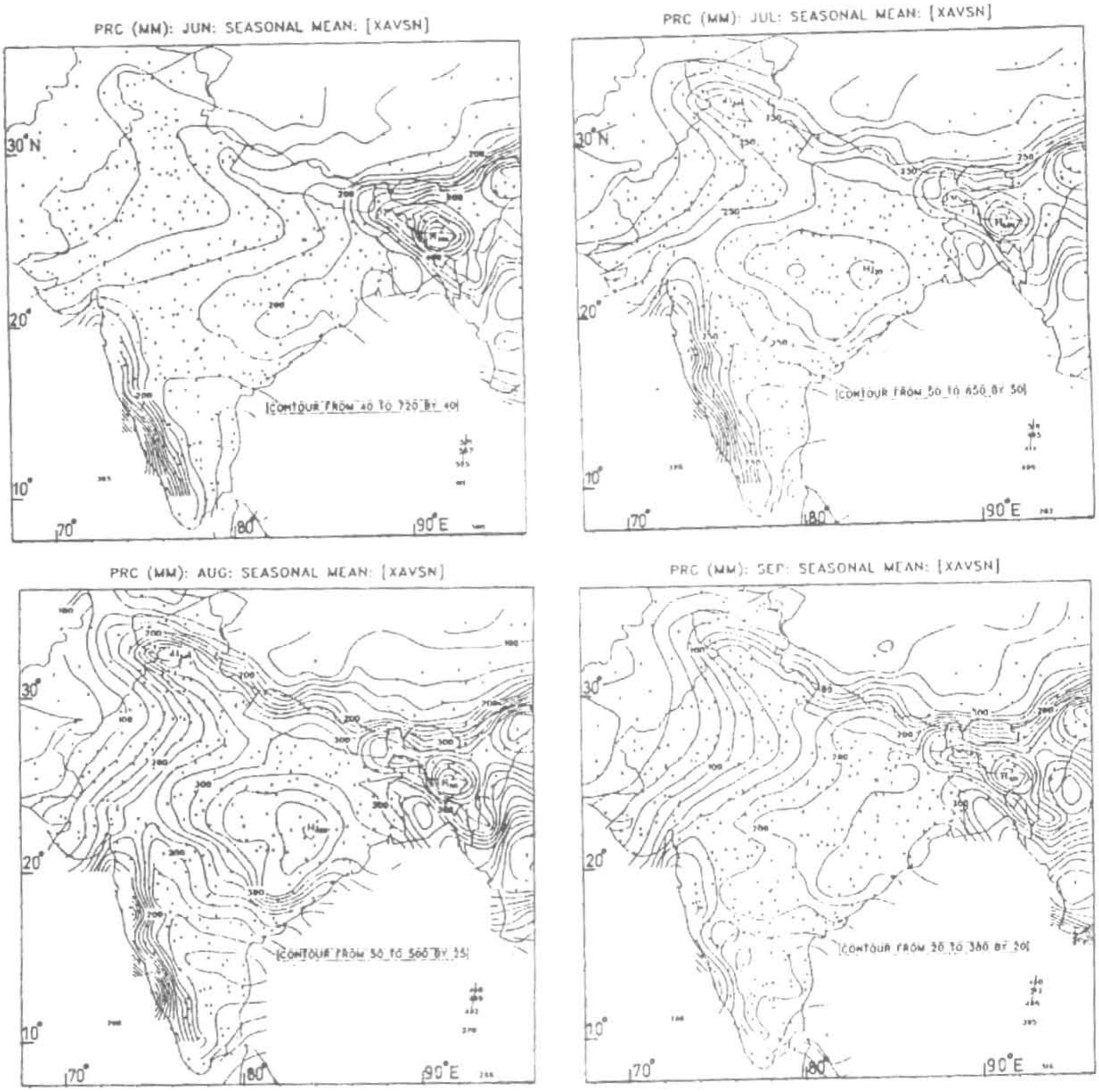


**Fig. 3.** Mean monsoon monthly precipitation (mm) over India

entire subcontinent. F-ratios exceed one everywhere in July (Fig. 4). Higher F-ratios are over Sri Lanka, southwest peninsula and adjacent upper part. They are also high over part of Sikkim, northeast India and Bangladesh. Lower F-ratios are observed over northeast peninsula, part of upper northwest subcontinent and eastern subcontinent. In August F-ratio contours (Fig. 5) show almost similar pattern as in July. Only overall, larger area is covered by higher F-ratios and lower F-ratio area over northeast peninsula is shifted upward than in July. In September (Fig. 5) F-ratio contours show systematic gradient from northwest to eastern southeast direction over India. The highest F-ratios (3.26) are over Great Indian desert in northwest subcontinent and lowest over and adjacent to upper east coast. F-ratios over Sri Lanka are however high.

In JA, monsoon is well established and in most active phase. F-ratios (Fig. 6) are highest along west coast and upper adjacent parts. This is the area of high precipitation due to off west coast trough and middle tropospheric cyclones during July and August. F-ratios are also high over Sikkim and adjacent upper and lower parts where high precipitation occurs due to

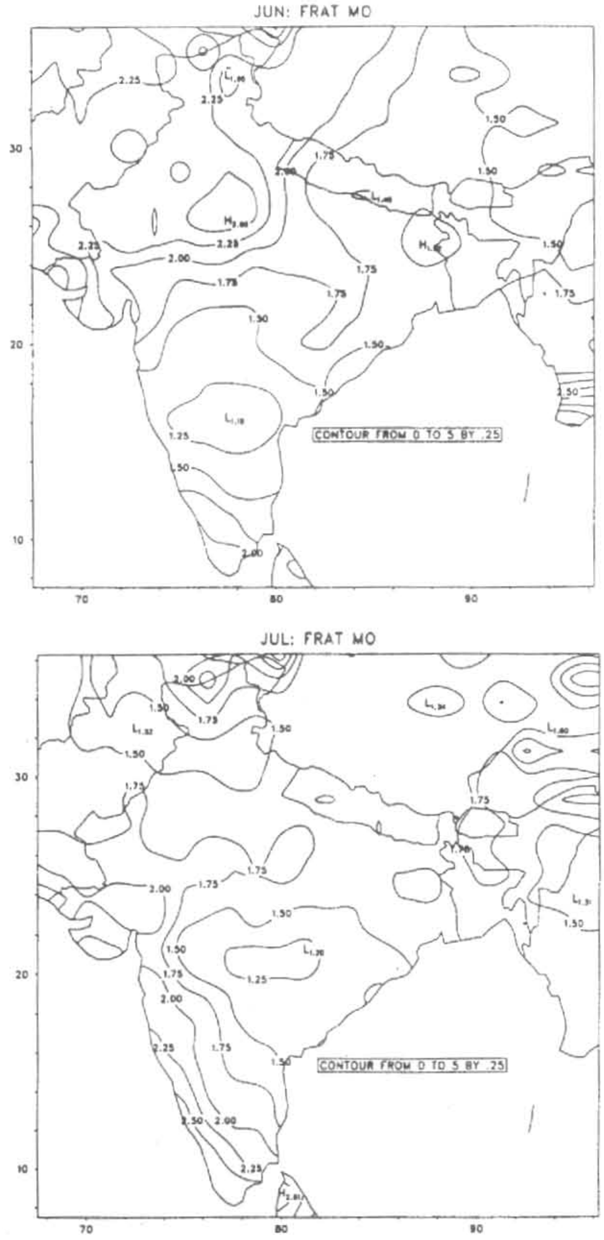


**Fig. 4.** Estimates of F-ratios for June and July precipitation over India

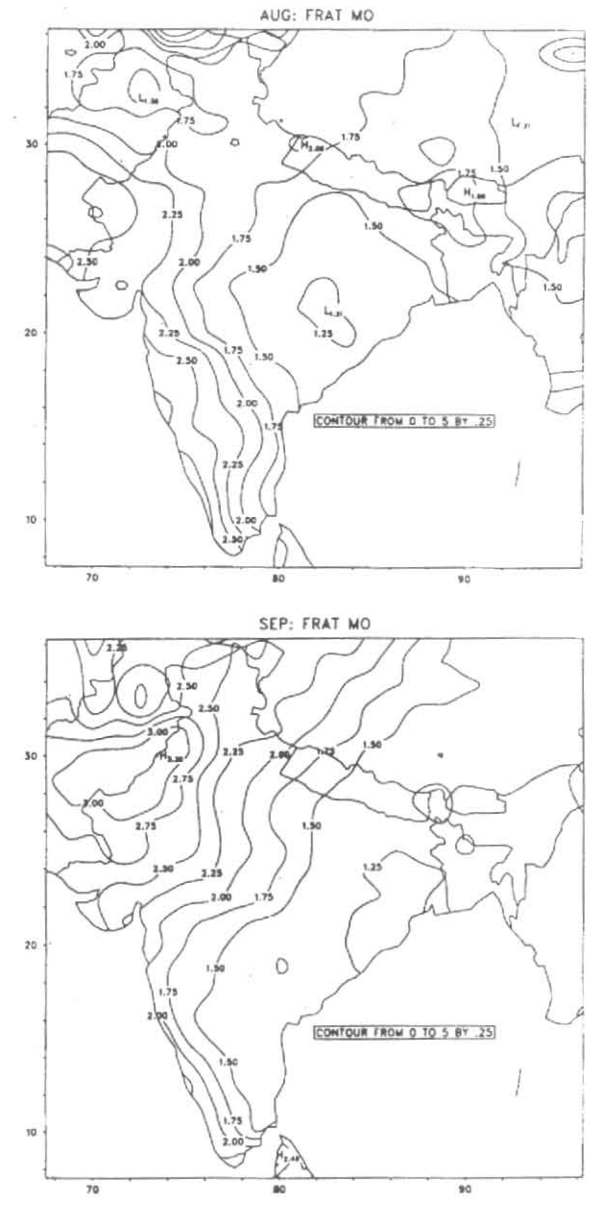


**Fig. 5.** Estimates of F-ratios for August and September precipitation over India

orography. F-ratios are lower along and adjacent parts of east coast and northwest subcontinent.

In JJA, F-ratio contour pattern is almost same as in JA but F-ratios are higher in general.

In JAS, F-ratios (Fig. 7) are high over northwest subcontinent and highest (2.50) over southern northwest subcontinent. Over this area of low and highly variable precipitation, higher F-ratios in the most active subseason are noteworthy.

## 7. Summary and concluding remarks

(*i*) SW monsoon precipitation over India is potentially predictable on seasonal, subseasonal as well as monthly scales. It is remarkable that on monthly and subseasonal scale the potential for prediction is very good comparable to and sometimes better than season/subseason. Over western peninsula potential predictability (pp) is high especially for whole season; July,

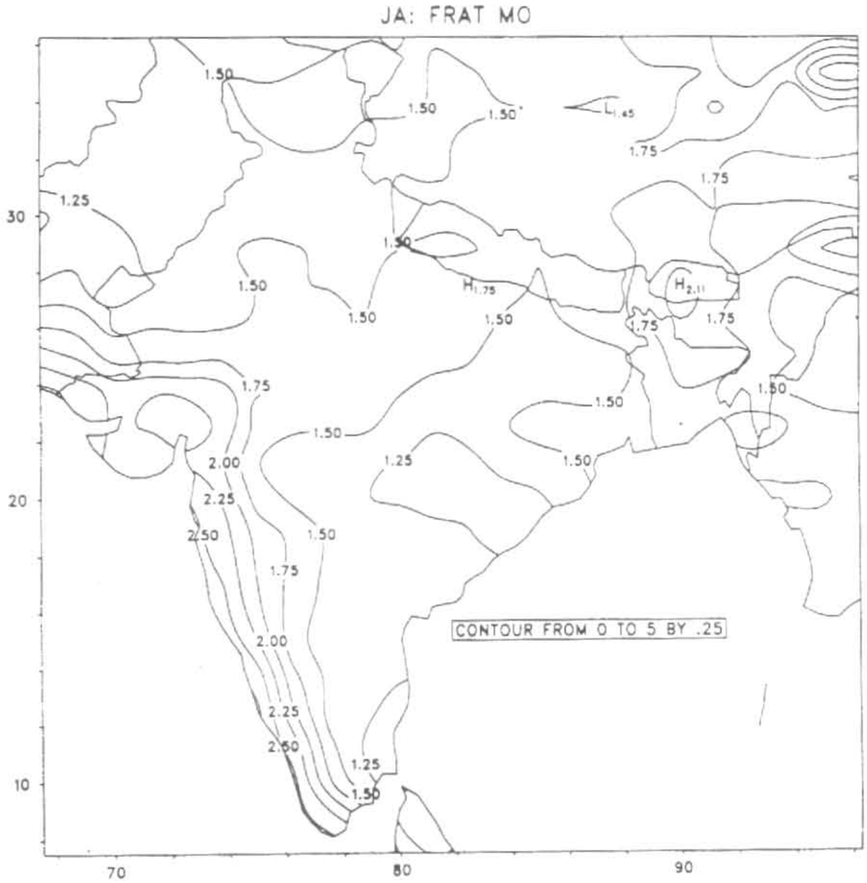


**Fig. 6.** Estimates of F-ratios for JA subseason precipitation over India

August months; and JA, JJA subseasons. Another area of high pp is upper Bangladesh and adjacent upper northeast India, Sikkim and part of Tibet during whole season; July, August months; and JA, JJA subseasons. Both these areas get high precipitation during the SW monsoon season. Over south peninsula pp is good in June, July and August months but generally low over eastern peninsula. Over northwest India pp is good and is very high in September and JAS subseason. Over northcentral India pp is found moderate on all the scales.

(*ii*) PP is good over principal area of NE monsoon precipitation *i.e.* southeast India and Sri Lanka in NE monsoon and winter season.

(*iii*) Precipitation over northern northwest India during winter and summer due to WD is potentially predictable.

This investigation reveals that long-range forecasting of precipitation in SW monsoon season has good scope on seasonal as well as intraseasonal scale over India. Besides, contours of potential predictability presented here are expected to be a feedback information for climate modelling. Based on potential predictability variation over the country, identified broad regions for development of SW monsoon prediction models are western peninsula, eastern peninsula, northwest India, northcentral India and northeast India. These regions are in close proximity with the six optimum regions appropriate for the study of monsoon variability over India according to Sontakke and Singh (1996). Prediction models attempted over these regions or part of it after filtering out appropriate climate noise from the respective regional precipitation series under consideration are expected to give better quantitative results. The global and regional predictors identified for long-range forecasting for country as a whole however may not be adequate for seasonal, subseasonal and monthly regional prediction models. Regional predictors are expected to be more important as

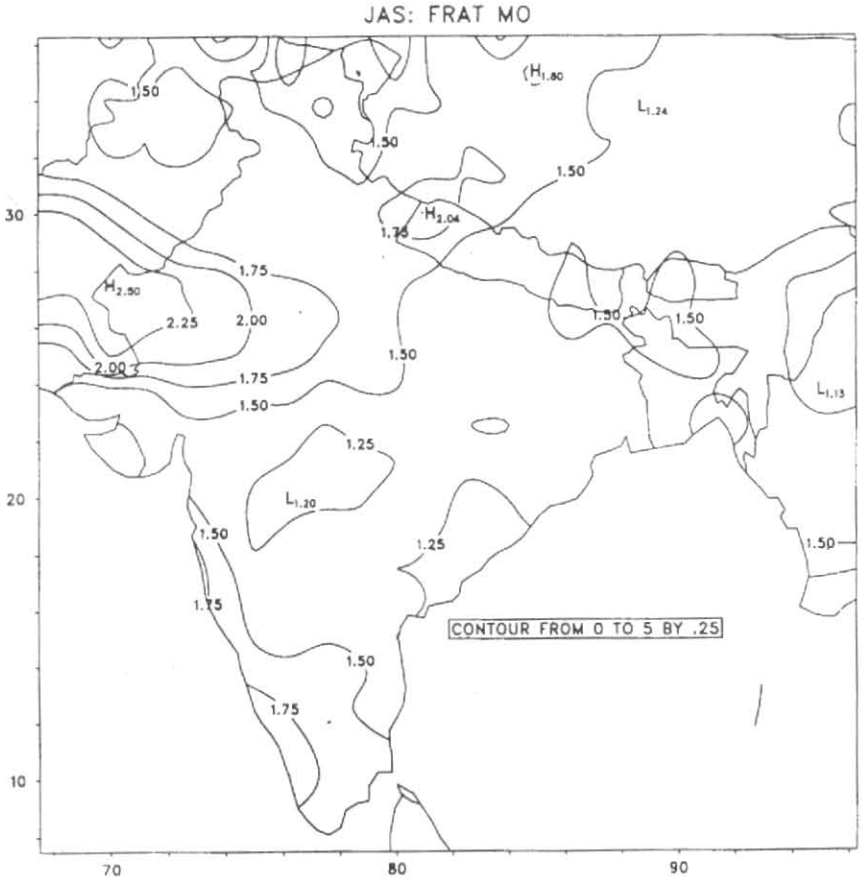


**Fig. 7.** Estimates of F-ratios for JAS subseason precipitation over India

they play major role in concerned areas. Each regional model will have to be attempted separately by avoiding overfitting due to intercorrelations between the identified predictors for realistic results. Singh and Sontakke (1999) and Sontakke and Singh (1999) have attempted the prediction of the 10-year future period for six region's monsoons (SW and NE) and annual precipitation series by modelling and extrapolating smoothed version of the series through SSA and low-pass filters.

The F-ratios at station level are potentially predictable. Therefore long-range forecast for still smaller spatial scales than the identified regions is possible. Main challenge is to separate out the appropriate noise from the series under consideration and catch the signal present in the series by modelling it. The attempts can also be made for seasonal, monsoon subseasonal and monthly scale's long-range forecast keeping in mind its potential predictability.

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