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Long range forecasting parameters *vis-a-vis* sub-divisional summer rainfall over India

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सार—देश के विभिन्न मौसम उप-मण्डलों की ग्रीष्म कालीन मानसून वर्षा का अंत: वार्षिक परिवर्तिता का अध्ययन किया गया है। 1958 से 1990 तक के आंकड़ों का उपयोग करके क्षेत्रीय एवं भूमण्डलीय प्राचलों पर आधारित आनुभाविक लांबिक फलनों (ई ओ एफ) के द्वारा देश के तीन विस्तृत उप-मण्डलों को पहचानने में सक्षम हो सके हैं।

प्रथम आनुभाविक लांबिक फलन (ई ओ एफ) का देश के उत्तर-पूर्व और दक्षिण-पूर्व भागों के अधिकतर उप-मंडलों में मानसून वर्षा के साथ सार्थक सहसंबंध नहीं पाया गया। तथापि बाकी उप-मंडलों में इस ई ओ एफ का वर्षा के साथ उल्लेखनीय रुप से सहसंबंध पाया गया।

ABSTRACT. Interannual variability of Empirical Orthogonal Functions (EOF) based upon regional/global parameters, associated with the summer monsoon rainfall over different meteorological sub-divisions of the country have been discussed, based upon the data during the years 1958 to 1990 enabling us to identify three broad sub-divisions of the country.

It was interesting to note that the first empirical orthogonal function did not show significant correlation with monsoon rainfall over most sub-divisions of the NE and SE parts of the country. However, this EOF was found to be significantly correlated with the rainfall over the remaining meteorological sub-divisions of the country.

Key words — Empirical Orthogonal Function (EOF), Power regression model, Interannual variability, Correlation coefficient.

1. Introduction

The southwest monsoon is the principal rainbearing season in India from June to September. Large interannual variation has been observed in the monsoon rainfall both in space and time affecting the water resources and agriculture in the country. Meteorologists have, therefore, been attempting to predict the variability patterns of the monsoon rainfall in both space and time since last 100 years (Blanford, 1884, Walker 1910) and more recently by Bhalme and Mooley (1980), Verma (1980), Thapliyal (1982), Shukla and Paolino (1983).

Recently, Gowariker *et al.* (1989, 1991) have developed a power regression model for the country's summer monsoon rainfall based on 16 parameters whose interdependence has been examined by Srivastava and Singh (1993) using EOF analysis. A question has been raised about the interannual variability pattern of EOF in relation to the monsoon rainfall over the meteorological sub-divisions of the country.

The object of this study is, therefore, to study these aspects and identify broad regions of the country and the corresponding empirical orthogonal functions based on regional and global parameters.

2. Data

We have used sixteen regional/global parameters (Gowariker *et al.* 1989, 1991) which have shown promise for the long range forecast of Indian summer monsoon rainfall during the last four years (Table 1). It may be noticed that the parameters are broadly divided into four groups related to temperature, pressure, wind and snow cover keeping in view their possible physical linkages with the monsoon rainfall. Empirical orthogonal functions and some derived linear functions from these have been woked out, utilising the data of 33 years, *i.e.*, 1958 to 1990 . The details of the method are given in the paper by Srivastava and Singh (1993).

3. Methodology

Empirical orthogonal functions based on all the 16 parameters were computed . The eigen vectors related to these EOFs are shown in Table 2 and their correlation coefficients with three broad sub-divisional monsoon seasonal rainfall are given in Table 3. Based on correlation coefficient (CC) the meteorological sub-divisions were grouped together, which showed significant correlation (at 5%, level of significance) with different EOFs. And then, various regions of the country and corresponding EOFs were also identified such that the interannual variability patterns of the monsoon rainfall and the EOF were found similar to each other over the respective region. Although EOFs were computed for all the 16 parameters, some of the parameters which do not have significant contribution in the variability of the function, were removed. Consequently, various linear functions based on lesser number of parameters were derived from these EOFs

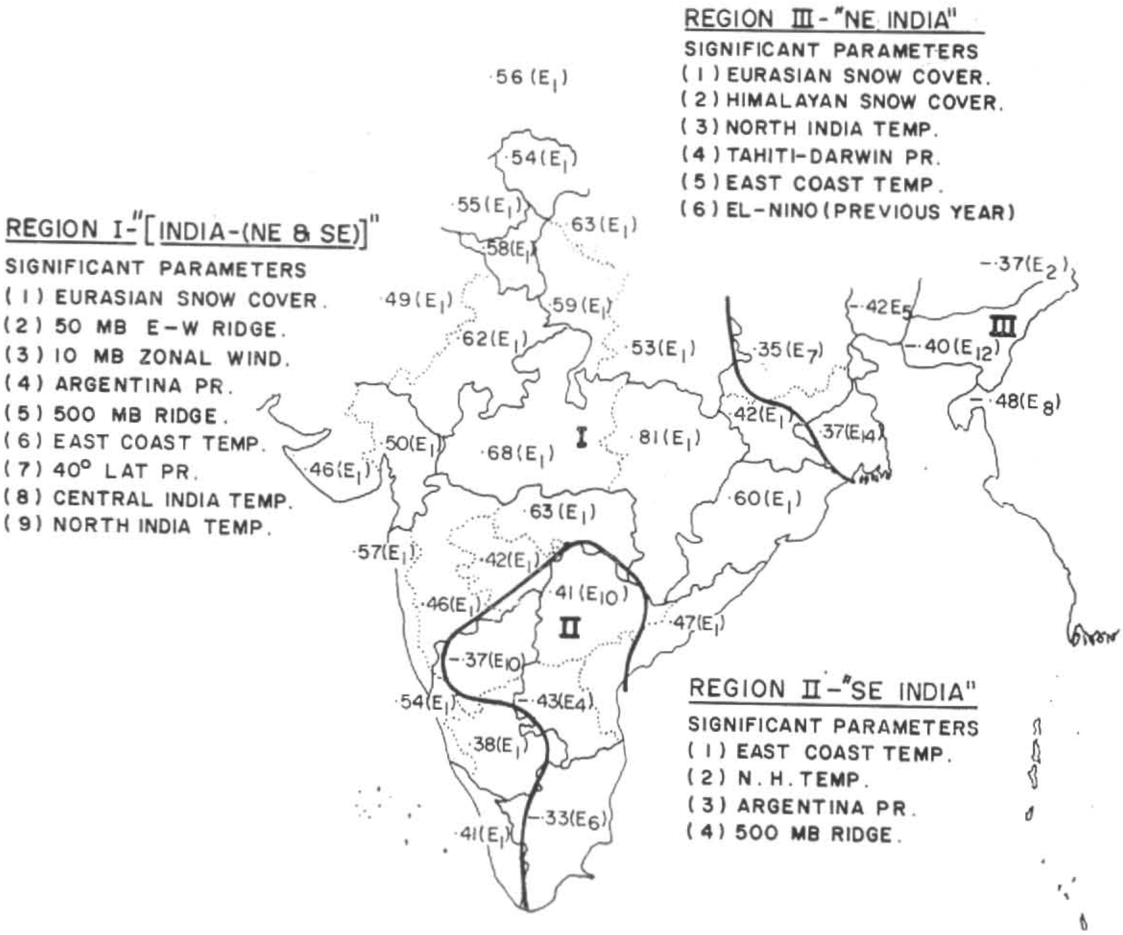

Fig. 1. Maximum correlation coefficients of sub-divisional monsoon seasonal rainfall and empirical orthogonal functions

and those functions were identified whose variability patterns were found similar to the monsoon rainfall pattern over different regions. Also, the influence of the significant intra-annual variability in the total monsoon rainfall (during June to September) over different parts of the country was evaluated.

4. Results and discussion

It may be seen from Fig. 1 that the first empirical orthogonal function (EOF) shows a significant correlation (0.36) at 5% level of significance with the monsoon rainfall for the meteorological sub-divisions, namely Orissa, west/east Madhya Pradesh, Bihar plateau, east/west Uttar Pradesh, hills of west Uttar Pradesh, Jammu & Kashmir, Himachal Pradesh, Punjab, Haryana, east and west Rajasthan, Gujarat, Maharashtra, south interior Karnataka, Kerala, coastal Karnataka. Some of the sub-divisions belonging to the central parts of the country, namely, Orissa, east and west Madhya Pradesh and Vidarbha have shown the correlation coefficient

TABLE 1

S. No.	Parameters
1	10 hPa westerly zonal wind (Jan)
2	500 hPa ridge over India (Apr)
3	50 hPa ridge-trough extent (Jan-Feb)
4	*El Nino* in current year
5	Central India temperature (May)
6	Northern India temperature (Mar)
7	East coast temperature (Mar)
8	Northern hemisphere temperature (Jan & Feb)
9	*El Nino* in previous year
10	Darwin pressure (Spring)
11	Eurasian snow cover (Previous Dec)
12	Indian Ocean equatorial pressure (Jan-May)
13	Himalayan snow cover (Jan-Mar)
14	Argentina pressure (Apr)
15	Tahiti-Darwin pressure (Spring)
16	36 to 40 Deg. pressure (Jan-Apr)

even greater than 0.6. The group of all these meteorological sub-divisions (significant at 5% level) referred to as "[India—(NE and SE)]" shows a very good correlation (0.84) (Table 3) between its monsoon rainfall and the first EOF. The RMSE between these two has been observed to be of the order of 4% over a long period of 33 years (1958-1990). The normalised variability patterns of the EOF and monsoon seasonal rainfall over this broad sub-division, namely "[India—(NE and SE)]" are shown in Fig. 2. It may be seen that the year to year variability of the first EOF is in very good agreement with the corresponding monsoon seasonal rainfall during all the years from 1958 to 1990 except 1978, 1985 and 1986. No other EOF shows a significant correlation with the monsoon rainfall over this broad sub-division. All these correlation coefficients, however, lie between —0.21 and +0.18 on normalized scale. It may also be interesting to note that east Madhya Pradesh is the smallest meteorological sub-division out of which the EOF shows a highly significant association (CC=0.81) with the monsoon rainfall.

We have also excluded some of the parameters whose contribution in the variability of first EOF was not found significant. Thus three linear functions were derived and are plotted in Fig. 2 on the normalised scale alongwith the monsoon rainfall over the broad sub-division "[India — (NE and SE)]". The last derived function is based only on two parameters, namely, 50 hPa — trough extension over the northern hemisphere and Eurasian snow cover which shows a very good correlation (0.85) and RMSE = 0.54 with the monsoon rainfall. Thus, with the knowledge of the first EOF and the linear function derived from it the monsoon rainfall from June to September over a broad sub-division, namely, "[India — (NE and SE)]" can be predicted in advance depending upon the availability of the parameters. On analysing the first EOF and these linear functions, it can be concluded that the main parameters responsible to explain the year to year variation in total rainfall during the monsoon season over this broad sub-division are zonal wind, 500 hPa ridge, 50 hPa east-west ridge, Vidarbha temperature, east coast temperature, north Indian temperature, Eurasian snow, Argentina pressure and pressure at 40° N latitudinal belt.

It may be noted that first EOF does not show any significant correlation with the monsoon rainfall over the different meteorological sub-divisions belonging to the southeast part of the country. These are north interior Karnataka, Telangana, Rayalaseema and Tamil Nadu. However, EOF 10 was found significantly correlated (at 5% level of significance) with the monsoon rainfall over Telangana and north interior Karnataka both (CC=0.41 and 0.37 respectively) and EOF 4 over the Rayalaseema region (CC=0.43). On the other hand, no EOF was significantly correlated with Tamil Nadu rainfall during this season which seems logical from synoptic and climatological view point as this meteorological sub-division has the main rain bearing pattern during northeast monsoon. On analysing the EOF 4 and EOF 10 it can be concluded that year to year variability in the total rainfall during the southwest monsoon over this broad sub-division, namely, 'SE India' consisting of north interior Karnataka, Telangana and Rayalaseema can, however, be explained with the help of a few parameters, namely, east coast temperature, northern hemispheric temperature, Argentina pressure and 500 hPa April ridge.

In NE part of the country also, the first EOF is not significantly correlated with any of the meteorological sub-divisional monsoon rainfall. However, EOF 7 over Bihar plains, EOF 14 over Gangetic West Bengal, EOF 2 over Arunachal Pradesh, EOF 12 over Assam & Meghalaya, EOF 5 over sub-Himalayan Gangetic West Bengal and EOF 8 over Nagaland, Manipur, Tripura have been found significantly correlated at 5% level with the monsoon rainfall over respective regions. Thus, the inter-annual monsoon rainfall variability over different parts of northeast India is explained by different EOFs. On analysing these EOFs, it was found that the parameters responsible to explain the year to year variability are (Tahiti-Darwin) pressure, north India temperature, east coast temperature, Eurasian snow Himalayan snow and *El Nino* (Prev).

TABLE 2

Eigen vectors of parameters

EOF	Parameters 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Variance explained
1	0.32	0.30	-0.37	-0.12	0.27	0.26	0.30	0.19	0.12	-0.14	-0.37	-0.14	0.07	-0.32	0.05	0.29	26.95
2	-0.07	0.07	0.04	-0.17	-0.14	-0.09	-0.22	-0.29	-0.20	-0.48	-0.03	-0.48	0.35	0.04	0.44	-0.02	17.65
3	0.16	-0.25	0.36	0.46	0.23	0.30	0.13	-0.36	-0.04	-0.04	-0.05	0.05	0.42	0.00	-0.21	0.23	8.97
4	0.18	-0.19	0.05	-0.44	-0.34	0.16	0.22	-0.08	-0.58	0.09	0.00	0.00	0.10	-0.29	-0.28	-0.15	8.32
5	0.42	-0.08	-0.20	0.28	-0.10	-0.53	-0.02	0.17	-0.04	0.13	0.23	0.15	0.39	-0.29	0.21	-0.04	7.43
6	-0.27	0.40	0.15	0.20	-0.03	0.15	-0.38	0.31	-0.44	0.12	-0.27	0.30	0.18	-0.11	0.11	0.08	6.61
7	0.09	0.19	-0.05	0.13	0.58	0.03	0.00	0.05	-0.22	-0.13	0.18	-0.09	-0.04	-0.03	-0.20	-0.67	5.59
8	-0.22	-0.34	0.24	-0.07	0.08	-0.03	-0.22	0.39	0.21	-0.43	0.09	-0.02	-0.03	-0.54	-0.19	0.07	4.72
9	0.23	0.27	0.13	0.35	-0.35	0.19	0.12	0.28	-0.16	-0.26	0.43	-0.28	-0.26	0.12	-0.06	0.18	3.12
10	0.21	0.27	-0.15	0.00	-0.21	0.24	-0.51	-0.48	0.25	0.01	0.15	0.12	-0.11	-0.36	-0.15	-0.07	2.91
11	0.03	-0.38	-0.12	0.36	-0.26	0.36	0.06	0.06	0.04	-0.02	-0.30	-0.02	-0.19	-0.13	0.42	-0.42	2.21
12	0.21	-0.18	-0.12	0.22	0.03	-0.38	-0.29	-0.10	-0.29	-0.10	-0.46	-0.20	-0.39	0.07	-0.30	0.16	1.89
13	0.30	0.01	0.38	-0.17	0.24	-0.07	0.08	-0.16	-0.16	-0.17	0.07	0.42	-0.42	-0.09	0.45	0.12	1.37
14	0.42	-0.29	-0.12	-0.26	0.10	0.31	-0.45	0.32	0.01	-0.05	0.08	0.12	0.16	0.45	0.01	0.04	1.21
15	0.27	0.27	0.42	-0.08	-0.29	-0.17	0.09	0.10	0.32	-0.23	-0.40	0.13	0.16	-0.16	-0.18	-0.34	0.68
16	0.20	0.03	0.44	-0.09	0.13	0.03	-0.17	0.12	0.11	0.59	-0.04	-0.53	-0.07	-0.17	0.14	-0.02	0.37

It may be noted that although the monsoon seasonal rainfall over all meteorological sub-divisions belonging to NE India (Region III, Fig. 2) have shown a significant association at 5% level with some of the EOFs over their respective regions their magnitudes are not very large. No correlation coefficient exceeds the limits of ± 0.48. On grouping all these sub-divisions into a broad sub-division, namely 'NE India', the correlation coefficient of monsoon rainfall over this region could not exceed 0.37 (Table 3) with the EOF number 12. Similarly over the SE India (Region II, Fig. 1), the correlation coefficient of monsoon rainfall could not obtain more than 0.43 with EOF number 10. Thus, the year to year variability of the monsoon seasonal rainfall over a broad sub-division, namely, "[India — (NE and SE)]" (Region I, Fig. 1) can be explained with the help of a few of the LRF parameters referred to above.

5. Conclusions

The study has brought out the following results :

(*i*) Year to year variability over a period of 33 years (1958-1990) of the first empirical orthogonal function derived from the long range forecast-regional/global 16 parameters shows a significant association with the inter-annual variability of the monsoon seasonal rainfall over a broad sub-division, namely, as "[India — (NE and SE)]".

(*ii*) The four parameters, namely, zonal wind 50 hPa ridge extension over northern hemisphere, Eurasian snow and Argentina pressure show maximum

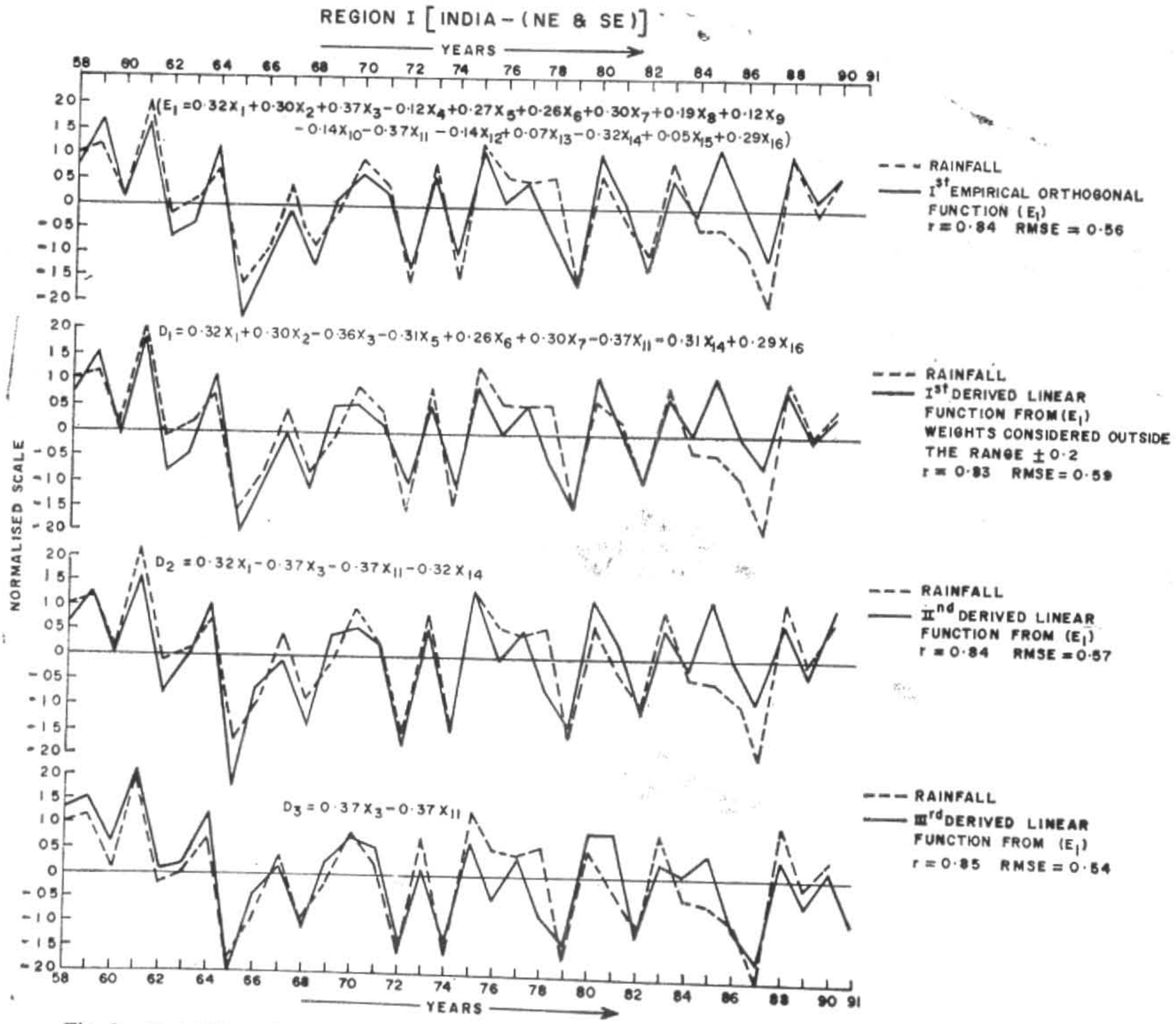

Fig. 2. Variability of monsoon seasonal rainfall and empirical orthogonal/derived linear functions for broad sub-division, namely, "[India — (NE and SE)]"

TABLE 3

Broad sub-division	Correlation matrix of broad sub-divisional monsoon rainfall and EOF															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
India — (NE & SE)	.84	.02	—.14	—.18	.18	.01	—.01	—.15	—.14	—.21	.04	.09	.05	.00	—.13	.07
SE India	.36	—.18	—.28	—.39	—.03	.04	.16	—.06	.01	—.43	.10	—.14	.20	.06	—.19	.20
NE India	—.04	—.31	—.18	.02	—.27	—.08	.13	—.07	.23	.31	—.06	—.37	.17	.18	.09	.01

contribution in explaining the inter-annual variability of the monsoon seasonal rainfall over the different parts of the country except northeast and southeast regions.

(*iii*) No orthogonal function has been found significantly associated at 5% level with the total rainfall during June to September over Tamil Nadu.

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