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Chapter 5

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1. Introduction

Forecasting monthly and seasonal mean monsoon rainfall over India is of great socio-economic importance. Most of the earlier efforts to forecast seasonal mean rainfall have looked for correlations among selected atmospheric variables preceding the monsoon season. It can be argued that there is no physical basis to assume that the atmospheric flows in the absence of changes in the external forcing, have any internal dynamical mechanisms which can provide a long-term memory, and therefore there should be little hope for long-term predictions based on preceding atmospheric states. However, it is likely that the influences of the external forcing can manifest themselves through specific atmospheric fluctuations and therefore provide an apparent predictability in terms of preceding atmospheric states. Although the solar heating (and its changes due to terrestrial and extra-terrestrial factors) is the only true external forcing, the slowly varying boundary conditions of sea surface temperature, soil moisture, albedo, snow and sea ice can also act as external forcings for the time scales over which these boundary conditions are either constant or slowly changing.

In this paper, we have examined the interannual variability of monsoon rainfall over India and monthly mean sea level pressure over the Northern Hemisphere. We do not find any evidence of a statistically significant relation between sea level pressure anywhere over the Northern Hemisphere during any month or season of the year and monsoon rainfall over India. Due to a lack of an extensive time series of global data we have not looked at possible relationships with the Southern Hemisphere circulation.

We speculate that the potential for long-range prediction of monsoon rainfall lies in the possible relationship between the boundary conditions at the earth's surface and associated circulation patterns.

2. Data

2.1 Rainfall Data

The rainfall data are derived from observed monthly mean rainfall for 31 subdivisions over India. A map of these subdivisions is presented in Fig.1.

29 subdivisions were grouped into coherent regions in order to study rainfall variability on a larger spatial scale, as well as to reduce climatic noise. Subdivisions displaying similar variability were grouped into the same regions, using Jagnathan (1968) as a guide. We grouped 29 subdivisions into 4 regions: Northeast India, Northwest India, Indian Peninsula and Southern India.
A listing of the subdivisions in each region, as well as a fifth region, Central India, which was suggested by D. R. Sikka, is presented in Table 1.

The rainfall for a particular year and a particular region was computed by weighting each subdivision in the region by the area covered by the subdivision. The area covered by each subdivision is given in Table 1. Seasonal mean summer rainfall time series were prepared for all five regions and total Indian monsoon rainfall, for 1901-1980.

2.2 Sea Level Pressure Data

We use the Northern Hemisphere monthly mean sea level pressure (SLP) data, as prepared by Trenberth and Paolino (1980). These maps, with a 5° latitude by 5° longitude resolution, have been re-analyzed onto a 13 x 13 grid covering the Northern Hemisphere. This analysis, described in Trenberth and Paolino (1981), combines the interpolation to the new grid with an averaging procedure in order to reduce computational time while still retaining the large scale features of the SLP fields.

An empirical orthogonal function (EOF) analysis was performed on both seasonal and monthly mean anomaly fields of SLP. The EOF analyses efficiently represent the variance of the data with a number of empirical functions, which are orthogonal. Only a few of these functions are needed to represent the bulk of the variance of the data. Related to these functions are time series of coefficients which represent the strengh of a particular year.

We will not consider the SLP data from the early part of the century due to problems in the data set noted by Trenberth and Paolino (1980). Seasonal and monthly mean anomaly fields of SLP are computed from the 53-year means for the period December 1924-November 1977. The EOF analyses are performed on these anomaly fields.

3. Results

3.1 Monsoon Rainfall Variability

The 80-year means of summer (JJAS) rainfall for the 31 subdivisions are shown in Fig. 2a. It can be seen that the maxima of monsoon rainfall occur on the west coast of India, with secondary maxima present in the northeast. A map of the standard deviations of the 80-year means of total rainfall is shown in Fig. 2b. Figure 2c shows the standard deviations from 80 years of percentage departure from normal rainfall. This map shows that the relative maxima of rainfall variability are present in the northwest.

The time series of percentage departure summer rainfall for each subdivision was correlated with the corresponding series for all subdivisions for the period 1901-1980. Maps of these correlation coefficients were useful in determining the classification of subdivisions into regions. A map showing the highest positive correlation at each subdivision with any other subdivision is shown in Fig. 3. The arrow points to the subdivision with the highest positive correlation present. This map shows that our grouping of subdivisions into different regions is consistent.

Time series of a areally averaged percentage departure rainfall for each of five regions and for the whole of India are presented in Fig. 4. The time series for the whole of India is in agreement with the one that was presented by Parthasarathy and Mooley (1978). It can be seen that the maxima and minima of these series (i.e. "good" monsoon years and "bad" monsoon years) match previously documented events (e.g., Sikka, 1980).

The relation of monsoon rainfall from one month to another was studied by computing correlation coefficients between successive months. Computing these coefficients for the 29 subdivisions (1901-1975) gave negative results--only a few of the subdivisions showed significant correlation with the next month's rainfall, and there was no consistency in pattern or sign for those stations which were above significance levels. Computing these coefficients for regional rainfall does give some significant correlation, as shown in Table 2. Notable is the lack of positive correlation from June to July. It is found that rainfall in a particular monsoon year shows correlation from July through September only when the whole of India is considered.

3.2 Monsoon rainfall--northern hemisphere SLP relationships

The EOFs for the anomalies of seasonal mean SLP were computed for Winter 1925-Autumn 1977. These EOFs are identical to those presented in Trenberth and Paolino (1981). The eigenvectors computed from anomalies of monthly mean SLP generally show the same basic patterns as the EOFs of their corresponding season.

We tested for a possible relationship between monsoon rainfall and the prevalent Northern Hemispheric surface circulation patterns by computing correlation coefficients between the EOF coefficient time series of the first five EOFs and the anomalies of time series of summer monsoon rainfall, for the period 1925-1977. There were no significant correlations between the EOFs of seasonal SLP and monsoon rainfall averaged over all of India. Some of the correlation coefficients relating regional rainfall to the seasonal EOFs were significant at or above the 95% significance level, but we could expect as many by chance.

The correlation coefficients between total monsoon rainfall and the coefficient time series for the first five EOFs of monthly mean SLP are shown in Table 3. There are some significant correlations, but not much more than we could expect by chance. It appears that the variation of the summer monsoon rainfall is only weekly, if at all, related to the prevalent patterns of the monthly mean Northern Hemispheric surface circulation, at least as represented by EOFs.

In order to test for any direct relation between monsoon rainfall and the Northern Hemisphere SLP fields themselves, correlation coefficients were computed between the total summer monsoon rainfall and the monthly mean SLP fields (for each month), for 1925-1977. The correlation maps for January, April, July and October are shown in Figure 5. There are some areas of significant correlation in most months, and the patterns display some continuity from month to month. However, the patterns do not seem to be of sufficient significance or areal extent to justify the postulation of a relationship between the monsoon and the Northern Hemispheric surface circulation, at least on a monthly time scale.

In order to determine if extreme monsoon years (years with a large rainfall deficit or a large rainfall surplus) might be related to variations of the Northern Hemisphere SLP fields, we composited monthly mean SLP fields for both the five highest and five lowest years from 51 year time series (from 1925-1975) of total monsoon rainfall.

The five years with the largest total monsoon rainfall areally averaged over all of India were: 1933, 1942, 1959, 1961 and 1975; the five years with the smallest rainfall were: 1939, 1941, 1951, 1965 and 1972. The means of SLP for each month, December 1924-November 1975, were subtracted from the monthly means for both the five good and the five bad years of monsoon rainfall. The resulting difference fields were judged to be statistically insignificant, since both the difference fields and the difference of the difference fields (SLP for good years - SLP for bad) were of the order of one standard deviation (of the SLP fields) or less. It appears that extremes in monsoon rainfall do not necessarily appear in years with extreme variations of the Northern Hemisphere SLP field.

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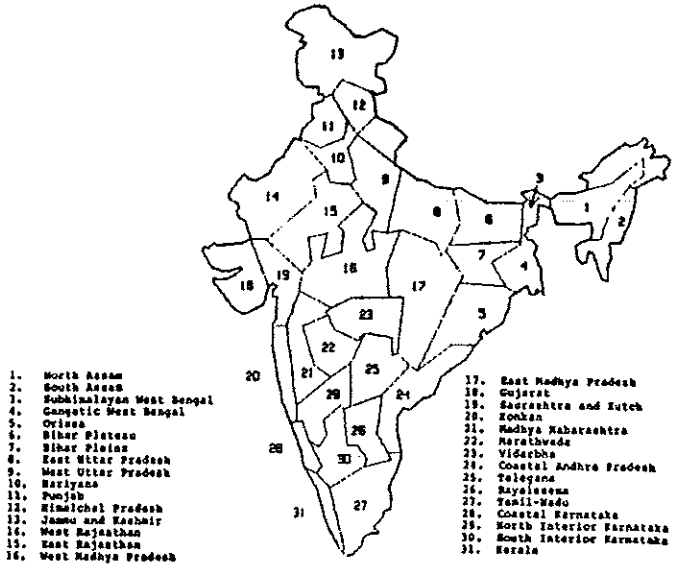


Fig. 1 Names and locations of Indian subdivisions.

Northeast India	Area (Km^2)
North Assam	130628
South Assam	122054
Subhimalayan West Bengal	16000
Gangetic West Bengal	71319
Bihar Plateau	79676
Bihar Plains	94360
Northwest India	
West Uttar Pradesh	145660
Hariyana	45000
Punjab	50376
Himachal Pradesh	55658
Jammu and Keshmir	222796
West Rajasthan	195161
East Rajasthan	147114

Southern India	Area (Km^2
Rayelseema	68070
Tamil-Nadu	131000
South Interior Karnataka	93000
Kerala	38859
Indian Peninsula	
West Madhya Pradesh	230147
East Madhya Pradesh	213300
Gujarat	84114
Saurashtra and Kutch	103589
Konkan	33549
Madhya Maharashtra	115313
Marathwada	66664
Vidarbha	95487
Coastal Andhra Pradesh	86548
Telangana	120661
Coastal Karnataka	18685
North Interior Karnataka	80294

Central India

Bihar Plateau
Bihar Plains
West Uttar Pradesh
Hariyana
Punjab
West Rajasthan
East Rajasthan
West Madhya Pradesh
East Madhya Pradesh
Gujarat
Saurashtra and Kutch
Vidarbha

Table 1 Listing of subdivisions and area (Km^2) of subdivisions used in compilation of regional rainfall.

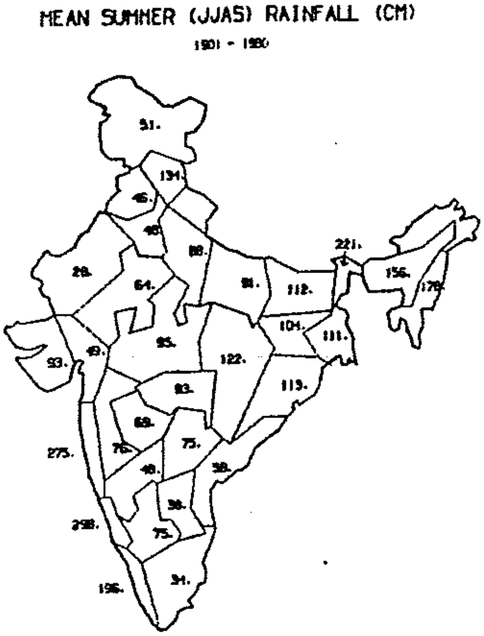


Fig. 2a 80 year means (1901-1980) of total summer (JJAS) monsoon rainfall (cm) for each subdivision.

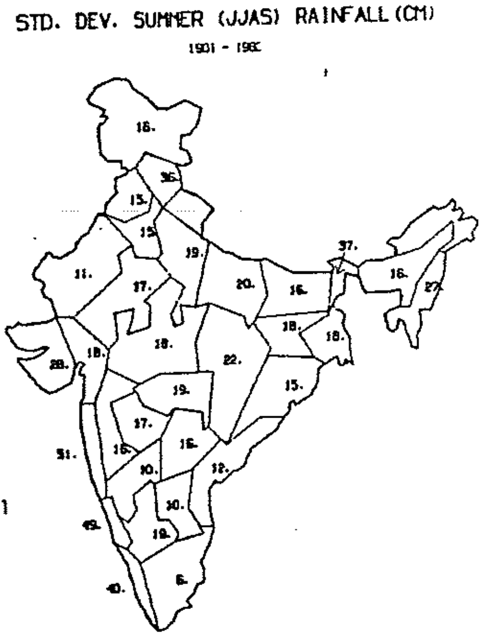


Fig. 2b Standard deviations from 80 year means (1901-1980) of total summer (JJAS) monsoon rainfall (cm) for each subdivision.

.rea (km²)

68070
131000
93000
38859

230147
213300
84114
103589
33549
115313
66664
95487
86548
120661
18685
80294

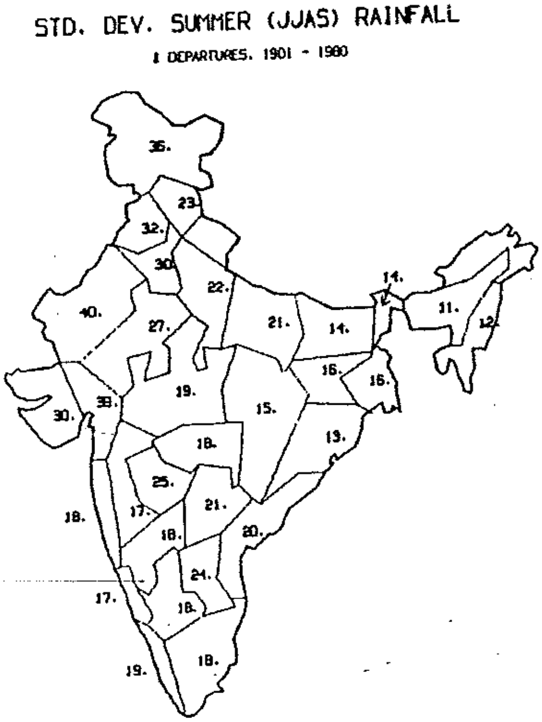


Fig. 2c Standard deviations from 80 years (1901-1980) of percentage departure from total summer (JJAS) monsoon rainfall for each subdivision.

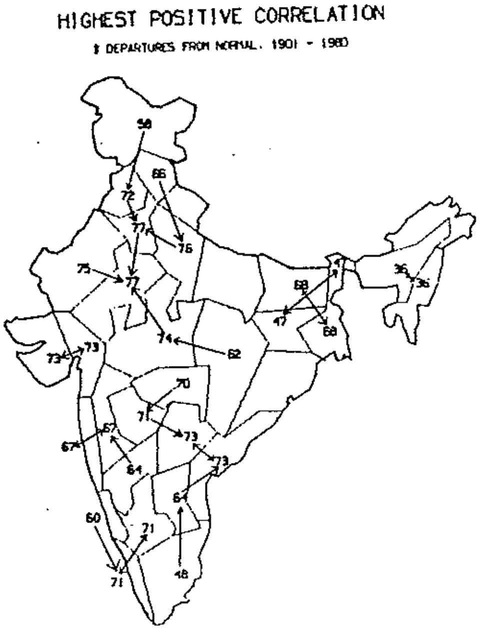
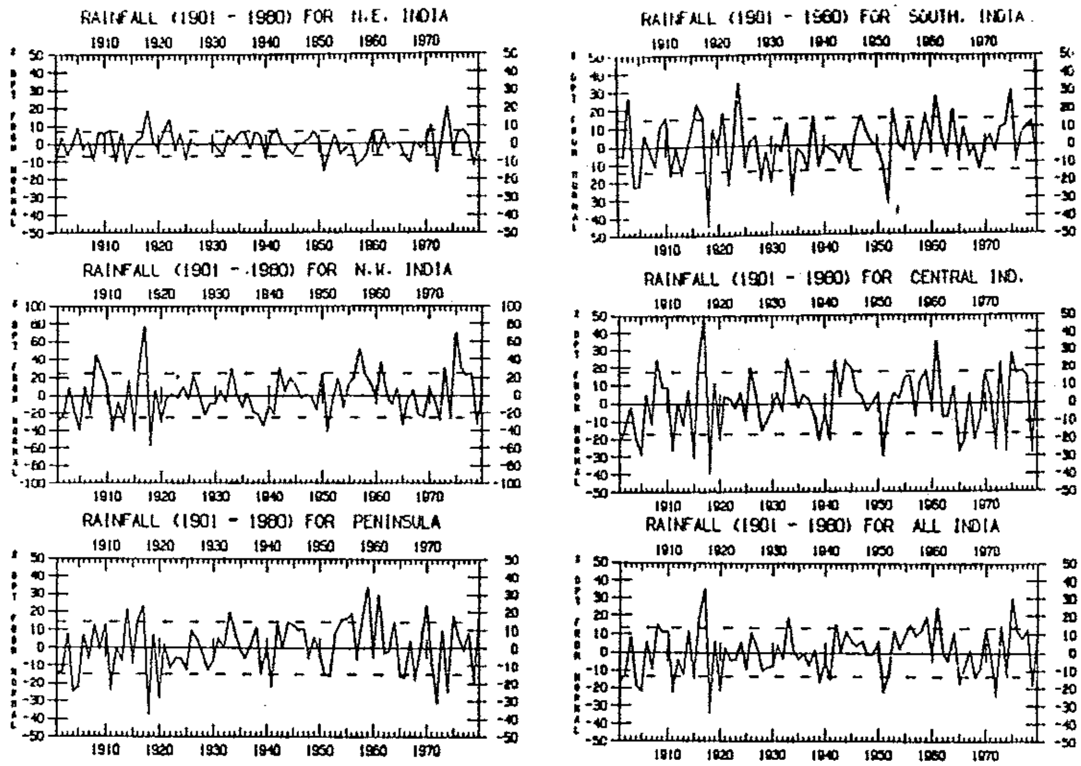


Fig. 3 Highest positive correlation (x 100) of total summer rainfall (1901 -1980) for each subdivision with all other subdivisions. Arrow points to subdivision where correlation is highest.


RAINFALL (1901 - 1980) FOR N.E. INDIA

RAINFALL (1901 - 1980) FOR SOUTH. INDIA

RAINFALL (1901 - 1980) FOR N.W. INDIA

RAINFALL (1901 - 1980) FOR CENTRAL IND.

RAINFALL (1901 - 1980) FOR PENINSULA

RAINFALL (1901 - 1980) FOR ALL INDIA

Fig. 4 Time series of areally averaged summer (JJAS) percentage departure rainfall (1901-1980) for five regions and for all 29 subdivisions combined. Dashed lines denote ± one standard deviation. Note different scale for Northwest India.

	JUNE-JULY	JULY-AUG.	AUG.-SEP.
NORTHEAST	-0.23	-0.16	-0.14
NORTHWEST	-0.01	0.31	0.17
PENINSULA	-0.16	0.05	0.27
SOUTHERN	-0.02	0.15	-0.11
ALL INDIA	-0.13	0.24	0.35

Table 2 Correlation of percentage departure rainfall of one month to the next, 1901-1975. 95%, 99%, and 99.9% significance levels correspond to ±.23, ±.30, and ±.40 respectively.

	EOF #1	EOF #2	EOF #3	EOF #4	EOF #5
DECEMBER	0.10	0.11	-0.10	0.15	0.24
JANUARY	0.01	-0.29	-0.01	0.02	0.05
FEBRUARY	0.10	-0.06	-0.01	0.11	0.07
MARCH	0.19	-0.08	0.08	0.06	0.27
APRIL	0.10	0.04	-.022	0.03	-0.10
MAY	0.07	-0.10	-0.00	0.14	0.04
JUNE	0.12	0.04	-0.26	0.11	-0.05
JULY	-0.27	0.18	0.26	0.02	0.06
AUGUST	-0.10	-0.19	-0.16	0.17	0.33
SEPTEMBER	0.34	0.02	0.16	-0.15	-0.18
OCTOBER	-0.10	-0.02	0.16	0.11	0.06
NOVEMBER	0.14	0.05	-0.13	-0.02	0.08

Table 3. Correlation of summer (JJAS) mean monsoon rainfall for the whole of India (1925-1977) with the coefficient time series of the first five EOFs of monthly mean SLP (Dec. 1924-Nov. 1977). 95%, 99% and 99.9% significance levels correspond to ±.27, ±.35, and ±.45, respectively.

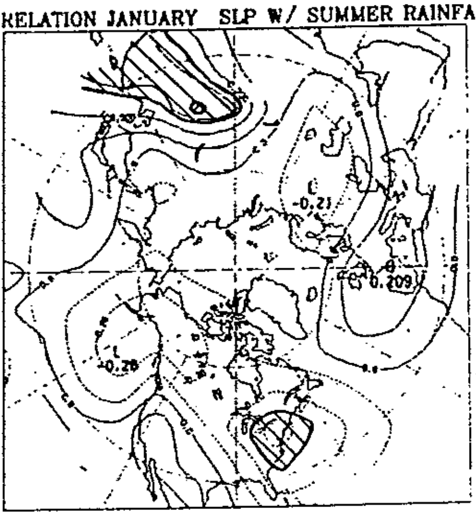

CORRELATION JANUARY SLP W/ SUMMER RAINFALL

Fig. 5a Correlation of January Northern Hemisphere SLP fields with total areally averaged percentage departure summer (JJAS) rainfall, 1925-1977. 95%, 99% and 99.9% significance levels correspond to ±.27, ±.35, ±.45, respectively. Hatched areas correspond to significance greater than 95%, cross hatched areas correspond to significance greater than 99%.

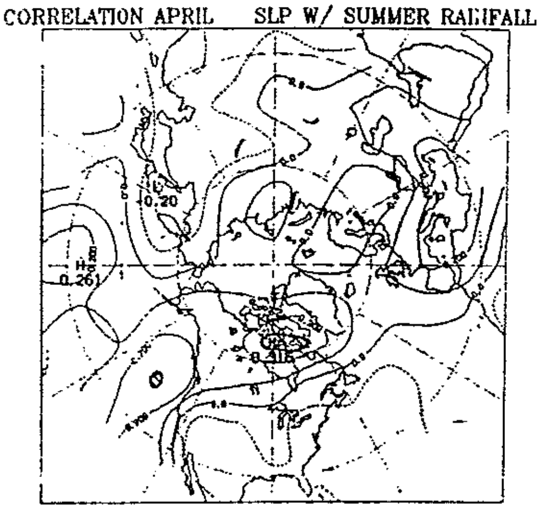

CORRELATION APRIL SLP W/ SUMMER RAINFALL

Fig. 5b Same as for figure 5a, but for April SLP.

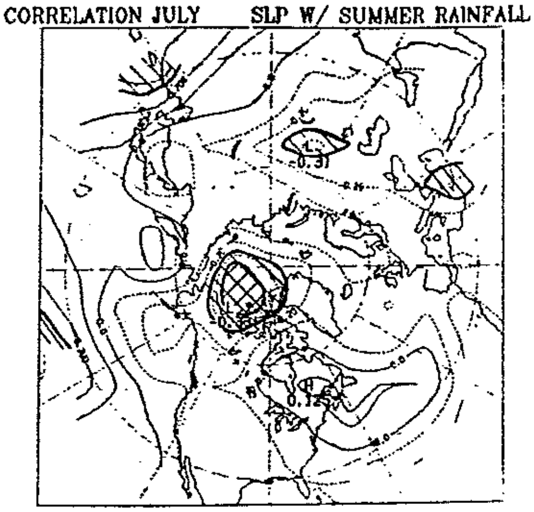

CORRELATION JULY SLP W/ SUMMER RAINFALL

Fig. 5c Same as for figure 5a, but for July SLP.

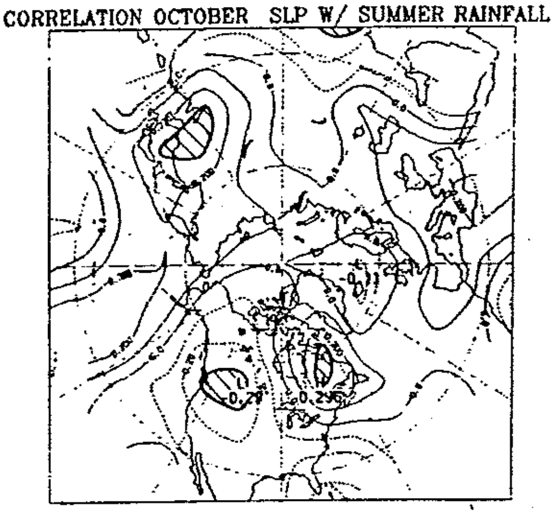

CORRELATION OCTOBER SLP W/ SUMMER RAINFALL

Fig. 5d Same as for figure 5a, but for October SLP.