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Role of Southern Hemispheric Equatorial Trough in Long Range Forecasting

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Abstract : *Satellite observed weekly mean cloud cover data for the premonsoon months of April and May over the Indian Ocean between 20S and 20N latitudes and 40 to 100E longitudes have been studied for the years 1972 to 1991 (except for the year 1978). Features of the southern hemispheric equatorial trough and their relationship with the performance of the southwest monsoon have been identified. An overall negative relationship between the activity of SHET during pre-monsoon months and the subsequent southwest monsoon activity has been observed. The features of the activity of SHET have been quantified by assigning an activity index ranging from 1 to 20. The activity index so assigned is highly correlated (CC ranging from -0.51 to -0.89) for those meteorological subdivisions of northwest and peninsular India where the rainfall variability is more. This relationship between the southern hemisperic equatorial trough activity index and the seasonal rainfall in each meteorological subdivision has been used to develop regression equations for seasonal forecasting of SW monsoon rainfall. The technique reported here appears promising in producing useful long range rainfall forecast for the SW monsoon season. In addition to this the results of this study are helpful in understanding the physical processes taking place over the Indian Ocean during the pre-monsoon months which also continue to appear during the period June to September leading to the development of Asian summer monsoon and its different phases.*

Introduction

Satellite observed cloudiness data from the Indian Ocean have been studied by several workers in an effort to improve our understanding of the development of southwest monsoon and its different phases. In this context, two results are important : (i) a slowly propagating south to north mode with a period of around 40 days (Sikka and Gadgil, 1980; Yasunari, 1981); a maximum cloud zone which develops near the equator moves to 30N at the rate of about 1 deg. lat. per day. However, the period of this mode has been found to vary, becoming as large as 60 days in the drought year of 1972 (Yasunari, 1980; De et al, 1988; Prasad et al. 1988 etc.). Prior to this an oscillation with a period of about 30 days in the wind field at 850 hPa level during SW monsoon had been reported by Dakshinamurti and Kesnavamurty (1976). (ii) recognition of southern hemispheric equatorial trough (SHET) as an important element of SW monsoon circulation (Prasad, 1981, 1982). Earlier the existence of an east west oriented double convergence zones in the equatorial Indian Ocean during the SW monsoon season over southeast Asia had been reported by several workers (Fletcher, 1945; Flohn, 1960 Koteswaram, 1960; Raman, 1965; Saha, 1971; Asnani, 1973 etc.). Recent investigations by

Prasad et al. (1983, 1988) and Johri and Prasad (1990) have further confirmed a dominating role of SHET in the development of SW monsoon and its different phases. Intense convection in the zone of SHET causes considerable reduction in the cross-equatorial flow of SE trades of southern hemisphere into north Indian Ocean leading to weak monsoon circulation over India. On the contrary, when SHET is close to equator and weak and allowing large cross-equatorial flow of SE trades in the north Indian Ocean, the SW monsoon is active. Encouraged from the results of these studies showing an intimate relationship between SHET and the activity of SW monsoon during the season, the authors conducted a pilot study to examine relationship, if any, between the activity of the SHET during the pre-monsoon months of April and May and the performance of the subsequent monsoon (Gupta and Prasad, 1991). An over all inverse relationship was observed between the activity of SHET during pre-monsoon months of April and May and the activity of SW monsoon. In the present study the results of the pilot study have been verified using cloud data for 12 more years. Section 2 deseribes the data used and the method of analysis The features of the activity of SHET during April and May, indicative of the performence of the SW monsoon have been identified and used in section 3 for quantifying the activity of SHET by assigning an activity index to its various features. The regression equations developed for the long range forecasting of seasonal rainfall in individual meteorological sub-division are reported in section 4. Section 5 describes the performance of the regression equations. Verification of the forecast technique is reported in section 6. The conclusions of the study are included in section 7.

Data used and method of analysis

NOAA published visible cloud imagey for the years 1972-1983 (except 1978) and INSAT 06 UTC visible imagery for the years 1984-1991 have been used to estimate the weekly mean cloud cover data. The reader is referred to a recent paper by Prasad et al. (1988) for the details of the method of analysis. An examination of the all India rainfall for the years under study (Table 1) reveals that the period witne-

Table 1 Departure of all India rainfall from its normal (100%) for the period 1965 to 1989

All India Rainfall Departure from Normal	Year (Departure)
− 21 % to −25 %	1972 (—25 %), 1979 (−21 %)
− 16 % to −20 %	1987 (−18 %), 1965 (—17 %), 1966 (−16 %)
− 11 % to —15 %	1974 (—15 %), 1982 (—14 %), 1986 (—13 %), 1968 (—11 %)
− 6 % to —10 %	1985 (−8 %)
0 % to + 5 %	1973 (+ 5 %), 1980 (+ 4 %), 1071 (+ 3 %), 1989 (+ 1 %), 1977 (+ 1 %), 1976 (0 %), 1981 (0 %), 1967 (0 %), 1984 (—4 %), 1969 (—3 %)
+ 6 % to + 10 %	1970 (+ 10 %), 1978 (+6 %)
+ 11 % to + 15 %	1983 (+ 15 %), 1975 (+ 12 %)
+ 16 % to + 20 %	1988 (+ 18 %)
+ 21 % to + 25 %	NIL

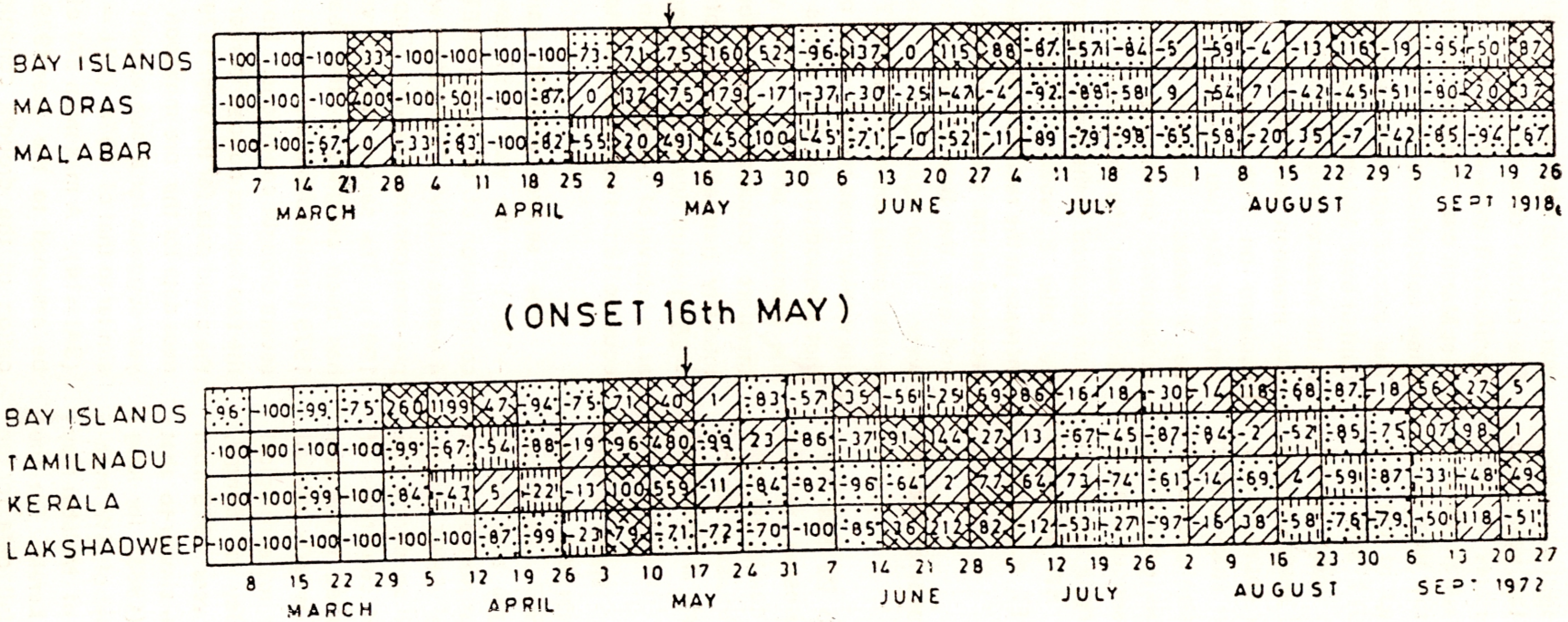
ssed large fluctuations of rainfall i.e., —25% in the year 1972 to +18% in the year 1988 with intermediate values of departures in other years. A comparision of the rainfall data for the present century shows that the two extremes of rainfall i.e —26% occurred in the year 1918 and +21% in the years 1917 and 1961. Thus the two extremes of all India rainfall fluctuations during the period of study compare very closely with that for the entire century. Thus, though the period under study is short (only 19 years) its rainfall variation is representative for the entire century. This is considered important so for as the representativeness of the period of study for developing a technique for long range forcasting of SW monsoon rainfall using the features of SHET during pre-monsoon months is concerned.

Southern hemispheric equatorial trough activity index (SAI)

An index ranging from 1 to 20 has been considered appropriate to represent various features of activity of SHET during the pre-monsoon months. The details of assigning the SAI values in individual years is described below.

During the period under study severe drought conditions prevailed over the country in the years 1972, 1979 and 1987. As discussed in the pilot study (Gupta and Prasad, 1991) a 7-8 week period was noticed in the year 1972 in the development of SHET during the pre-monsoon months as well as during the SW monsoon season. Drought conditions of similar intensity had also prevailed in the year 1918. We have examined the weekly rainfall data (Fig. 1) of southern most meteorological sub-divisions of India viz. Bay of Bengal, Madras and Malabar for the year 1918 from March to September in a manner similar to that used by Joseph and Pillai (1988) for long range forecasting of date of onset of SW monsoon over Kerala. The region of Malabar may be considered to represent Kerala. For the sake of comparision the rainfall data for the year 1972 has also been entered in the diagram. The rainfall data for the year 1918 shows a significicant increase in the week ending on 21st March over Malabar region and in all the three subdivisions in the subsequent week. The second significant increase in the weekly rainfall over Malabar subdivision was recorded in the week ending on 9th May. The onset of SW monsoon over Malabar was subsequently declared on 11th May. Thus the period between the two rainfall peaks comes out to be 7 weeks. Similarly after the onset the subsequent significant increase in weekly rainfall over the subdivisions under consideration occurred in the week ending on 4th July i.e. after 8 weeks. The fourth significant increase in the rainfall over Malabar region was recorded in the week ending on 22nd August and over the Bay Islands in the subsequent week. Here again the interval between the rainfall peaks comes out to be 7 weeks. Thus the weekly mean rainfall data of 1918 suggest that a periodicity of 7-8 weeks was present in the monsoon activlty in that year. We may therefore conclude that droughts of this intensity (rainfall departure of the order of −25%) result due to the development of SHET at an interval of 7-8 weeks. An activity index equal to 18 has been assigned to this feature.

The severe drought (rainfall departure —18%) in the year 1987 developed due to continuation of an active SHET for a period of 4 weeks in July. This feature was seen in the pre-monsoon months also (Gupta and Prasad, 1991). The second highest value (SAI=17) has been assigned to this feature. The year 1979 (rainfall departure —21%) also witnessed severe drought conditions. However, none of the two features noticed earlier were present in the cloud data for the year 1979. The cloudiness data for the pre-monsoon months for that year suggests for a subsequent poor monsoon similar to that of 1974 (SAI = 15) and 1982 (SAI=14). A maximum SAI of 14 could only be assigned to the year 1979. The intensification of the drought conditions in that year



	7	14	21	28	4	11	18	25	2	9	16	23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	5	12	19	26
BAY ISLANDS	-100	-100	-100	33	-100	-100	-100	-100	-73	71	75	160	52	-96	137	0	115	88	-67	-57	-84	-5	-59	-4	-13	116	-19	-95	-50	87
MADRAS	-100	-100	-100	200	-100	-50	-100	-87	0	137	75	179	-17	-37	-30	-25	-47	-4	-92	-88	-58	9	-54	71	-42	-45	-51	-80	20	37
MALABAR	-100	-100	-67	0	-33	-83	-100	-82	-55	20	49	45	100	-45	-71	-10	-52	-11	-89	-79	-98	-65	-58	-20	35	-7	-42	-85	-94	-67
	MARCH				APRIL				MAY					JUNE				JULY				AUGUST					SEPT 1918			

(ONSET 16th MAY)

	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30	6	13	20	27
BAY ISLANDS	-96	-100	-99	-75	260	1199	47	-94	-75	71	40	1	-83	-57	35	-56	-25	69	86	-16	18	-30	-14	118	-68	-87	-18	56	27	5
TAMILNADU	-100	-100	-100	-100	-99	-67	-54	-88	-19	96	480	-99	23	-86	-37	91	44	27	13	-67	-45	-87	-84	-2	-52	-85	-75	107	98	1
KERALA	-100	-100	-99	-100	-84	-43	5	-22	-13	100	559	-11	-84	-82	-96	-64	2	77	64	73	-74	-61	-14	-69	4	-59	-87	-33	-48	49
LAKSHADWEEP	-100	-100	-100	-100	-100	-100	-87	-99	-23	79	-71	-72	-70	-100	-85	36	212	82	-12	-53	-27	-97	-16	38	-58	-76	-79	-50	118	-51
	MARCH				APRIL				MAY					JUNE				JULY				AUGUST					SEPT 1972			

FIG 1 PERCENTAGE DEPARTURES OF WEEKLY RAINFALL

LEGEND
- ▩ Excess 20% or more
- ▨ Normal 19% to -19%
- ▥ Deficient -20% to -59%
- ░ Scanty -60% to -99%
- □ No Rain -100%

was due to the intensification of SHET in the second half of August which caused an early withdrawal of SW monsoon from NW India and certain parts of central India (Prasad et al. 1988). An activity index of 16 has been assigned to the drought year 1986.

It has been possible to include here the detailed discussion on the features of the activity of SHET related to excess or close to normal rainfall. Instead, these features have been briefly summarised in table 2. Table 2 also contains the SAI values related to various features of SHET activity during April and May. It is an observed fact that SW monsoon shows large variability from year to year and two monsoons cannot be treated identical though they may have many similarities. This is also seen in the feature of the activity of SHET during the pre-monsoon months. Neverthless, it is hoped, at this stage, that the SAI value assigned using the table 2 may be accurate within ± 2 SAI number. It is likely that the table 2 may get modified, to some extent, in future when more cloud data become available.

Table 2 SAI and related features of equatorial cloudiness

SAI No,	Features of equatorial cloudiness as seen in time - latitude cross-section of weekly mean cloud data during April and May
1	SHET completely absent during April. Northern hemispheric equatorial trough (NHET) active in all the weeks of April and May. In April NHET lies between equator and 5N, In May it shows movement north-wards and May reach upto 20N. Development of SHET may be seen for a week or two in May while there is no weakening of NHET.
2	SHET completely absent during April. NHET active between equator and 5N. SHET mau appear for a week or two in the first half of May. SHET, which may show slight weakeing, is also present and shows progressive northward movement and reaches 15 20N by the end of May.
3	Appearance of a prominent cross-equatorial cloud band in April which may extend in the first or second week of May.
4	Appearance of a cross-equatorial cloud band in the first half of April which is followed by the appearance of NHET and its progressive movement towards north reaching 15N by the end of May. SHET is generally undeveloped during both the pre-monsoon months.
5	Similar cloud features as described for SAI=4. But in addition to this there is occasional development of SHET not lasting for more than a week.
6	Appearance of a prominent cross-equatorial cloud band during the last three weeks of April. Appearance of yet another such band but predominantly to the north of 5S by the end of May. The other feature for this SAI number is the appearance of SHET at an interval of 4 weeks.
7	Appearance of a cross-equatorial cloud band extending upto 10N in the first week of April which is followed by the appearance of yet another cloud band across the equator but mainly to the north equator and reaches upto 15N by the end of May.

8 Appearance of SHET in the first or second week of April which weakens and NHET develops subsequently between equator and 5N. SHET again develops and an interval of 5 to 6 weeks, weakens in the subsequent week and NHET develops between equator and 5N. Thereafter NHET shows progressive movement towards north reaching 15N by the end of May.

9 SHET develops during the first half of April. This is followed by the appearance of a cross-equatorial cloud band in May which reaches upto 10N only by the end of May,

10 Appearance of a very weak cross equatorial band in the first half of April between 10S and 5N, This is followed by the appearance of another cross-equatorial cloud band by the end of April or in the beginning of May. This band is also confined to the latitude bands between 10S and 10N. Thereafter the SHET is not seen upto the end of May. A weak NHET develops by the end of May.

11 Cloud features similar to those described above for SAI=10. In addition SHET develops for a week or two in May.

12 Absence of SHET or cross-equatorial cloud band in the first half of April which is followed by the development of a cross-equatorial cloud band in the second half of April. This is followed by the development of SHET in May which lasts for a week or two. SHET weakens by the end of May.

13 Appearance of an active SHET in the second half of April which is followed by the appearance of cross equatorial cloud band beginning from the second half of May. This band is seen upto the end of May being confined to the latitude belts of 5S and 15N. The other feature being associated with the SAI number is the appearance of a weak cross-equatorial cloud band in the first half of April and another weak band in the second half of May. This band is mainly confined to the latitude belts of 5S and 15N.

14 Cloud features very similar to those described for SAI=13. The only difference being that the cloud band which develops in May is mainly confined to the latitude belts 10S to 10N.

15 Appearance of a prominent cloud band across the equator in the first half of April reaching upto 10N. This is followed by the development of another prominent cloud band predominantly to the north of equator reaching upto 15N in May. In addition to these features which are indicative of a much lower SAI number, SHET develops in between period of these two bands in a more southerly latitude, i.e. between 10 and 20S for three consecutive weeks. Yet another equatorial cloud feature which could be assigned this SAI number is the development of a week cloud band in the first half of April which is mainly confined to the south of equator. Thereafter both SHET and NHET develop simultaneously. NHET shows slow or no movement towards north.

16 Absence of SHET, NHET or a cloud band across the equator during the first three weeks of April. Thereafter a cloud band develops lasting for 2 to 3 weeks and it is mainly confined to the latitude belts between 10S and 5N. SHET weakens and NHET develops thereafter which reaches upto 10N by the end of May.

17	In general, the SHET remains active during April and May with occasional appearance of NHET in some of the weeks which does not last for more than a week.
18	In general, the SHET remains active during April and May in a more southerly latitude, i.e. between 5S and 15S. Normally SHET develops between equator and 10S. The other cloud feature for this SAI number is the appearance of an active SHET for three consecutive weeks in May.
19	Complete absence of NHET or a cross-equatorial cloud band during April and May and presence of an active SHET throughout this period.
20	Appearance of a period of 7-8 weeks in the development of SHET.

Correlation between the SAI and the seasonal rainfall in different meteorological subdivisions

The correlation coefficients (CCs) were worked out between the originally assigned values of SAI (SET 1 values of SAI in table 3) and the seasonal rainfall in each meteorological subdivision. In order to find the best fit (straight line) between the SAI values and all India seasonal rainfall 5 sets of SAI values (table 3) were used. The set 2 values SAI gave the best fit (table 4). Set 2 was followed by set 1. This was also the case with sub-divisional seasonal rainfall. Also the CCs for set 1 values of SAI are very close to the CCs for set 2 values of SAI (Fig. 2) and therefore not reproduced here. It may be noted that the CCs are significant at 95% level ($| CC | \geqslant .49$) for almost all the subdivisions of peninsular and NW India where the rainfall variability is more. CCs are small for the subdivisions of northeast India including the subdivisions of Orissa, Bihar plateau and Bihar plains. Except for Bihar plains the CCs are negative in all other sub-divisions. The CC is also high for the Bay Islands and not very low of Lakshadweep. The values of the CCs suggest a very intimate relationship between SAI and the rainfall during SW monsoon season. The values of CCs picturise the well known characteristic of the SW monsoon rainfall distribution that the coefficient of variation is high over peninsular and NW india, the two regions for which a useful long range rainfall forecast is most needed during the SW monsoon season.

Regression equations for different met. subsubdivisions

As mentioned above, 5 sets of SAI values were used for finding the best fit between the SAI valus and the seasonal rainfall in each subdivision. The constants of regression equations for various subdivisions for set 2 values of SAI (table 3) are given in table 5. Table 6 summarises the results of the perfomance of the regression equations for the set 2 values of SAI. For this purpose we have grouped the the departures of observed and computed rainfall in 5 groups. A number of 21 sub-divisions (i.e. 60% of the total number of meteorological sub-divisions (35) falling in the range of departure + 15% is considered here as a limit for a useful forecast. The departures were within ± 15% in 21 or more sub-divisions in 13 years out of 16 years including the year 1979 which stands out as an exception.

An examination of the percentage departure of rainfall from the computed one for each sub-division in different years shows that the performance of the regression equations is much better than that reflected in Table 6 if we exclude the very heavy rainfalls in some meteorological sub-divisions which were in excess of the maximum to be obtained from these equations. For example, in the year 1975,

Table 3 Different sets of SAI values

Year	Set 1	Set 2	Set 3	Set 4	Set 5
1972	18	20	20	20	20
1973	6	6	5	5	4
1974	15	15	14	14	14
1975	4	4	4	4	4
1976	10	10	13	14	15
1977	9	9	10	10	10
1979	14	14	15	15	15
1980	6	7	5	4	6
1982	14	14	14	14	14
1983	3	3	5	5	5
1984	13	13	14	14	14
1985	14	15	15	16	16
1986	16	16	17	17	17
1987	17	18	20	18	19
1988	2	1	2	2	1
1989	8	8	6	5	8

Table 4 Recorded all India seasonal rainfall (%), computed rainfall (%) and its departure from recorded rainfall for different sets of SAI values

Year	Recorded rainfall	Computed rainfall and departures Set 1	Set 2	Set 3	Set 4	Set 5
1972	75	791 (−4)	76 (−1)	78 (−3)	78 (−3)	79 (−4)
1973	105	107 (−2)	107 (−2)	109 (−4)	108 (−3)	111 (−6)
1974	85	86 (−1)	86 (−1)	88 (−3)	88 (−3)	88 (−3)
1975	112	111 (1)	112 (0)	111 (1)	110 (2)	111 (1)
1976	100	89 (11)	98 (2)	92 (8)	90 (10)	89 (11)
1977	101	99 (2)	100 (1)	99 (2)	98 (3)	99 (2)
1979	79	89 (−10)	89 (−10)	88 (−9)	88 (−10)	89 (−10)
1980	104	107 (−3)	105 (−1)	109 (−5)	110 (−6)	107 (−3)
1982	86	91 (−5)	89 (−3)	90 (−4)	90 (−4)	91 (−5)
1983	115	109 (6)	114 (1)	109 (6)	108 (7)	109 (6)
1984	96	91 (5)	91 (5)	90 (6)	90 (6)	91 (5)
1985	92	87 (5)	87 (5)	88 (4)	86 (6)	87 (5)
1986	87	85 (2)	85 (2)	84 (3)	84 (3)	85 (2)
1987	82	81 (1)	80 (2)	78 (4)	82 (0)	81 (1)
1988	118	117 (1)	118 (0)	115 (3)	114 (4)	117 (1)
1989	101	103 (−2)	103 (−2)	107 (−6)	108 (−7)	103 (−2)
CC between SAI and rainfall		−0.96	−0.96	−0.92	−0.90	−0.91
Constants of regression equation	a=	−2.4	−2.3	−2.0	−2.0	−2.0
	b=	121.7	120.5	119.1	118.2	119.1

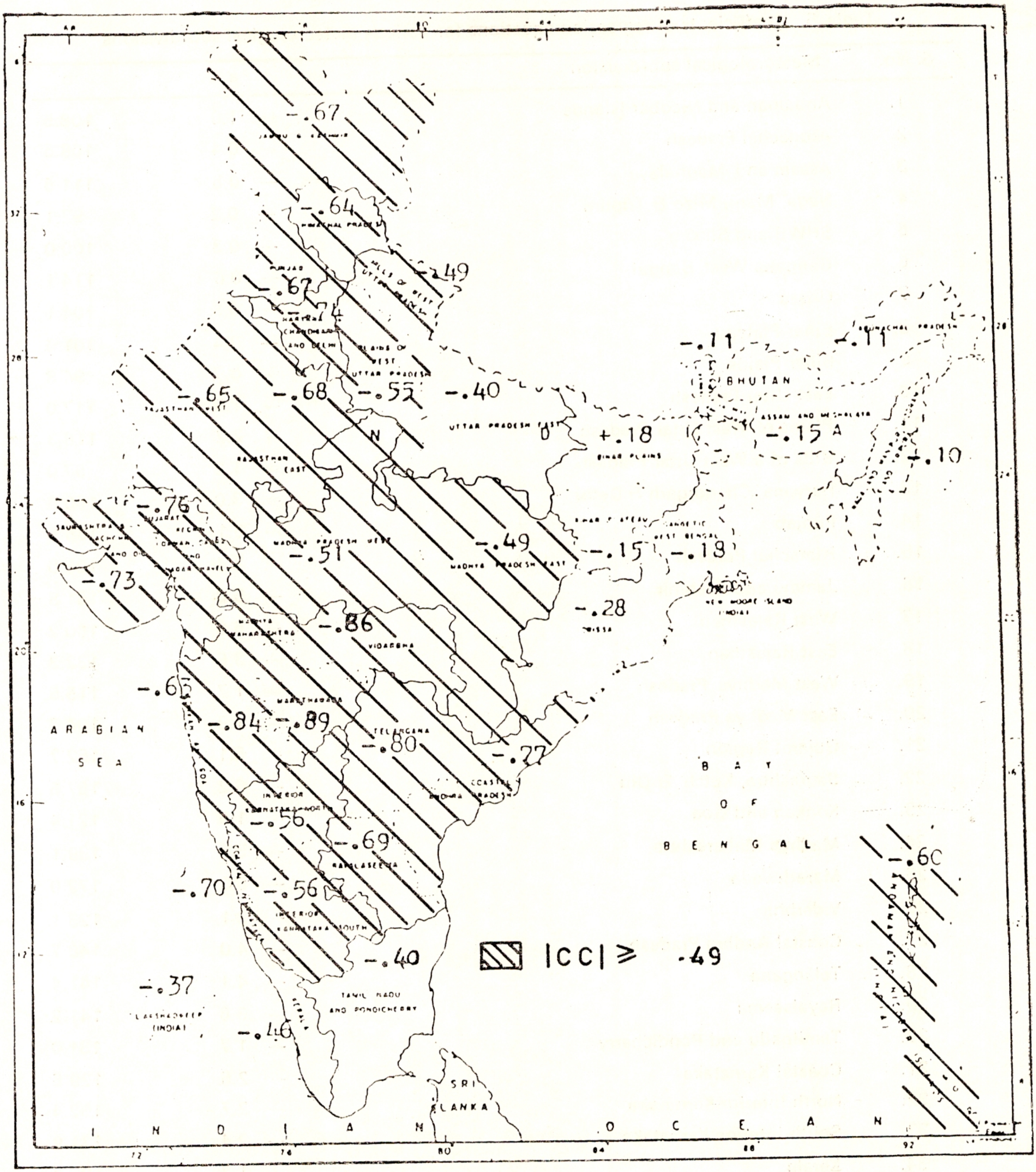


Fig. 2 Correlation coefficients between SAI and seasonal rainfall during SW monsoon in different meteorological sub-divisions.

Table 5 Coefficients of regression equations for various meteorological sub-divisions

S. No.	Meteorological sub-division	a	b
1.	Andaman and Nicobar Islands	— 1.6	108.5
2.	Arunachal Pradesh	— 0.4	108.5
3.	Assam and Meghalaya	— 0.5	111.5
4.	Naga, Mani, Mizo & Tripura	— 0.2	92.1
5.	SHWB and Sikkim	— 0.3	100.0
6.	Gangetic West Bengal	— 0.6	114.1
7.	Orissa	— 0.8	104.1
8.	Bihar Plateau	— 0.4	101.6
9.	Bihar Plains	+ 0.7	94.8
10.	East Uttar Pradesh	— 1.9	117.0
11.	Plains of West Uttar Pradesh	— 2.2	118.3
12.	Hills of a West Uttar Pradesh	— 1.2	97.0
13.	Haryana, Chandigarh & Delhi	— 3.0	160.6
14.	Punjab	— 5.1	165.6
15.	Himachal Pradesh	— 2.4	108.0
16.	Jammu and Kashmir	— 5.0	161.8
17.	West Rajasthan	— 5.6	160.2
18.	East Rajasthan	— 3.6	132.3
19.	West Madhya Pradesh	— 1.7	115.5
20.	East Madhya Pradesh	— 1.3	104.7
21.	Gujarat Region	— 5.1	152.7
22.	Saurashtra, Kutch & Diu	— 6.2	157.6
23.	Konkan and Goa	— 1.9	121.4
24.	Madhya Maharashtra	— 3.6	139.1
25.	Marathwada	— 6.3	172.0
26.	Vidarbha	— 3.1	123.1
27.	Coastal Andhra Pradesh	— 4.0	140.7
28.	Telangana	— 4.1	141.4
29.	Rayalseema	— 3.6	141.2
30.	Tamilnadu and Pondicherry	— 1.7	131.0
31.	Coastal Karnataka	— 2.5	129.5
32.	North Interior Karnataka	— 2.7	132.4
33.	South Interior Karnataka	— 2.4	131.9
34.	Kerala	— 1.3	105.3
35.	Lakshadweep	— 1.2	115.1

Table 6 Percentage departure of computed rainfall from observed rainfall for SAI value of Set 2

Year	No. of meteorological sub-divisions with observed rainfall - computed rainfall lying				
	within ±10% (a)	±11 to ±15% (b)	within ±15% (c)	±16 to ±20% (d)	>+20% or <−20% (e)
1972	18	8	26	2	7
1973	20	7	27	1	3
1974	17	5	22	3	10
1975	18	5	23	5	7
1976	14	7	21	3	11
1977	20	5	25	2	8
1979	7	8	15	6	14
1980	14	6	20	5	10
1982	22	4	26	3	6
1983	18	6	24	2	9
1984	18	4	22	5	8
1985	18	3	21	7	7
1986	19	8	27	5	3
1987	13	4	17	8	10
1988	16	5	21	4	10
1989	17	6	23	1	11

Jammu and Kashmir, West Rajasthan, Coastal Karnataka and Lakshadeep reported 228%, 215%, 159% and 137% of rainfall respectively. The rainfall for 1975 for these sub-divisions from the regression equations comes out to be 142%, 138%, 119% and 110% respectively. In the year 1979, the departures are less than —15% in 9 sub-divisions, namely, Bihar Plateau Bihar Plains, East U.P., Plains of west U.P., Hills of west U.P., Haryana, Punjab, Himachal Pradesh, Jammu and Kashmir, west and east M.P., from where the SW monsoon withdraw early. In most of the other sub-divisions the departures are within ± 15%. It follows from column (e) of table 6 that on an average the departures are less than —20% or more than 20% in about 8 sub-divisions, if we do not consider the exception year 1979. The column (a) of the table shows that on an average the departures are within ± 10% in as many as 62% of the sub-divisions.

6. Verification of the forecast technique

Satellite observed cloudiness data for the period 1965-1971 have not been included in the study for the development of the technique reported here. The technique could be verified on this data if the same could be available. The data is not presently available to the authors. The cloud data for the year 1981, which was not available at the time of the development of the technique, forms yet another set of data used hero for the verification purposes. A value of SAI=7 has been used for computing rainfall for both the years i.e. 1990 and 1981. For the SW monsoon-1990 experimental forecast was prepared with SAI=7. However. when the cloud data for the year 1981 became available, it was found that instead of 7 appropriate SAI value for 1990 could be 6. However, since the assigned value of SAI for 1990 for preparing the experimental forecast was within the error limit (± 2 SAI Number), the computations have been reproduced for SAI=7 only. In the following section we describe the cloud features in the premonsoon months , the SAI value which could be assigned to the cloud features, the computed rainfall both for the all India as well as in each meteorological sub-division and its comparison with the actual rainfall.

(i) SW monsoon-1990

The WMCC data for April and May 1990 shows that a maximum cloud zone (MCZ) developed between 10S and 5N in the first week of April. This MCZ moved to the Bay of Bengal where a vortex developed in the third week of April, Once again a MCZ developed between 5S and 15S in the fourth week of April. This MCZ also showed northward movement and reached the latitude belt 15-20N where a vortex developed in the week ending on 12th May. Like the previous MCZ, this MCZ also took three weeks to reach the northern most latitude belt (15-20N). In this week itself yet another MCZ developed between equator and 10S. This MCZ moved northward in the Arabian Sea in the subsequent week causing a vortex to develop there. A MCZ once again appeared close to equator, between equator and 5S in the last two weeks of May. The last two weeks of May also witnessed the development of an active NHET with embedded vortex in east Arabian Sea and Bay of Bengal. The time latitude cross-section of WMCC data is shown in Fig. 3. A period of three weeks is present in the development of SHET which showed quick movement northward. Strong cross-equatorial flow, one of the feature associated with good monsoon, existed in April and from the beginning of the first week of May which continued till the end of May.

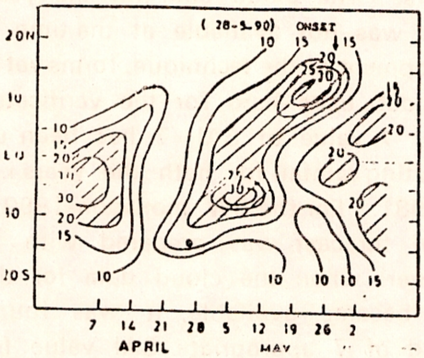


Fig. 3 Time-latitude cross-section of weekly mean cloud cover for April and May 1990

The WMCC data for the premonsoon months of April and May 1990 suggest a lower value of SAI for this year as compared to the year 1989 (SAI=8). Accordingly a value of 7 was assigned to the features of SHET for the year 1990. The computed and reported rainfall for various meteorological sub-divisions is shown in table 7. It follows from table 7 that the computed rainfall was within ± 15% of the reported value in as many as 20 subdivisions. The reported all India rainfall was 106% as against computed being 104 ± 4%.

(ii) SW monsoon-1991

The time-latitude cross section of WMCC data for the year 1981 is shown in Fig. 4. An E-W oriented cloud band is seen covering the areas between 10S to 10N during the first three weeks of April. Thereafter NHET is seen to be active till the week ending on 2 June 1981. However, during the weeks ending on 5 May, 19 May and 2 June a NW-SE oriented cloud band is seen south of equator.

Fig.3 : Time-latitude cross-section of weekl mean cloud cover for April and May 1990.

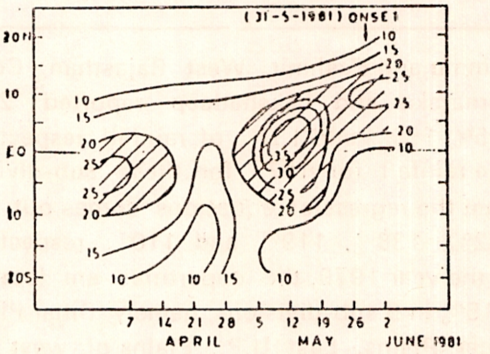


Fig. 4 Same as fig.3 but for the year 1981.

Fig. 4 Same as fig. 3 but for the year 1981

The signals for drought as well as excess rainfall were absent in WMCC data for this year.

Tahle 7 Reported and computed rainfall % of normal and their departure range for the years 1981, 1990 and 1991

Meteorological sub-division	1981		1990		1991	
	R	C	R	C	R	C
Andaman & Nicobar Islds.	99 N	97 N	74 D	97 N	109 N	86 N
Arunachal Pradesh	118 N	106 N	122 E	106 N	94 N	103 N
Assam & Meghalaya	98 N	108 N	103 N	108 N	105 N	105 N
Naga.. Mani., Mizo. & Tripura	72 D	91 N	103 N	91 N	93 N	89 N
SHWB & Sikkim	92 N	98 N	105 N	98 N	118 N	96 N
Gangetic West Bengal	126 E	110 N	107 N	110 N	99 N	106 N
Orissa	93 N	99 N	91 N	99 N	100 N	96 N
Bihar Plateau	95 N	99 N	123 E	99 N	100 N	96 N
Bihar Plains	97 N	100 N	105 N	100 N	87 N	105 N
East U.P.	113 N	104 N	107 N	104 N	94 N	90 N
Plains of West U.P.	85 N	103 N	108 N	103 N	89 N	97 N
Hills of West U.P.	78 D	89 N	102 N	80 N	61 D	80 D
Har., Chandi. & Delhi	109 N	126 E	118 N	126 E	75 D	99 N
Punjab	81 N	130 E	140 E	130 E	81 N	94 N
Himachal Pradesh	72 D	91 N	107 N	91 N	68 D	74 D
Jammu & Kashmir	97 N	127 E	104 N	127 E	60 D	92 N
West Rajasthan	68 D	121 E	163 E	121 E	62 D	82 N
East Rajesthan	92 N	107 N	98 N	107 N	68 D	82 N
West M.P.	86 N	104 N	122 E	104 N	86 N	92 N
East M.P.	87 N	96 N	110 N	96 N	85 N	87 N
Gujarat Region	104 N	117 N	123 E	117 N	88 N	81 N
Sauras , Kutch and Diu	101 N	114 N	99 N	114 N	64 D	71 D
Konkan & Goa	115 N	108 N	104 N	108 N	98 N	95 N
Madhya Maharashtra	124 E	114 N	104 N	114 N	113 N	89 N
Marathwada	106 N	128 E	115 N	128 E	77 D	84 N
Vidarbha	114 N	101 N	127 E	101 N	81 N	80 D
Coastal A.P.	110 N	113 N	90 N	113N	117 N	85 N
Telangana	118 N	112 N	113 N	112N	90 N	84 N
Rayalseema	122 E	116 N	87 N	116N	114 N	91 N
Tamil Nadu & Pondi.	141 E	119 N	84 N	119N	113 N	107 N
Coastal Karnataka	112 N	112 N	106 N	112N	110 N	95 N
North Int. Karnataka	146 E	114 N	97 N	114N	110 N	95 N
South Int. Karnataka	116 N	115 N	97 N	115N	114 N	98 N
Kerala	124 E	96 N	75 D	96N	115 N	87 N
Lakshadweep	113 N	107 N	77 D	107N	122 E	98 N

Further the cloud features are very similar to those observed in the year 1980, Accordingly a value of 7 is assigned to SAI for the SW monsoon of the year 1981 with a possible error of 2SAI number. The computed rainfall for various meteorological sub-divisions is shown in table 7. A comparision with the reported rainfall shows that the reported rainfall was within ± 15% of the forecasted value in as many as 22 sub-divisions. Except for the sub-divisions of Punjab, Jammu and Kashmir and West Rajasthan where the departures are large, else-where the forecast is reasonably good. This is particularly true for peninsular India including Gujarat region, Saurastra, Kutch and Diu, and NE India. The reported all India rainfall was 100% as against computed being 104 ± 4%.

(iii) SW moonsoon–1991

In contrast to the years 1990 and 1981, the SHET activity during pre-monsoon of May 1991 showed features relating to below normal rainfall (Fig. 5). However, the features of severe drought were not seen, A value of 14 was assigned to SAI. The experimental forecast prepared using SAI = 14 is reproduced in table 7. It follows from the table that computed rainfall was within ± 15% of the reported value in as many as 22 (63%) sub-divisions and within ± 10% in as many as 17 (49%) sub-divisions. The reported all India rainfall was 91% as against computed being 88 ± 4%.

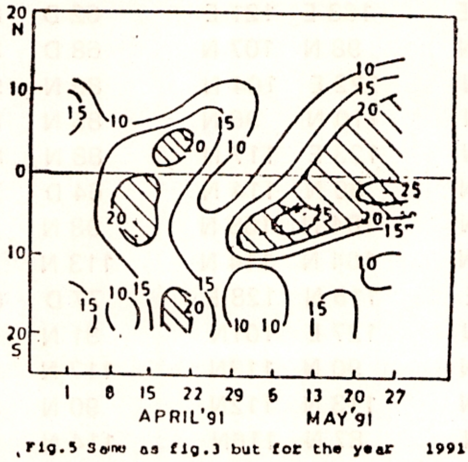


Fig. 5 Same as fig. 3 but for the year 1991

It may be concluded from the verifications for the three years reported above that the computed rainfall in individual sub-divisions was within ± 15% in as many as 60% of the sub-divisions which include the sub-divisions of drought prone areas of NW and Peninsular India.

10. Conclusions

(1) Absence of SHET and development of an active northern hemispheric equatorial trough (NHET) in pre-monsoon months appears to be a signal for an excess rainfall during the SW monsoon season. The other signal for excess rainfall is the development of a prominant cloud band across the equator in the beginning of April and thereafter again after an interval of about 4-5 weeks.

(2) A period of 7-8 week in the development of SHET or persistence of SHET for 3-4 weeks in continuation in the pre-monsoon months appears to be a signal for severe drought condition in that year.

(3) Absence of a band across the equator in the month of April is generally followed by poor performance of monsoon.

(4) A prominant band across the equator in the month of April, if followed by the continuation or SHET for 3-4 weeks appears to be a signal for likely failure of the monsoon in that year.

(6) Absence of SHET in the pre-monsoon months or its presence not lasting for more than a week is a signal for normal or close to normal southwest monsoon rainfall.

(6) Drought conditions may get aggravated due to intensification of the SHET during the season itself as as was the case in the year 1979.

(7) The technique reported in this paper is able to produce useful long range rainfall forecast for the SW monsoon season.

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