J. Ind. Geophys. Union (October 2010)
Vol.14, No.4, pp.233-248

South Indian Convergence Zone Model: A new approach to seasonal forecasting of summer monsoon rainfall in India Part I: South Indian Convergence Zone and its role in the development of Indian summer monsoon

Onkari Prasad, O.P. Singh[1] and Sant Prasad[2]
43, Ritu Apartments, A-4 Paschim Vihar, New Delhi -110 063
[1]India Meteorological Department, Lodi Road, New Delhi -110 003
[2]32, Pragati Apartments, Paschim Vihar, New Delhi-110 063
Email:onkaripraad06@yahoo.com; op_singh54@yahoo.com; sant.prasad@gmail.com

ABSTRACT
Relationship between Indian Summer Monsoon Rainfall (ISMR) and South Indian Convergence Zone (SICZ) has been studied using rainfall and cloud data for a period of 29 years (1979,1982-2009).That the SICZ forms an important element of Southwest Monsoon (SWM) circulation system, plays a crucial role in its development and its intra-seasonal changes ('active'/ 'break' cycle) have been confirmed. The intensity of SICZ is inversely related to the intensity of SWM, in general: When SICZ is weak and close to equator allowing large Cross Equatorial Flow (CEF) of southeast trades into the North Indian Ocean (NIO) SWM is active and vice versa. This inverse relationship also exists between the activity of SICZ during the period January-May. It is shown that the features of SICZ, as seen in the patterns of clouds developing in the near equatorial regions of Indian Ocean (IO) during the period January-May, contain signals about likely performance of summer monsoon over India. A method of quantifying the activity of SICZ and detecting the signals, as precursor to the performance of SWM over the Indian subcontinent, are discussed.

INTRODUCTION

ISMR refers to total rainfall during the period 1 June to 30 September for India as a whole. Based on the average rainfall during the period 1941-1990, ISMR is 89 cm. Though it accounts for about 80% of the annual rainfall for India as a whole and as much as 90% in some of the states, ISMR exhibits large inter-annual variability (Fig.1). This variation has made socio-economic impacts. The need for a reliable forecast of drought and excess rainfall, not only for country as a whole, but for each meteorological sub-division (numbering 36) has been felt for long. Seasonal forecasting of summer monsoon rainfall has, therefore, remained one of the important aspects of weather forecasting in India. Though seasonal forecast of ISMR is being issued since 1886 (Blandford 1884), predicting drought and excess rainfall seasons has remained a challenge till date. None of the statistical or dynamical models could predict the recent droughts of 2002, 2004 and 2009. Recently, Gadgil, Rajeevan & Francis (2007) have discussed the limitations of operational models in forecasting extremes of summer monsoon rainfall. They have noted that reliable seasonal forecast of summer monsoon rainfall, particularly of its extremes, i.e., 'Flood' and 'Drought' is still elusive.

In the context of the above mentioned scenario of seasonal forecasting of ISMR, a model proposed by Gupta & Prasad (1992,1993) (hereafter referred to as SICZ Model) should be considered as an important development. The model has since produced reasonably good forecasts for ISMR for the past 20 years (1990-2009) (Fig.2).The results of verification of forecasts for the years 1990-1992 and 1990-1998 are found to be reliable and satisfactory as reported by Prasad (1993, 2000, 2001).

The model uses only one data, i.e., satellite observed cloud data from IO region to find the features in the development of SICZ. SICZ had not been recognized as an element of summer monsoon circulation system till 1981 (Saha 1971; Krishnamurty & Bhalme,1976; Prasad, Mishra & Jain 1978; Sikka & Gadgil,1980; Yasunari 1980, 1981) when Prasad (1981,1982) reported its important role in the development of Indian summer monsoon and its different phases. This was followed by Prasad, Mishra & Jain (1983), Prasad et al.,

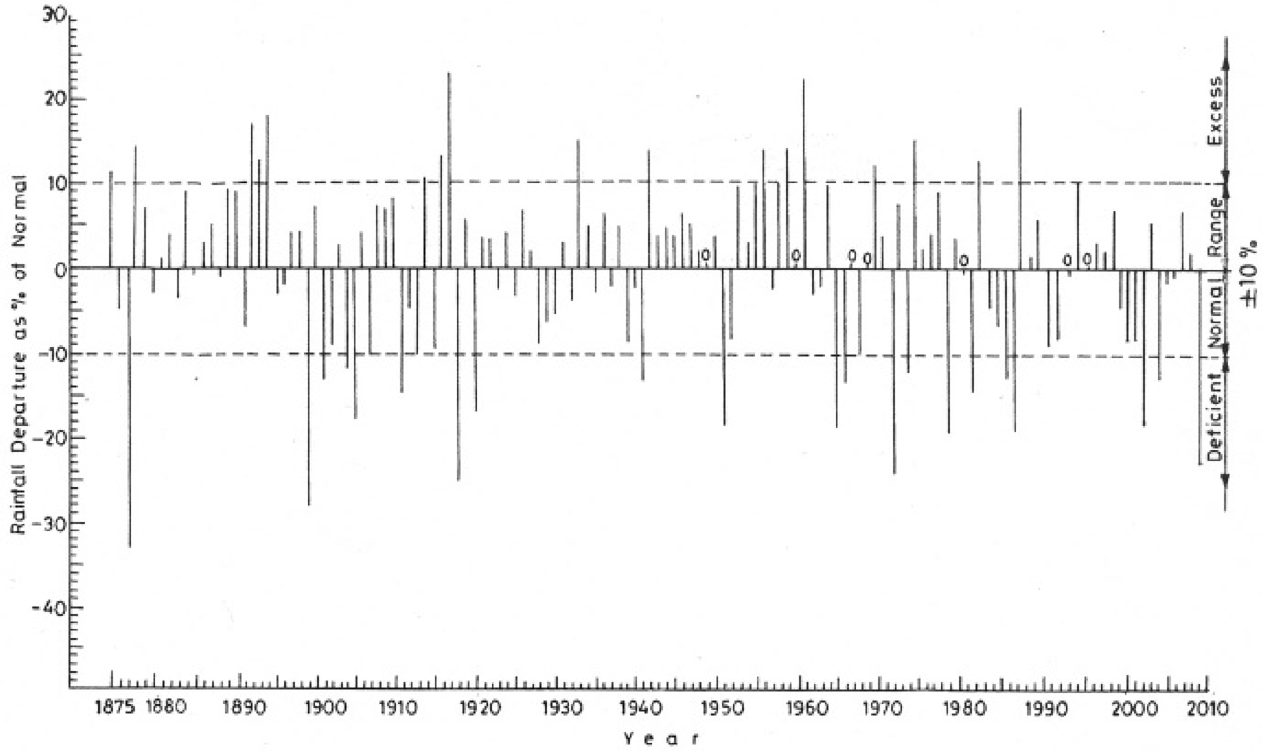


Figure 1. Indian Summer Monsoon Rainfall (ISMR) 1875-2009.

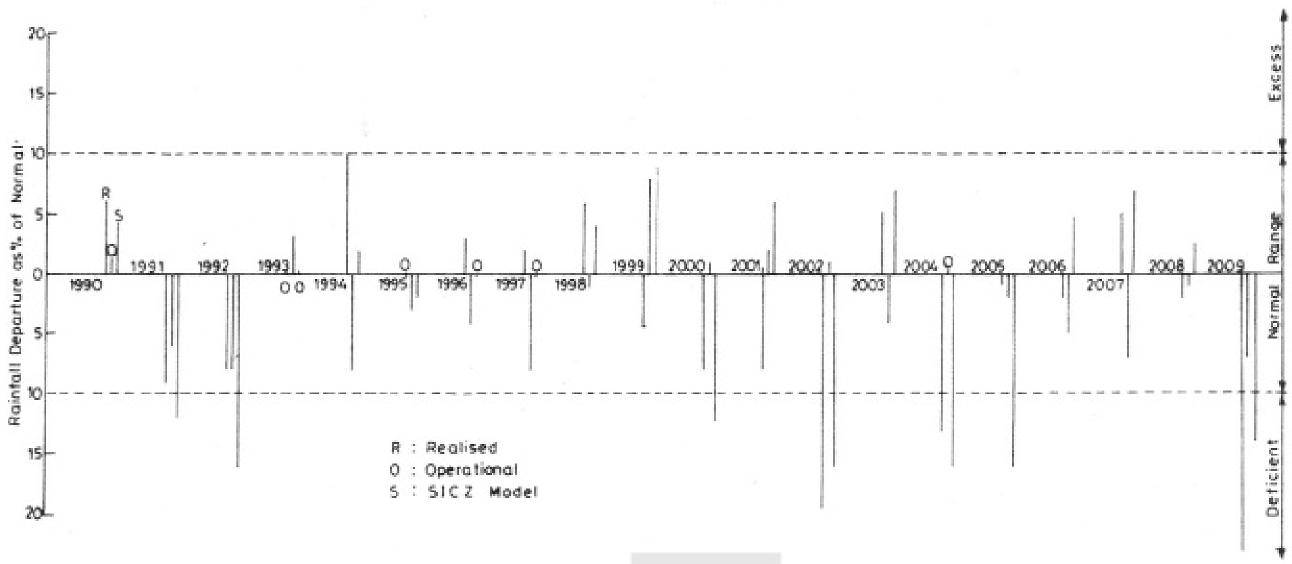


Figure 2. Forecast ISMR for the period 1990-2009 from SICZ and operational models.

(1988), Johri & Prasad (1990), Gupta & Prasad (1991,1992), De, Prasad & Vaidya 1995), De & Mukhopadhyay (2002) and Gadgil & Joseph (2003) who further confirmed the findings.

The SICZ model scores over other models of seasonal forecasting of rainfall on several counts. While the role of other models is limited to giving seasonal forecast of ISMR, SICZ model monitors the activity of SICZ throughout the year and has successfully explained the following, in addition to forecast of ISMR: (i) intra-seasonal changes in summer monsoon, i.e., 'active'/'break' cycle, (ii) delayed onset of monsoon over Kerala (iii) early withdrawal of monsoon from north and central India, (iv) development of 'dry' and 'wet' spells etc. SICZ model is also used for predicting rainfall in individual meteorological subdivisions of India (36).

A method had been proposed by Gupta & Prasad (1992) to quantify the activity of SICZ by assigning an index, called SICZ Activity Index (SAI)), ranked from 1 to 20, to pre-monsoon (April-May) cloud features. As per the inverse relationship between SICZ and the summer monsoon, the lowest value of the index (=1) was assigned to the cloud features in the year 1988 when ISMR was 18% above normal. The highest value of the index (=20) had been assigned to the cloud features in the severe drought year 1972 when ISMR was 26% below normal. The value of the index assigned to cloud features during the period of model development, 1972-1989, and thereafter till 2009, are given in Table 1. It was found that the activity index so assigned was significantly correlated with ISMR (CC >.9). The linear regression equation between SAI and ISMR (R) was found to be

$$R = -2.3 \times SAI + 120.5$$

where R is expressed in Cm. As mentioned earlier, the results of verification of forecasts for the years 1990-1992 and 1990-1998 were found to be reliable and satisfactory. Verification of forecasts for ISMR, for the period 1990-2009 are given in Fig.2. The forecasts of operational model (Gowariker et al., 1989) have also been included in Fig.2 for the sake of comparison. SICZ model forecast was reasonably good (in 17 years out of the 20 years), except in the years 1999, 2001 and 2005 when the difference between the forecast and realized rainfall was large. This aspect shall be examined in a future study.

Recently, the methodology of assigning SAI, using cloud data for pre-monsoon months of April and May, has been improved and tested for the sub-division of Tamilnadu and Pondicherry (Prasad, Singh & Subramanian 2010).The verification results have shown that the forecast of SWM seasonal rainfall for the sub-division of Tamilnadu and Pondicherry has improved. In the present study we have examined the improved methodology for predicting ISMR and rainfall in meteorological sub-divisions. In an effort to detect the signals, as precursor of likely performance of summer monsoon, as early as possible, cloud data for the period January-March have also been studied and included in assigning SAI.

DATA USED AND METHOD OF ANALYSIS

Rainfall data for the period 1972-2009 published by IMD in 'Mausam' under 'Weather Summary' for southwest monsoon season have been used in the study. Cloud data for the months of January to May for a period of 37 years (1972-2009 except 1978 when cloud data was not available from 16th March) and for SWM season (June-September) for 29 years (1979,1982-2009) have been used in the study. Reader is referred to a recent paper by Prasad, Singh and Subramanian (2010) for the method of analysis of cloud data.

FORECASTING ASPECTS OF ACTIVITY OF SICZ

The new approach to seasonal forecasting of summer monsoon rainfall is based on the finding that the activity of SICZ during the period January-May has a relationship with its activity during SWM season. The activity of SICZ during the period January-May contains signals, as precursors of likely performance of summer monsoon. For the purpose of recognizing these signals in cloud data, years have been grouped into 'Normal', 'Excess' and 'Deficient' monsoons. Mean cloudiness and cloud anomalies for the 3 groups of years have been worked out and used here.

Table 1. South Indian Convergence Zone (SICZ) Activity Index (SAI) during the period 1972-2009.

Year	1972	1973	1974	1975	1976	1977	1978	1979	1980	
SAI	20	4	14	4	15	10	N.A.	15	6	
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
SAI	7	14	5	14	16	17	19	1	8	7
Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
SAI	14	16	9	8	10	9	9	7	5	14
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	
SAI	6	16	6	16	16	7	6	7	14	

Mean cloudiness and cloud anomalies during June-September of 'Normal', 'Excess' and 'deficient' monsoons

Fig.3a shows the mean cloudiness during June-September for 10 'Normal' monsoon years (1989,1990,1993,1995,1996,1997,2005,2006,2007,2008) (Fig.1). ISMR was either normal or within ± 5% of normal in these years. Fig.3b shows mean cloudiness for 3 'Excess' monsoon years (1983, 1988, 1994). Similarly, Fig.3c shows mean cloudiness for 6 'Deficient' monsoon years (1982, 1986, 1987, 2002, 2004, 2009). Cloud anomalies for these 3 groups of years are given in Fig.4a-c. Main features of cloudiness and cloud anomalies pertaining to these 3 groups of years are briefly summarized in Table 2. It follows from the description of mean cloudiness and cloud anomalies that there is a pattern in the development of equatorial cloudiness during 3 groups of years.

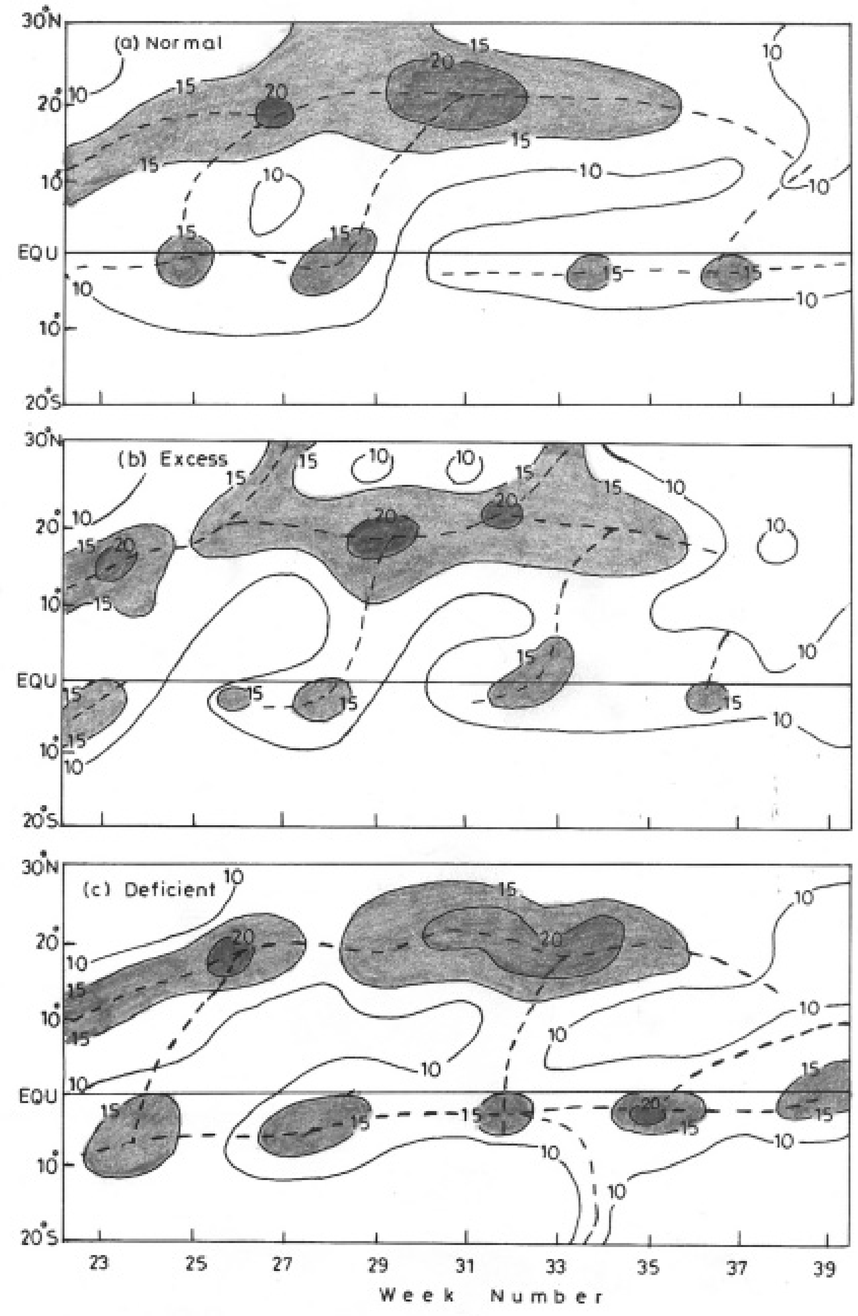


Figure 3a-c. Mean cloudiness during June-September of 'Normal', 'Excess' and 'Deficient' monsoons.

Table 2. Main features of mean cloudiness and cloud anomalies during SWM season.

Month	Main features		
	'Normal' monsoon	'Excess' monsoon	'Deficient' monsoon
June-September	1. Presence of a MCZ to the north of equator from June to August. 2. Development of 3 SPCAs which move northward. 3. South-north movement of a weak SPCAs from the zone of SICZ to 30° N lat. in each month except August when their is no development of a SPCAs in the zone of SICZ.	1. Absence of a MCZ in the zone of SICZ. 2. Development of a prominent SPCAs in the zone of SICZ in June, July and August and its northward movement. 3. August SPCAs affects the areas to the south of 20° N lat. for 3 weeks in continuation.	1. Presence of a MCZ to the north as well to the south of equator. The MCZ to the north does not reach up to 30°N lat. in any of the months. 2. Development of 4 prominent SPCAs in the zone of SICZ. Only June and August spells move northward. 3. Absence of northward movement of a SPCAs in July.

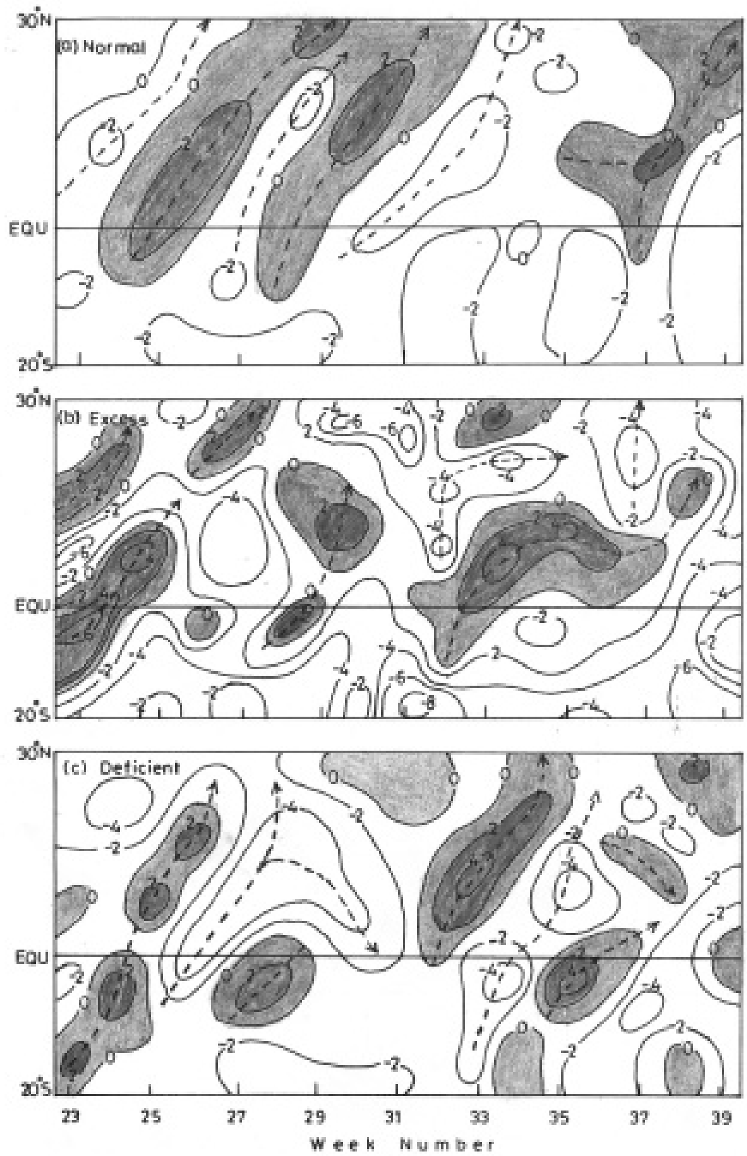


Figure 4a-c. Mean cloud anomalies during June-September of 'Normal', 'Excess' and 'Deficient' monsoons.

Mean cloudiness and cloud anomalies during January-May of 'Normal', 'Excess' and 'deficient' monsoons

Fig. 5a-c show the mean cloudiness during January-May for 10 'Normal' monsoons (1976, 1977, 1980, 1989, 1993, 1995, 1996, 1997, 2006), 3 'Excess' monsoons (1983, 1988, 1994) and 6 'Deficient' monsoons (1982, 1986, 1987, 2002 ,2004, 2009) respectively. Cloud anomalies are shown in Fig.6a-c. Main features of cloudiness and cloud anomalies pertaining to these 3 groups of years are briefly summarized in Table 3.

It follows from the description of features of equatorial cloudiness during January-May that the 3 groups of years have distinct patterns of development of cloudiness as was the case during SWM season. For example, in the case of 'Excess' monsoon years, there is a tendency for equatorial convection to move northward from the beginning of January itself. On the contrary in the years of 'Deficient' monsoons convection remains confined mainly to the south of equator from January till the end of March.

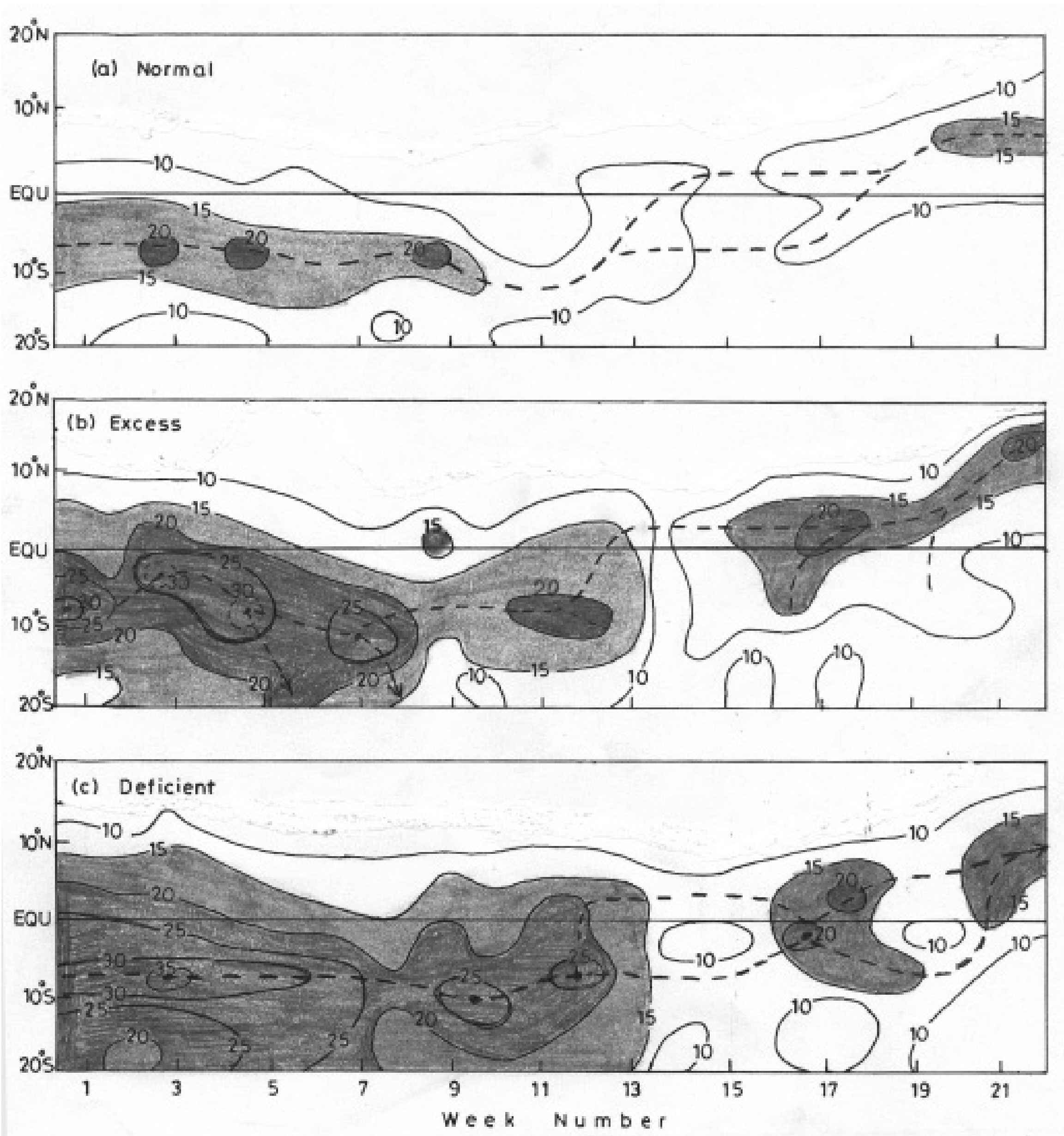


Figure 5a-c. Same as Fig.3a-c, but for the period January-May.

Table 3. Main features of mean cloudiness and cloud anomalies during January-May.

Month	Main features		
	'Normal' monsoon	'Excess' monsoon	'Deficient' monsoon
January-March	1. Presence of a MCZ between Equator and 10° S lat. from January beginning till the middle of March. 2. The MCZ is weak as the area occupied by 20% weekly mean cloudiness is small. 3. Development of 2 SNCAs which are confined to area south of equator.	1. Development of an active spell of SICZ from January till the third week of February and another short lived spell n March. 2. Development of alternate SPCAs and SNCAs during January-March. SPCAs move both to the south and north of equator.	1. Presence of an active SICZ (area occupied by 20% or more weekly mean cloudiness) from January beginning till the end of March 2. PCAs dominate the areas south of equator from January beginning till the end of March. They also extend to the north of equator occasionally .
April-May	4. Appearance of double cloud bands from the second half of March till the second half of May. Merger of both the cloud bands into one and its northward movement up to 10° N lat. by the end of May. 5. Development of 2 SPCAs. May anomalies are prominent. Both anomalies originate close to equator and move up to 20° N Lat..	3. Development of a cloud band north of equator from the beginning of April. It progressively moves northward and reaches the lat. belt 15° N-20° N by the end of May. 4. Development of alternate SPCAs and SNCAs. SPCAs are very prominent and it moves from close to equator to 15° N lat by the end of May.	3. Development a MCZ in April end and May end. Both remain confined to the areas south of 10° N lat.. April MCZ moves both to the north and south of equator. 4. Development of alternate SPCAs and SNCAs. Both the anomalies move to the north as well as to the south of equator.

QUANTIFICATION OF THE FEATURES OF EQUATORIAL CLOUDINESS

Quantification of the features of equatorial cloudiness is the most important aspect of SICZ model. This has been shown here by assigning an index, called SICZ Activity Index (SAI), ranked from 1 to 12, to the equatorial cloud features during the period January-May. Recognition of patterns in the development of cloudiness in the near equatorial regions of IO, as discussed below, forms the basis for assigning SAI. Taking the ISMR data for the period, 1972-2009, the range of variation of ISMR between an extreme drought year 1972 and a flood year 1988 is about 43%. Even a longer period, 1901-2009, data of ISMR also gives a similar range (47%). This range of variation has been divided into 12 groups and each group represents about 4 % variation of ISMR (Table 4). These 12 groups may also be considered as representing 12 categories of SWM: 'Monsoon Category-1 (M1)' to 'Monsoon Category-12 (M12)', where M1 refers to 'Excess' monsoon with highest ISMR and M12 to 'Drought' with lowest rainfall. Development of cloud patterns have been discussed below for each category of monsoon with the help of mean cloudiness and cloud anomalies.

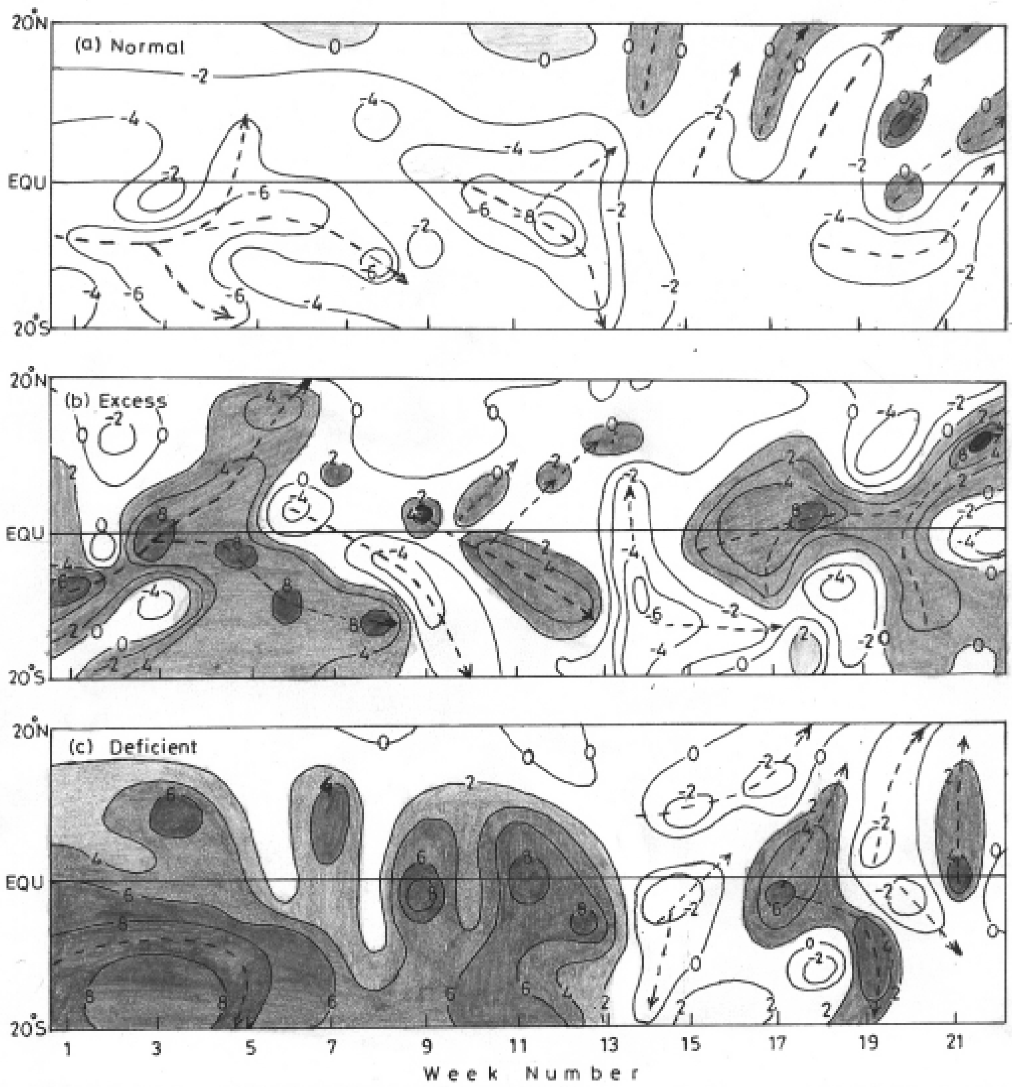


Figure 6a-c. Same as Fig. 4a-c but for the period January-May.

'Excess' monsoon (M1- M4)

ISMR was 21% above normal in the year 1961. Cloud data are not available for 1961(M1 category). There is only one year, i.e.,1988, in M2 category. Weekly mean cloudiness for the period January-May 1988 is given in Fig. 7a. Spells of active convection in SIO had a tendency to move northward from January itself. SICZ was completely absent in April and May. Equatorial trough to the north of equator was well marked from the beginning of April. These features are reflected in the anomaly chart also (Fig.8a). Absence of southward movement of the Spells of Positive Cloud Anomalies (SPCAs) during January-March is another characteristic feature of the anomaly chart.

There are 2 years (1975, 1983) in M3. Mean cloudiness for M3 category are given in Fig. 7b and cloud anomalies in Fig. 8b. The MCZ had a tendency to move northward during January-March. Considerable weakening of SICZ and development of equatorial trough to the north was seen during April and May. In the anomaly chart, SPCAs as well as Spells of Negative Cloud Anomalies (SNCAs) both had a tendency to move to the north as well as to the south of equator during January-March. During April and May, SPCAs developed at an interval of 2-3 weeks only. There is only one year (1994) in M4 category. Mean cloudiness in the year 1994 is given in Fig. 7c. Considerable reduction in cloud amounts is seen during January to March. Equatorial trough to the north of equator started developing from the middle of April and moved progressively northward up to 15° N lat. Above mentioned features are seen in the anomaly chart (Fig.8c) also.

Table 4. Monsoon Category, range of % departure of ISMR , year (% departure of ISMR) and number of years when cloud data was available during the period January-May 1972-2009

Monsoon category		Range of % departure of ISMR from normal (100%) From	To	Year (% departure of ISMR from normal)	No. of years when cloud data was available
Excess	M1	≥ 23	20	1961 (21)	-
	M2	19	16	1988 (18)	1
	M3	15	12	1975 (15), 1983 (12)	2
	M4	11	8	1994 (10)	1
Normal	M5	7	4	1998(6), 2003(5), 2007(5), 1973(4), 1981 (4), 1990 (4)	6
	M6	3	0	1996(3), 1997(2),1977(1),1989(1),1976 (0), 1980 (0), 1993(0), 1995 (0)	8
	M7	-1	-4	2005(-1),2006(-1),2008 (-2), 1984 (-4),1999(-4)	5
	M8	-5	-8	1992(-7), 2000(-8)	2
Deficient	M9	-9	-12	1991(-9), 2001(-9), 1985(-10)	3
	M10	-13	-16	1986(-13), 2004 (-13), 1982(-14), 1974 (-15)	4
	M11	-17	-20	2002 (-19)	1
	M12	-21	≤-24	1979(-21), 2009(-23), 1972(-25)	3

Normal' monsoon (*M5 - M8*)

There are 6 years (1973, 1981, 1990, 1998, 2003, 2007) in M5. Mean cloudiness and cloud anomalies are shown in Figs.9a and Fig.10a respectively. The MCZ associated with SICZ moved southward. Equatorial trough to the north of equator developed in the beginning of April and moved northward. Alternate SPCAs and SNCAs developed. SNCAs were less marked. The interval between the two prominent SPCAs during April-May was 4 weeks. There are 8 years (1976, 1977, 1980, 1989, 1993, 1995, 1996, 1997) in M6. SICZ was active, week after week, during January-February (Fig. 9b). SICZ was practically absent in April-May. Alternate SNCAs and SPCAs developed from January to May. SPCAs and SNCAs (Fig. 10b) moved to the north as well as to the south. SNCAs were more prominent.

There are 4 years (1999, 2005, 2006, 2008) in M7. Mean cloudiness for this category (Fig.9c) is similar to that for M6. However, the axis of MCZ associated with SICZ moved to more southerly latitudes during February and March. Negative cloud anomalies (Fig.10c) dominated the areas to the south of equator till February. Three weak SPCAs developed in April and May at an interval of 2-3 weeks. There are 3 years (1984,1992, 2000) in M8. SICZ remained active from January till May (Fig.9d). A weak trough developed to the north of equator in May. This feature, also seen in the anomaly chart (Fig.10d), is a significant change from the cloud features associated with M2 –M7.Three prominent SNCAs developed at an interval of 6-7 weeks.

'Deficient' monsoons (*M9- M12*)

There are 3 years (1985,1991,2001) in M9. SICZ remained active from January to May but for 2 weeks in April (Fig.11a.). April SPCAs (Fig. 12a) moved more to the south of equator. May SPCAs was mainly confined to areas south of equator. There are 4 years (1974,1982,1986,2004) in M10. SICZ remained active from January to March in a more southerly latitude (Fig. 11b). A weak trough developed to the north of equator from the beginning

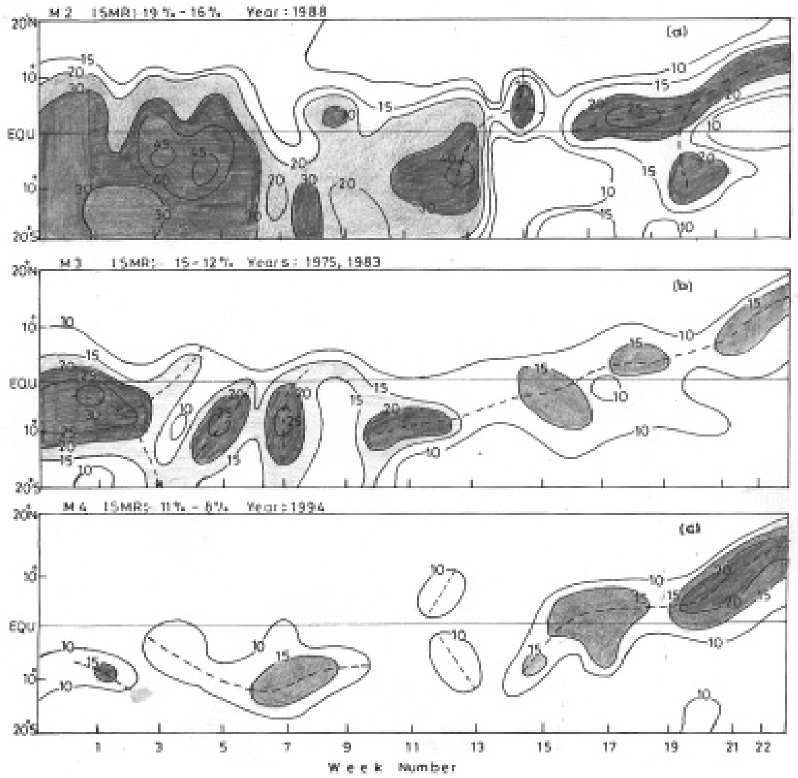


Figure 7a-c. Mean cloudiness during Jan-May of 'Excess' monsoons [M2-M4].

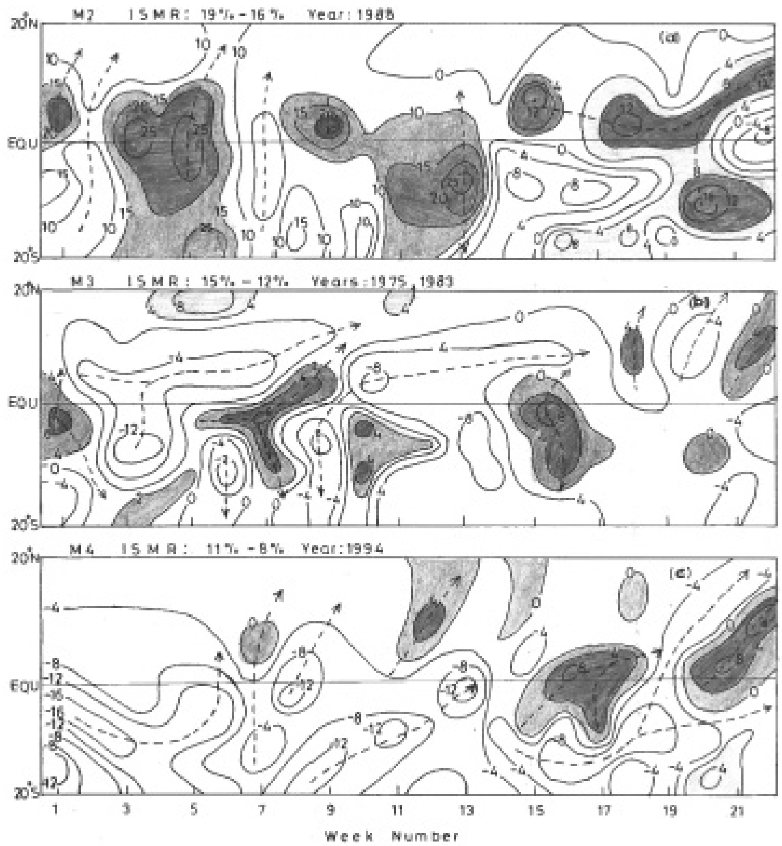


Figure 8a-c. Mean cloud anomalies during Jan-May of 'Excess' monsoons [M2-M4].

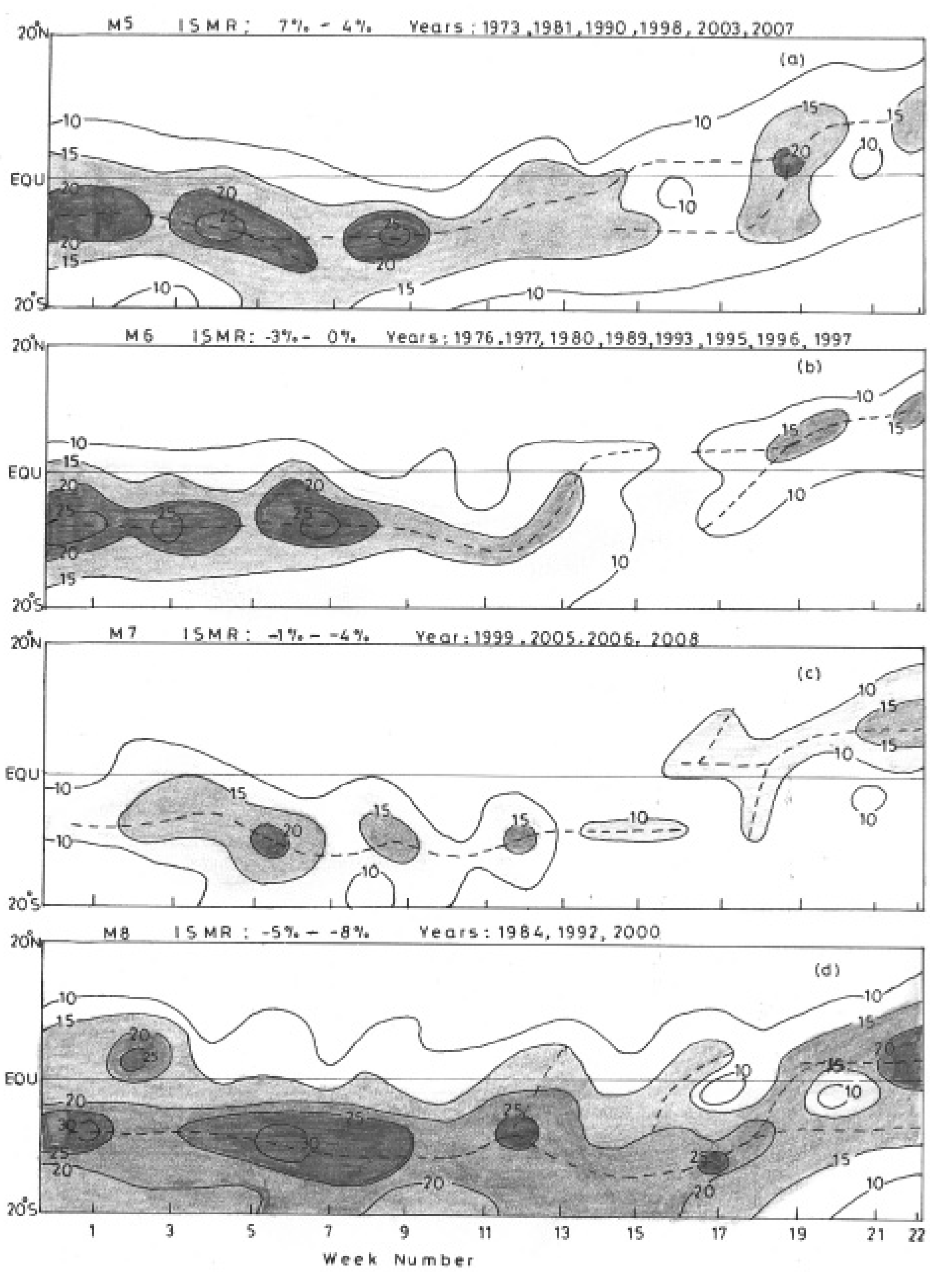


Figure 9a-d. Same as Fig.7 but for 'Normal' monsoons [M5-M8].

of April but it remained confined to the areas south of 10° N lat. only. An important feature of the anomaly chart (Fig. 12b) is the appearance of alternate SPCAs and SNCAs which lasted for 3-4 weeks in continuation. This feature is typically associated with 'Drought'. The other 'Drought' signal present in the anomaly chart is a very weak S-N oscillation.

There is only one year (2002) in M11. SICZ remained active from January to April but for 2 weeks in February (Fig.11c). Thereafter SICZ developed for 3-4 weeks in continuation from the last week of April. In the anomaly chart (Fig.12c) development of SPCAs and SNCs for 4 weeks in continuation is seen from January to May. The other prominent feature of the anomaly chart is movement of SPCAs both to the north and south of equator. There are 3 years (1972,1979,2009) in M12. Cloud data for the period January-March was not available in 1972 and there were some missing data in 1979.

SICZ remained active from January to April (Fig.11d). SICZ continued to remain active for a period of 4 weeks in continuation. Movement of the MCZ both to the north and south of equator during pre-monsoon months was the other feature of the mean cloudiness. In the anomaly chart (Fig. 12d) SPCAs were prominent from the second half of January till the second half of March. While the SNCAs continued for 3 weeks in continuation, SPCAs lasted for 2 weeks only. Both type of anomalies moved to the north as well to the south of equator.

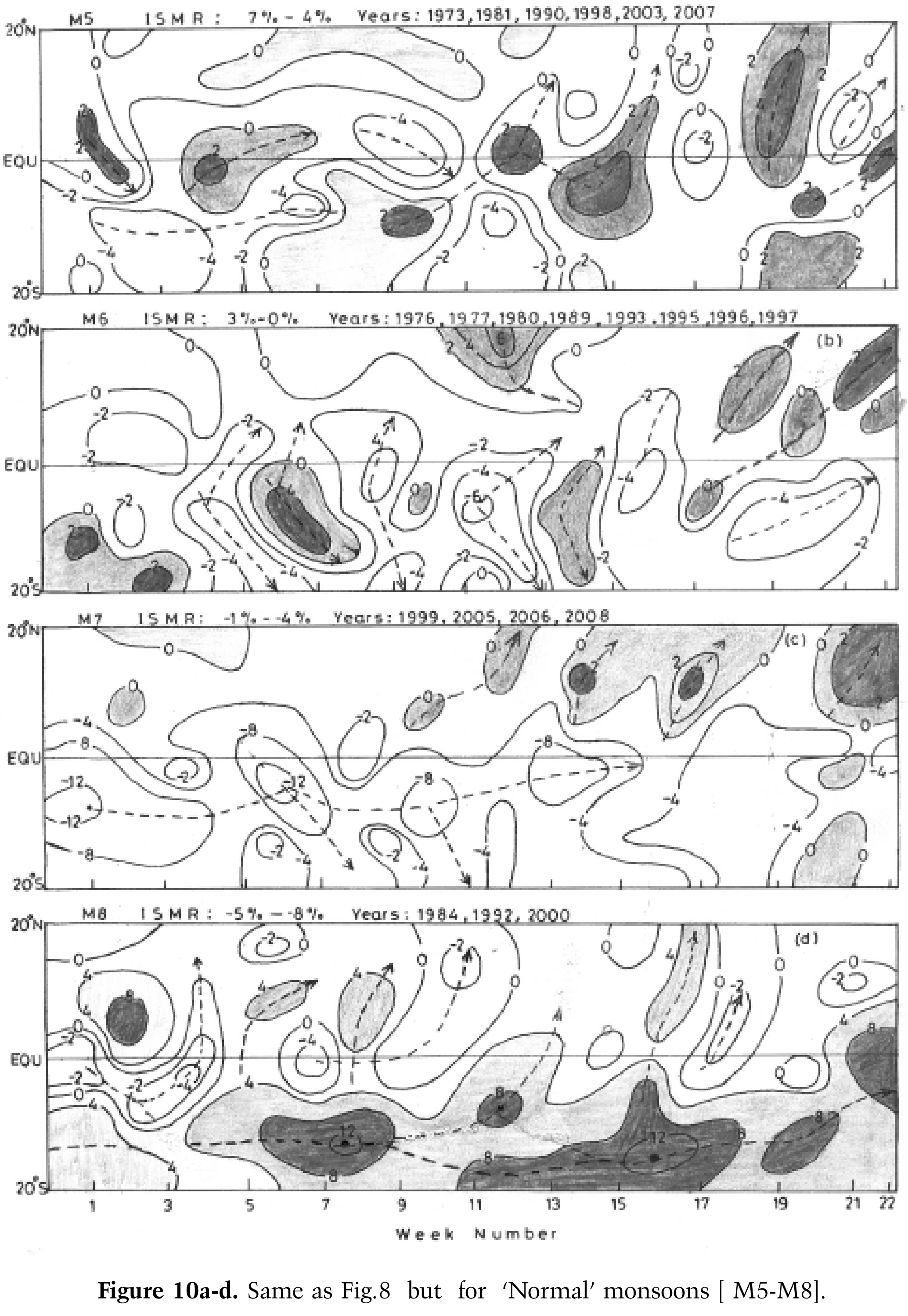


Figure 10a-d. Same as Fig.8 but for 'Normal' monsoons [M5-M8].

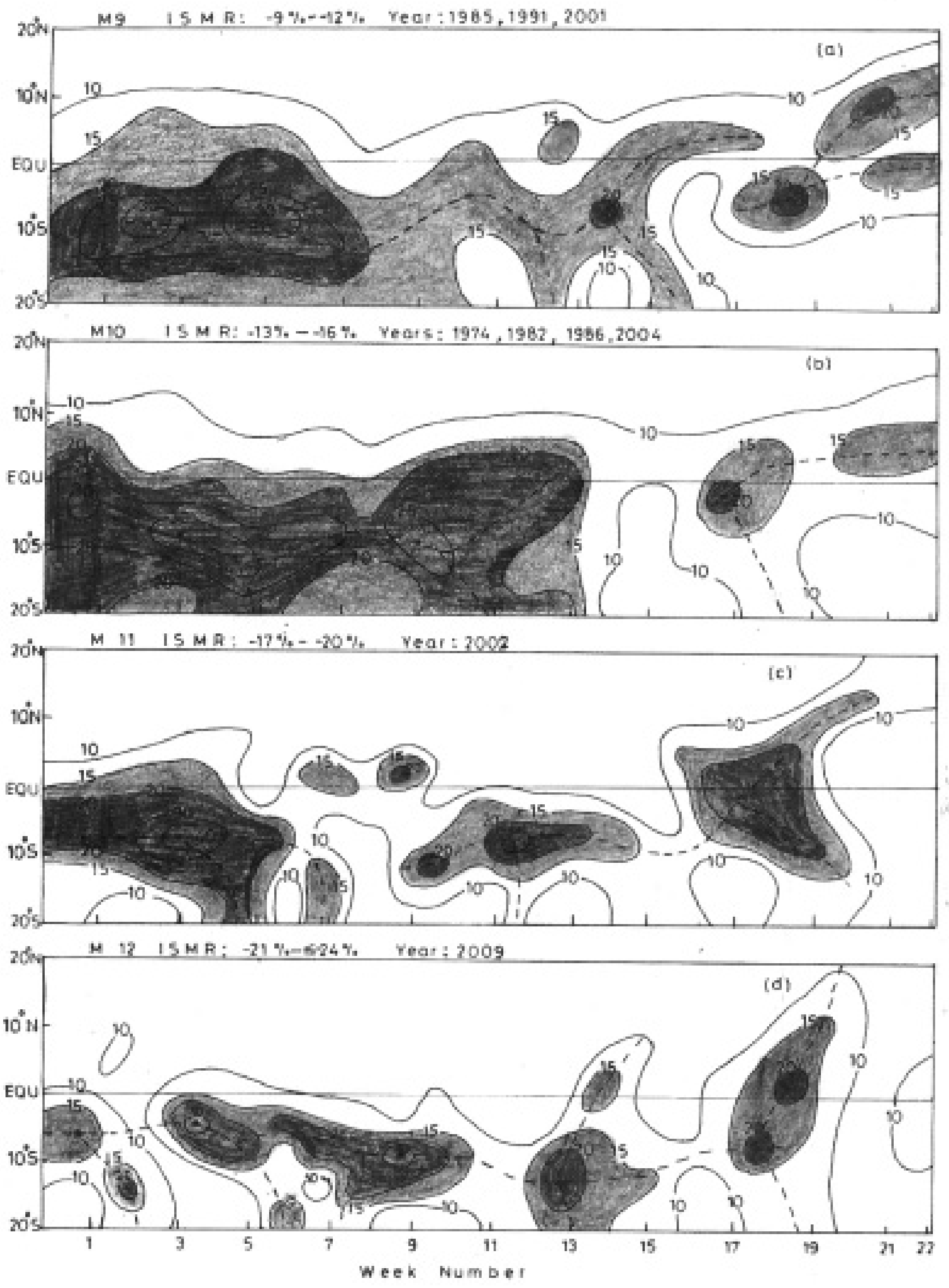


Figure 11a-d. Same as Fig.7 but for 'Deficient' monsoons [M9-M12].

The analysis of mean cloudiness and cloud anomalies have shown that they differ from one category of monsoon to another. Therefore, the cloud features for ach category could be assigned an index. Thus the cloud features pertaining to M2-M12 categories of southwest monsoon could be assigned SAI from 2 to 12 respectively.

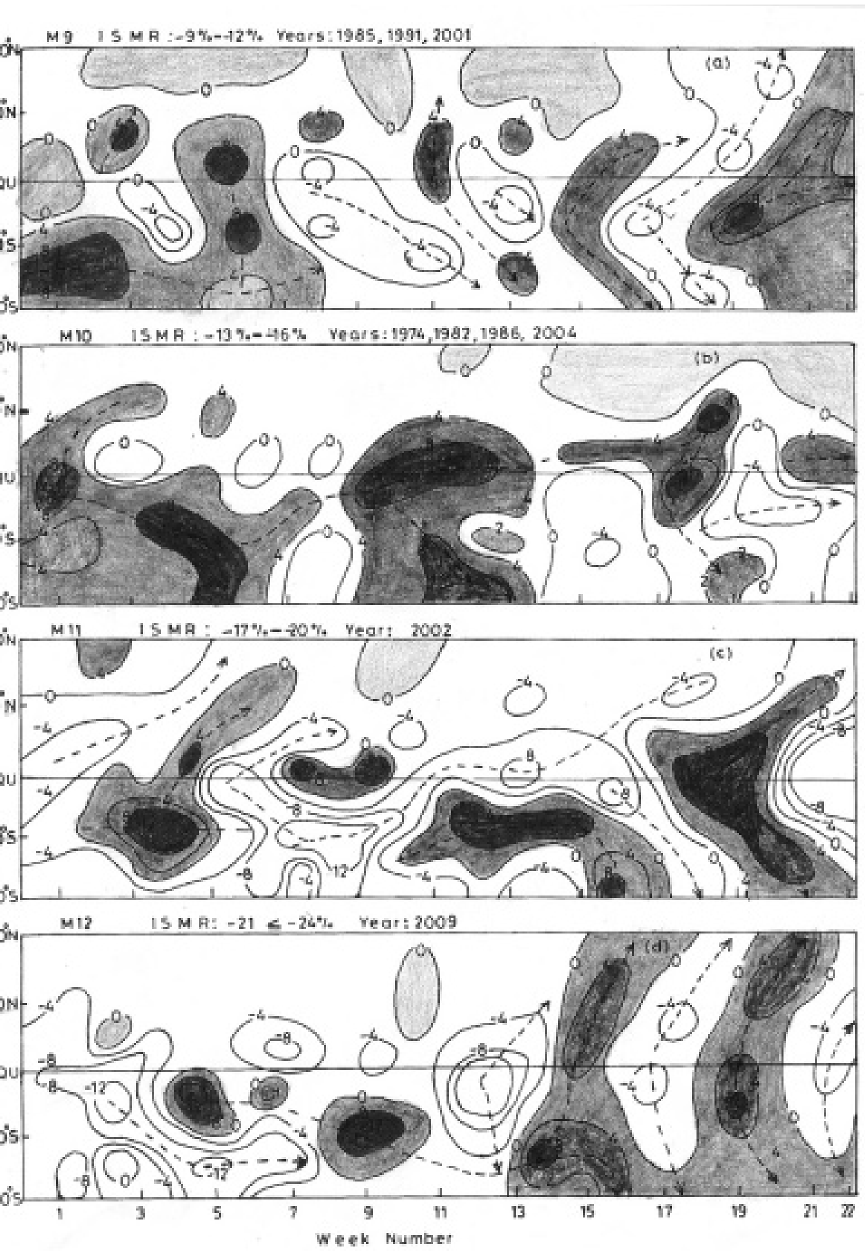


Figure 12a-d. Same as Fig.8 but for 'Deficient' monsoons [M9-M12].

CONCLUSIONS

Long period satellite observed cloud data from the Indian Ocean region have confirmed the earlier findings that SICZ forms an important element of Indian summer monsoon circulation system and that it plays a crucial role in the development of Indian summer monsoon and its intra-seasonal changes. There is, in general, an inverse relationship between the intensity of SICZ and summer monsoon.

Activity of SICZ during the period January-May contains signals about likely performance of summer monsoon over India. These signals could be detected with the help of mean cloudiness and cloud anomalies. The features identified in mean cloudiness and cloud anomalies pertaining to different categories of monsoon could be used to assign SICZ Activity Index (SAI).

The improved method of assigning SAI, correlation coefficients between SAI and ISMR as well as seasonal southwest monsoon rainfall in each meteorological sub-division, regression equations and verification of forecasts shall be included in Pt II of the study.

ACKNOWLEDGEMENTS

The authors express their sincere thanks to AVM (Dr.) Ajit Tyagi, Director General of Meteorology for his keen interest in the development of models for seasonal forecasting of rainfall in India. Data used in the study are also gratefully acknowledged. The authors express their sincere thanks to anonymous reviewers for their critical comments. Encouragement received from Professors U.S. De, P.V. Joseph, Sulochana Gadgil and R. R. Kelkar is also gratefully acknowledged. One of the authors (OP) is indebted to his spiritual guru , H. H. Maa Purnanandaji, Spiritual Head, Satyavrat Institute of Subjective Sciences, B-17, Sector 62, Institutional Area, NCR, Noida-201307 for being a constant source of inner inspiration. Inverse relationship between SICZ and Indian summer monsoon was reported, for the first time, when OP had been working as a research scholar at the Department of Meteorology and Climatology, Moscow State University , Moscw (Russia). OP would like to record his sincere gratitude to his Ph.D. supervisor, Prof. P. N. Belov and his colleagues at the Department of Meteorology and Climatology, Moscow State University, Moscow (Russia).

REFERENCES

Blandford, H. F.,1884. On the connection of the Himalayan snowfall and season of droughts in Indian, Proc. Royl. Soc., London, 37, 3-22.

De, U.S., Prasad, O. & Vaidya, D.V.,1995.The influence of Southern Hemispheric Equatorial Trough on rainfall during southwest monsoon, Theor. Appl. Climatol., 52, 177-181.

De, U. S. & Mukhopadhyay, R. K., 2002. Breaks in monsoons and related precursors, Mausam, 53, 309-318.

Gadgil, S. & Joseph, P.V., 2003. On 'breaks' of the Indian monsoon, Proc. Indian Acad. Sci. (Earth & Planet. Sci.), 112, 529-558.

Gadgil, S., Rajeevan, M. & Francis, P. A., 2007. Monsoon Variability: Links to major oscillations over the equatorial Pacific and Indian Ocean, Current Science, 93 (2), 182-194.

Gowariker, V., Thapliyal, V., Sarker, R. P., Mandal, G. S. & Sikka, D. R., 1989. Parametric and power regression models: New approach to long range forecasting of monsoon rainfall in India, Mausam, 40, 115-122.

Gupta, G. R. & Prasad, O., 1991.Activity of south Indian Ocean convergence zone as seen in satellite cloud data during pre-monsoon months, Mausam, 42, 145-150.

Gupta, G .R. & Prasad, O., 1992. Role of southern hemispheric equatorial trough in long range forecasting', Jalvigyan Sameeksha- a publication of Indian National Committee on Hydrology, VII, 83-97.

Gupta, G. R. & Prasad, O., 1993. Southern hemispheric equatorial trough model of sub-division-wise long range forecast of monthly rainfall', Hydrology Journal,16, 49-76.

Johri, A.P. & Prasad, O.,1990. Interaction between Southern Hemispheric Equatorial Trough and monsoon circulation during severe drought years, Mausam,41, 597-602.

Krishnamurty, T.N. & Bhalme, H.N., 1976. Oscillation of monsoon system, Pt. I, Observational aspect., J. Atmos. Sci.,33, 1937-1954.

Prasad, O., Mishra, D.K. & Jain, R.K.,1978, A preliminary study of the cloud clusters in the near equatorial regions of Indian Ocean, IJMHG, 29 , 375-380.

Prasad, O., 1981. Vertical circulation during 'break' in monsoon', Herald Moscow State University, Ser.5, 74-77.

Prasad, O., 1982. Development of Indian summer monsoon and its different phases', Ph. D. Dissertation, Hydro-meteorological Centre USSR, Moscow, 118p. (In Russian)

Prasad, O., Mishra, D. K. & Jain, R.K., 1983. Satellite observed cloud distribution over Indian Ocean during southwest monsoon', Mausam, 34, 449-454.

Prasad, O., Rama Sastry, A.A., Hansda, A.K. & De, U. S., 1988. Role of southern hemispheric equatorial trough in medium range forecasting', Mausam, 39, 167-178.

Prasad, O., 1993. Performance of southern hemispheric equatorial trough model of sub-division-wise long Range forecast of rainfall during southwest and north-east monsoons, TROPMET-1993, 159-166.

Prasad, O., 2000.Sub-division-wise long range forecast of rainfall during southwest monsoon, TROPMET-2000, 222-226.

Prasad, O., 2001. Sub-division-wise long range forecast of bi-monthly rainfall during southwest monsoon', TROPMET -2001, 252-257.

Prasad, O., Singh, O.P. & Subramanian, S. K., 2010. Seasonal forecast of southwest monsoon rainfall-District level, JIGU, 10, 93-114.

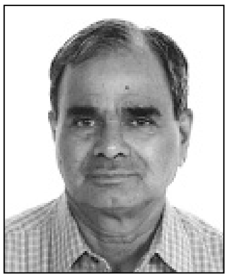
Saha, K.R., 1971. Mean cloud distribution over tropical oceans, Tellus, 23,183-195.

Sikka, D.R. & Gadgil, S., 1980. On the maximum cloud zone and the ITCZ over Indian longitudes during the southwest monsoon', MWR, 108,1840-1853.

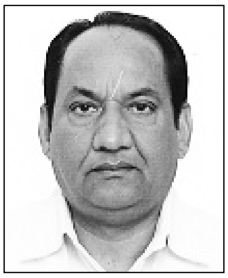
Yasunari, T., 1980. A quasi -stationary appearance of 30 to 40 day period in the cloudiness fluctuations during the summer monsoon', J. Met. Soc. Japan, Ser. II, 58, 225-229.

Yasunari, T., 1981. Structure of an Indian summer monsoon system with around 40-day period', J. Met. Soc. Japan, Ser. II, 59, 336-354.

(Revised accepted 2010 September, 6; Received 2010 June 6)



Dr. Onkari Prasad: Born in 1946, Dr. Onkari Prasad obtained his B.Sc. and M.Sc. (Geophysics) degrees from Banaras Hindu University in 1965 and 1967 respectively. He had been working as a Junior Research Fellow at National Geophysical Research Institute (NGRI) Hyderabad before joining India Meteorological Department (IMD) in 1969. He was on study leave and obtained his Ph.D. degree in (Geophysics) from Moscow State University, Moscow (Russia) (formerly USSR) in 1982. While in service in IMD he worked in the forecasting offices at New Delhi, Pune and Bhopal. While posted at Pune, he taught Satellite Meteorology to forecasters of Advanced Training Batches at World Meteorological Organisation (WMO) recognised training centre of IMD for 4 years. He retired from IMD as Director in 2006. He has published 32 research papers in national and international journals. His research work, particularly during the past 3 decades, has proved helpful in understanding southwest monsoon and long range forecasting of monsoon rainfall in India. Post retirement, Dr. Prasad is actively engaged in developing models for district level long range forecast of seasonal rainfall.



Dr. O.P. Singh: Born in 1954, Dr. O. P. Singh has had an excellent academic career with a Masters and a Doctorate degree in Applied Mathematics from the University of Allahabad and the Indian Institute of Technology, Kanpur respectively. He joined India Meteorological Department (IMD) in 1980. He has nearly 15 years teaching experience in Physical and Dynamical Meteorology, besides Numerical Weather Prediction at the advanced level World Meteorological Organisation-recognised courses conducted by IMD. His research interest covers a wide spectrum of topics in meteorology- from meso-scale thunderstorms to large scale monsoons. He has published 63 research papers in leading national and international journals, besides about 40 abstracts published in the proceedings of symposia and conferences. He has been awarded with prestigious Dr. B. N. Desai award of Indian Meteorological Society and Mausam Shodh Puraskar of India Meteorological Department for his research contributions in the field of Atmospheric Sciences. He has also had 3 years experience of working as Head of Theoritical Division at South Asian Association of Regional Cooperation (SAARC) Meteorological Research Centre.

Dr. Sant Prasad received his M.Sc.(physics) degree from Agra University, Agra in 1968 and Ph.D. (Physics) degree from Indian Institute of Technology, Delhi in 1975. He joined IMD in 1974 as Assistant Meteorologist and retired as Additional Director General of Meteorology in 2007. While in service in IMD, he worked in the field of Satellite Meteorology for 25 years and in Hydrology for 5 years. Dr. Prasad has immense experience in ' Satellite Data Processing and derivation of meteorological products' from the data of various geo-stationery and orbiting Indian and foreign satellites. He also handled various computer systems and maintained them for more than two decades. He developed the expertise of writing software programs in FORTRAN, PASCAL,C++ and MACRO languages. He was instrumental in establishing National Satellite Data Centre and putting satellite imagery data and derived products on IMD's web-site at Delhi, in framing number of projects, Request For Proposals (RFPs). He wrote a comprehensive RFP for INSAT-3D satellite. He taught data processing, C++ language and Satellite Meteorology to IMD and Air Force officers. He gave several presentations in IMD, SAC Ahmedabad, MCF Hassan, JNU Hyderabad, IIT Delhi etc. He helped the scientists at SAC Ahmedabad to establish a Satellite Data Reception and Archival Centre. He has published 40 research papers in national and international journals. Dr. Prasad received J. Das Gupta award of Indian Meteorological Society in 1989 for a creative work on derivation of 'Sea Surface Temperature'.