Open access e-Journal
Earth Science India, eISSN: 0974 – 8350
Vol. 4(III), July, 2011, pp. 159-170
http://www.earthscienceindia.info/

Interaction between Tendency of Effective Strength Index and Thermal Field over Tibetan Plateau in Relation with Sub-divisional Summer Monsoon Rainfall over India

S.B.Kakade, Ashwini Kulkarni and S.S.Dugam
Indian Institute of Tropical Meteorology, Pune, India
Email: kakade@tropmet.res.in

Abstract

North Atlantic Oscillation (NAO) and Southern Oscillation (SO) are two large-scale atmospheric oscillations in northern mid-latitude and equatorial southern hemispheres respectively. Effective Strength Index (ESI) is defined as the linear combination of NAO and SO and ESI tendency is the algebraic difference between April-ESI and January-ESI. The location and intensity of Tibetan anticyclone is one of the important components in deciding strength of seasonal monsoon rainfall over India and hence the relationship of thermal field over Tibetan Plateau (25-45°N, 75-100°E) with ESI tendency is discussed in this paper. The correlation analysis suggests that northern part of Tibetan Plateau is directly associated with ESI tendency and the relationship is statistically significant at 5% level. We have also examined the relationship between ESI tendency with seasonal rainfall over homogeneous sub-divisions of India. The number of sub-divisions showing significant relationship with ESI tendency is increasing in recent years. Further, analysis suggests that three sub-divisions to the north of 25°N (Region-1) and ten sub-divisions to the south of 20° N (Region-2) are showing significant associations between rainfall and ESI tendency in various 30-year epochs. The area-weighted rainfall over these Regions is calculated and it is observed that the relationship of ESI-tendency with this Regional rainfall has strengthened in recent years. Regression equations for predicting area weighted rainfall for these two Regions are developed and their performance is tested.

Keywords: Effective Strength Index (ESI), ESI tendency, thermal field, Tibetan anticyclone

Introduction

Long-range forecast (LRF) of all-Indian Summer Monsoon Rainfall (ISMR) has a long history. Rao (1965), Thapliyal (1986), and Krishna Kumar (1995) have reviewed some of the techniques used for LRF of ISMR for over past century. In order to maintain the thermal equilibrium in northern and southern hemispheres there is an epochal variation in the predictand–predictor relationship, which makes it necessary to search for the new parameters for the statistical LRF techniques. Following the failure of the operational forecast in 2002 and 2004, there is a need for the identification of predictors, which have physical relationships with ISMR.

North Atlantic Oscillation (NAO) and Southern Oscillation (SO) are the two large-scale atmospheric alterations in northern and southern hemispheres respectively. These two oscillations exist throughout the year simultaneously, and individually affect ISMR. Kakade and Dugam (2000) have defined an index called Effective Strength Index (ESI) on the basis of monthly indices of NAO and SO. Further they have also discussed how this ESI represents

Open access e-Journal
Earth Science India, eISSN: 0974 – 8350
Vol. 4(III), July, 2011, pp. 159-170
http://www.earthscienceindia.info/

the combined effect of NAO and SO. This ESI in the month of April is inversely associated with ISMR and the relationship is statistically significant at 1% level. They have also shown that during excess monsoon years, the ESI decreases from January to April whereas during deficient monsoon years, there is a rising tendency of ESI from January to April. Further study by Kakade and Dugam (2006) has shown that the tendency of ESI from January to April can be used as a precursor for the prediction of summer monsoon rainfall over different homogeneous Regions of India like northwest India, west central India, peninsular India and India as a whole. This ESI tendency has predicted the reduced rainfall activity in 2002 and 2004 with reasonable skill (Kakade and Dugam, 2006). Therefore, ESI tendency can be used as one of the predictors along with already existing parameters. In this paper, we have studied the relationship between ESI tendency and summer monsoon rainfall over India on smaller spatial scales (*i.e.* sub-divisions) and the Region of Indian sub-continent where the relationship between ESI tendency and rainfall is highly significant is identified.

Monsoon circulation over India is a large-scale thermally driven phenomenon. For the prediction of summer monsoon rainfall on sub-divisional scale using ESI tendency, we should know the effect of ESI tendency on thermal field over 5° X 5° latitude-longitude blocks of Indian Region in general and over Tibetan Region in particular. This Region is selected because Tibetan Plateau acts as heat source in summer season and the location and intensity of upper air Tibetan anticyclone is one of the important components of the monsoon circulation over Indian sub-continent. Many earlier studies by Raghavan (1973), Krishnamurty and Bhalme (1976), Ye (1981), Murakami (1987), Yanai *et al.* (1992), Yanai and Li (1994), Yimin *et al.* (2007) etc. have discussed some characteristics of the summer circulation over the Tibetan Plateau and its effect on Asian summer monsoon rainfall. The heating of this elevated landmass in summer leads to the development of an intense anticyclone in the upper troposphere, which is popularly known as Tibetan anticyclone with strong east-northeasterly flow over north India. During the summer season, it is centered over southeast Tibet. Further, the equatorward outflow from this anticyclone gains easterly angular momentum and therefore it appears as an easterly jet stream over SE Asia south of 20N between 150 hPa and 100 hPa. The upper tropospheric Tibetan anticyclone is predominantly forced by the heating and by the orography (Yimin *et al.,* 2007). Hence, in this paper we discuss the effect of ESI tendency on the thermal field over Indian sub-continent in relation to summer monsoon rainfall over different sub-divisions of India.

Due to temporal and spatial variability of ISMR, the predictor-predictand relationship also shows variability on space-time domain. When any predictor of ISMR is correlated with summer monsoon rainfall over different sub-divisions of India then it may show statistically significant association for some sub-divisions and for certain epochs only. Thus, it is rather tough to delineate the Region of India where the summer monsoon rainfall is highly associated with the predictor under consideration. Here an attempt has been made to delineate the Region of India where summer monsoon rainfall is highly associated with ESI tendency, which can be used as the predictor of ISMR (Kakade and Dugam, 2000; Kakade and Dugam, 2006).

Data Used

For this study, the following data for the period 1951-2006 have been used:

1. Indian summer monsoon rainfall (ISMR): The summer monsoon rainfall (June-September) data for different subdivisions, homogeneous Regions of India and India as a whole for the period 1871-2006 have been taken from the web site www.tropmet.res.in. The percentage departure of this data from long term mean is calculated and these indices are used for further analysis.

2. Temperature: 5° X 5° temperature anomaly (in °C) with respect to 1961-90 mean over the Region 5°N-45°N, 60°E-100°E have been obtained from http://www.cru.uea.ac.uk/cru/data/temperature.

3. North Atlantic Oscillation (NAO): The NAO data have been taken from www.cpc.ncep.noaa.gov.

4. Southern Oscillation (SO): The SO data have been taken from www.cpc.ncep.noaa.gov.

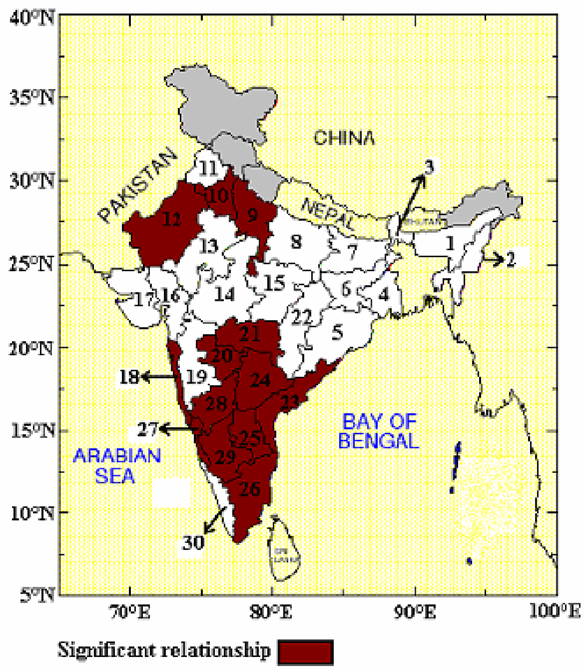
5. Effective Strength Index (ESI): The algebraic difference between monthly indices of NAO and SO is calculated for each month for the period 1951-2006. The deviation from the annual mean difference series, for the period 1951–2000, is calculated for each month and this anomaly series is then divided by the standard deviation of the annual mean difference series for the same period. ESI tendency is the difference between April and January ESI values.

Discussion

30-year running correlation coefficients between ESI tendency and summer monsoon rainfall over different sub-divisions of India have been computed for serial 27 epochs during 1951-2006. We found out the number of epochs showing statistically significant relationship for each sub-division. The standard deviation of this sub-divisional frequency distribution was 9. The sub-division for which frequency was more than one standard deviation has been considered as highly affected sub-division by ESI tendency. There were thirteen sub-divisions showing statistically significant relationship between ESI tendency and summer monsoon rainfall (Fig. 1). This Region consists of some part of north-west India (Region-1) and some part of Peninsular India (Region-2).

The time series for 1951-2006 of area weighted rainfall departures for these contiguous Regions (Region-1 and Region-2) and the Region consisting of all 13 sub-divisions (Region-3) were prepared. The correlation coefficients for 1951-2006 period between ESI tendency and these area weighted rainfall series of Region-1, Region-2 and Region-3 were -0.44, -0.46 and -0.51 respectively. All these correlation coefficients are statistically significant at 1% level (shown in Fig. 2).

Open access e-Journal
Earth Science India, eISSN: 0974 – 8350
Vol. 4(III), July, 2011, pp. 159-170
http://www.earthscienceindia.info/



	Sub-division number
Region-1	9, 10, 12
Region-2	18, 20, 21, 23, 24, 25, 26, 27, 28, 29
Region-3	9, 10, 12, 18, 20, 21, 23, 24, 25, 26, 27, 28, 29

No.	Sub-division name
1	Assam and Meghalaya
2	Naga., Mani., Mizo. And Tripura
3	Sub-Him. W. Bengal and Sikkam
4	Gangetic West Bengal
5	Orissa
6	Jharkhand
7	Bihar
8	East Uttar Pradesh
9	West Uttar Pradesh
10	Haryana, Chandigarh and Delhi
11	Punjab
12	West Rajasthan
13	East Rajasthan
14	West Madhya Pradesh
15	East Madhya Pradesh
16	Gujarat
17	Saurashtra, Kutch and Diu
18	Konkan and Goa
19	Madhya Maharashtra
20	Marathwada
21	Vidarbha
22	Chattisgarh
23	Coastal Andhra Pradesh
24	Telangana
25	Rayalaseema
26	Tamil Nadu and Pondicherry
27	Coastal Karnataka
28	North Interior Karnataka
29	South Interior Karnataka
30	Kerala

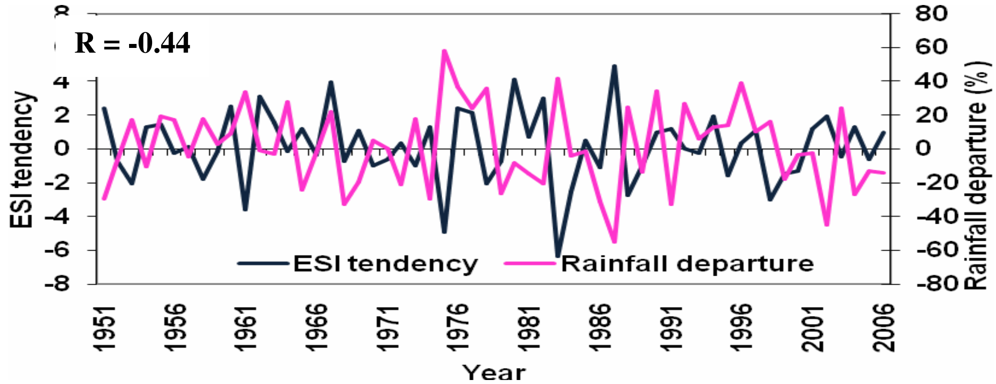
Fig. 1: The Region of strong relationship between ESI tendency and summer monsoon rainfall.

30-year running correlation coefficients of ESI tendency with area weighted rainfall series over three Regions (Region-1, Region-2 and Region-3) and ISMR are shown in Fig. 3. It suggests that the relationship of ESI tendency with area weighted rainfall series over Region-1, Region-2 and Region-3 is statistically significant at 1% level for all 30-year epochs from 1968, 1958 and 1953 to recent epochs respectively.

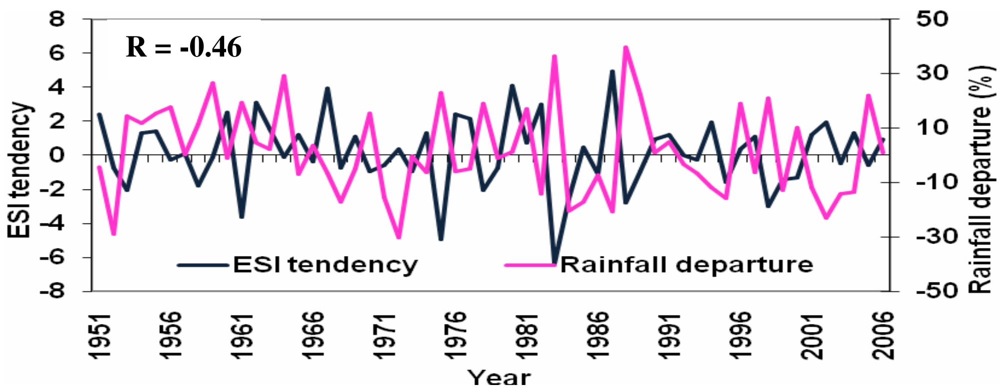
Region-3 does not contain the area of core monsoon zone as defined by Rajeevan *et al.* (2008). This analysis suggests that the rainfall over core monsoon zone is not showing significant association with ESI tendency. It may be due to the fact that the rainfall over this core monsoon zone is largely influenced by active/break spell as discussed by Goswami *et al.* (2003), Rajeevan *et al.* (2008) etc. Moreover, Kulkarni *et al.* (2009) had also pointed out that the active/break spells do not play any vital role in the rainfall variability over northwest India and southeast Peninsular India.

Open access e-Journal
Earth Science India, eISSN: 0974 – 8350
Vol. 4(III), July, 2011, pp. 159-170
http://www.earthscienceindia.info/

(a)



(b)



(c)

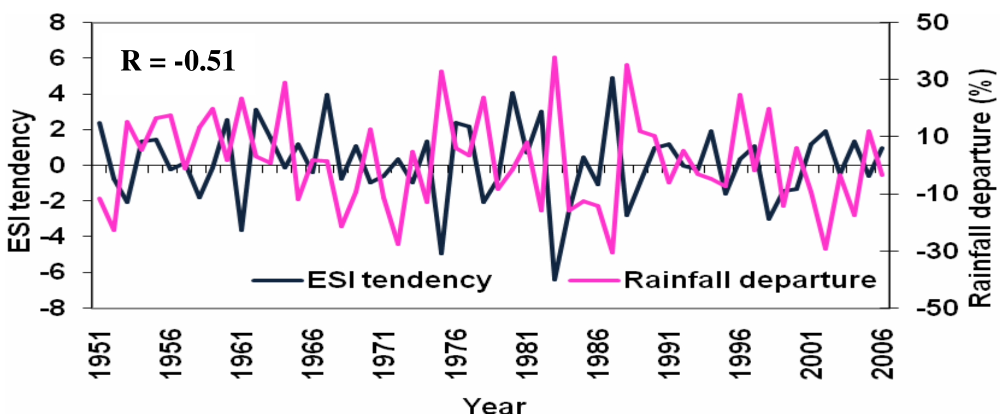


Fig.2: Inter-annual variability of ESI tendency with area weighted rainfall departures over (a) Region-1, (b) Region-2 and (c) Region-3 for 1951-2006.

Open access e-Journal
Earth Science India, eISSN: 0974 – 8350
Vol. 4(III), July, 2011, pp. 159-170
http://www.earthscienceindia.info/

(a)

(b)

(c)

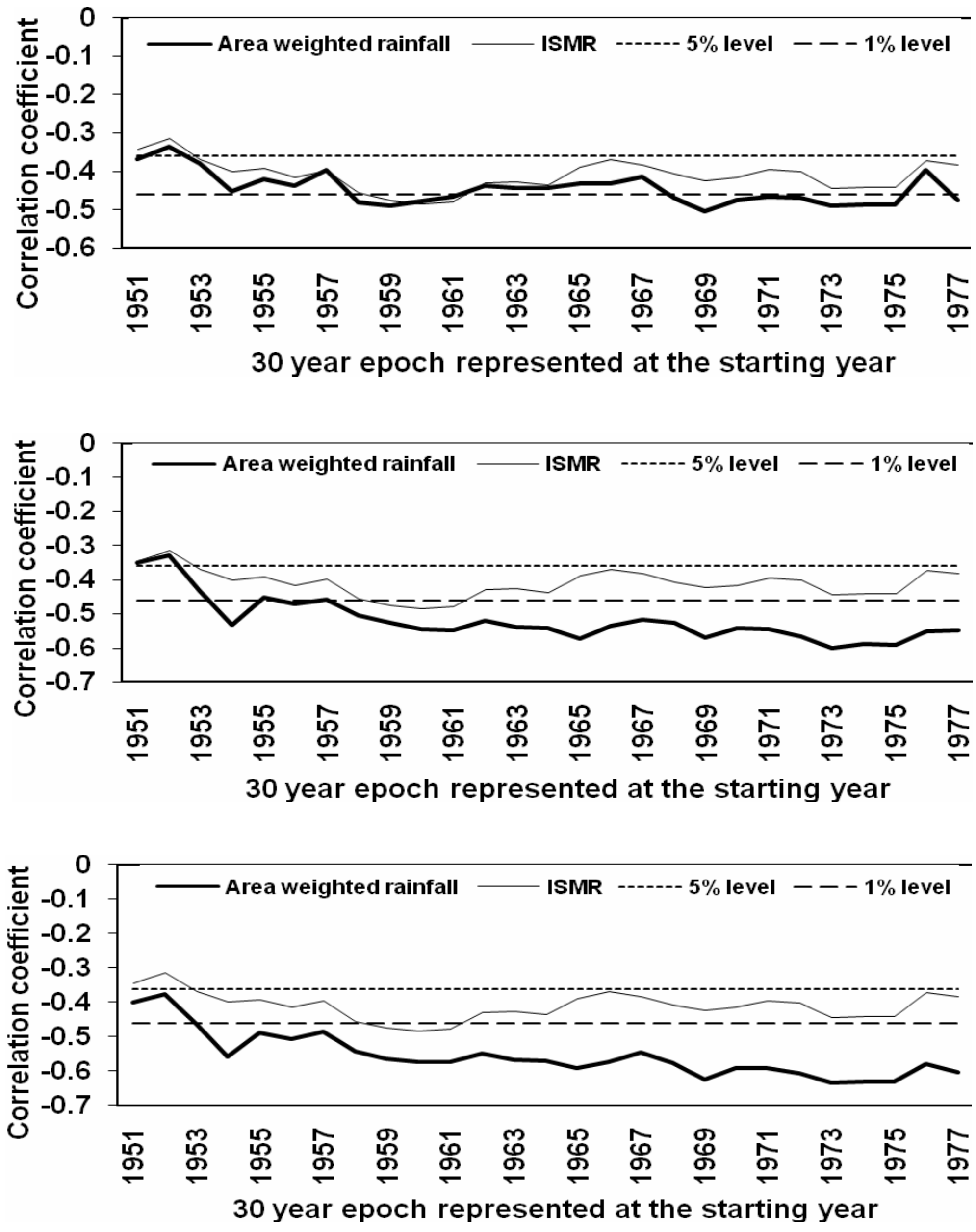


Fig. 3: 30-year running correlation coefficients of ESI tendency with ISMR and area weighted rainfall departures over (a) Region-1, (b) Region-2 and (c) Region-3 during 1951-2006.

Monthly Variation of NAO and SO during Positive/Negative ESI Tendency

Since ESI is defined on NAO and SO monthly indices, we must know monthly variability in the phases of NAO and SO indices during positive and negative phases of ESI tendency. Out of 56 years in 1951-2006, 29 years show positive ESI tendency and 27 years show negative ESI tendency. The positive ESI tendency years are 1951, 1954, 1955, 1957, 1960, 1962, 1963, 1965, 1967, 1969, 1972, 1974, 1976, 1977, 1980, 1981, 1982, 1985, 1987, 1990, 1991, 1992, 1994, 1996, 1997, 2001, 2002, 2004 and 2006. The negative ESI tendency years are 1952, 1953, 1956, 1958, 1959, 1961, 1964, 1966, 1968, 1970, 1971, 1973, 1975, 1978, 1979, 1983, 1984, 1986, 1988, 1989, 1993, 1995, 1998, 1999, 2000, 2003 and 2005.

Fig. 4 depicts the composite monthly means of NAO and SO during positive and negative ESI tendency. The composite analysis suggested that the phase of SO is negative (positive) when the ESI tendency was positive (negative) from May through September (end of monsoon season). The composite monthly means of NAO also showed opposite epochs in positive and negative ESI tendency from May through September, but the phase of NAO was not persisting during positive or negative ESI tendency like the phase of SO. During positive (negative) ESI tendency, monthly mean composites of NAO in May and June were negative (positive), in July it became positive (negative). Due to this phase change of NAO, particularly in pre-monsoon month May, we concentrated on the relationship of NAO in May with thermal field over Indian Region.

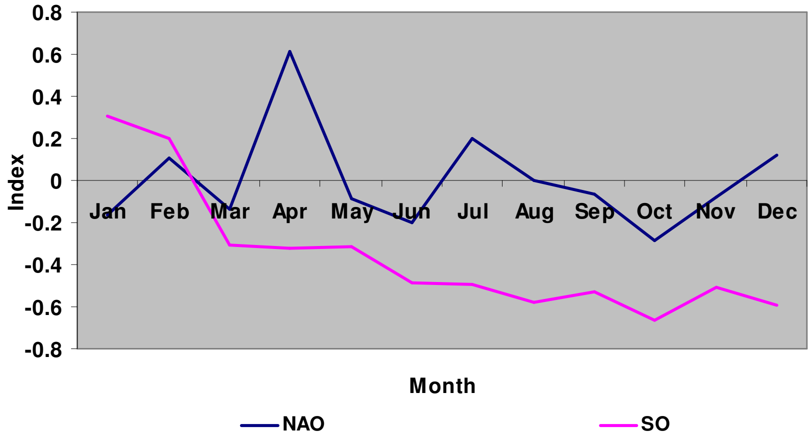
ESI Tendency and Temperature Anomaly over the Region 5°N-45°N, 60°E-100°E

ISMR is a thermally driven phenomenon. Walker (1923) used temperatures over different parts of the globe and over Indian Region for the long-range forecasting of rainfall over peninsular India. More recently, Northern hemispheric winter (January-February) temperature (Verma *et al.,* 1985; Verma, 1986), Indian east coast temperature (March mean minimum temperature over Calcutta, Vishakhapatnam, Chennai and Masulipatnam), North Indian temperature (March minimum temperature over Jaisaslmer, Jaipur and Calcutta) have been used for the forecasting of summer monsoon rainfall over India by Gowariker *et al.* (1989).

Heating over Tibetan Plateau plays a crucial role in the seasonal evolution of meridional thermal gradient (Yanai *et al.,* 1992; Wu and Zhang 1998 and Wu *et al.,* 2002) and the same is considered as an important driving mechanism for the monsoon annual cycle as suggested by Goswami *et al.* (2006), the prediction of seasonal mean depends on the interannual variability of this monsoon annual cycle. Therefore, in order to understand the relationship between ESI tendency and summer monsoon rainfall over different sub-divisions of India, the effect of ESI tendency on thermal field over Indian Region must be studied in detail.

Open access e-Journal
Earth Science India, eISSN: 0974 – 8350
Vol. 4(III), July, 2011, pp. 159-170
http://www.earthscienceindia.info/

(a)



(b)

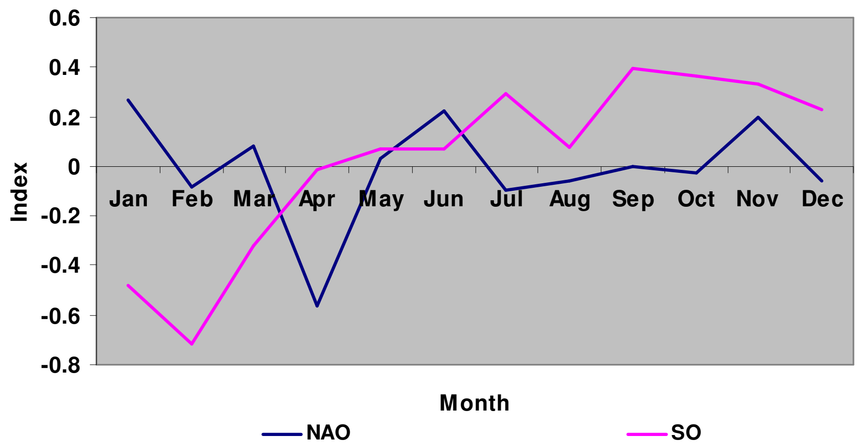


Fig. 4: The composite mean of NAO and SO during (a) positive ESI tendency years (29 years) and (b) negative ESI tendency years (27 years) in 1951-2006.

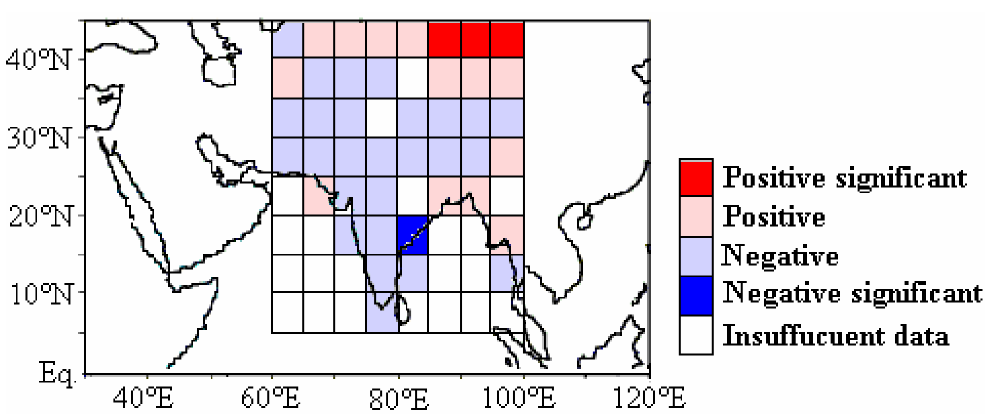


Fig. 5: Association of ESI tendency with temperature anomaly over 5° X 5° grid of the Indian Region (5°N-45°N, 60°E-100°E).

Open access e-Journal
Earth Science India, eISSN: 0974 – 8350
Vol. 4(III), July, 2011, pp. 159-170
http://www.earthscienceindia.info/

Fig. 5 shows the correlation coefficients of ESI tendency with May temperature anomaly over each 5° X 5° latitude-longitude block of the Indian Region 5°N-45°N, 60°E-100°E. It suggests that the statistically significant (at 5% level) association of ESI tendency with temperature anomaly in the month of May is direct over the Region 40°N-45°N, 85°E-100°E and is inverse over the Region 15°N-20°N, 80°E-85°E. Thus, positive (negative) ESI tendency is linked with above-normal (below-normal) temperature over the Region 40°N-45°N, 85°E-100°E and below-normal (above-normal) temperature over the Region 15°N-20°N, 80°E-85°E in May.

NAO in May and Temperature Anomaly over the Region 5°N-45°N, 60°E-100°E

As discussed in previous section, NAO in May is considered for the correlation analysis of NAO and temperature anomaly over Indian Region. Fig. 6 shows the correlation coefficients of May NAO with temperature anomaly over each 5° X 5° latitude-longitude block of the Region (5°N-45°N, 60°E-100°E) in June. It suggests an inverse association which is statistically significant at 5% level between May NAO and temperature anomaly over the Regions (40°N-45°N, 75°E-95°E) and (15°N-20°N, 70°E-80°E) in June.

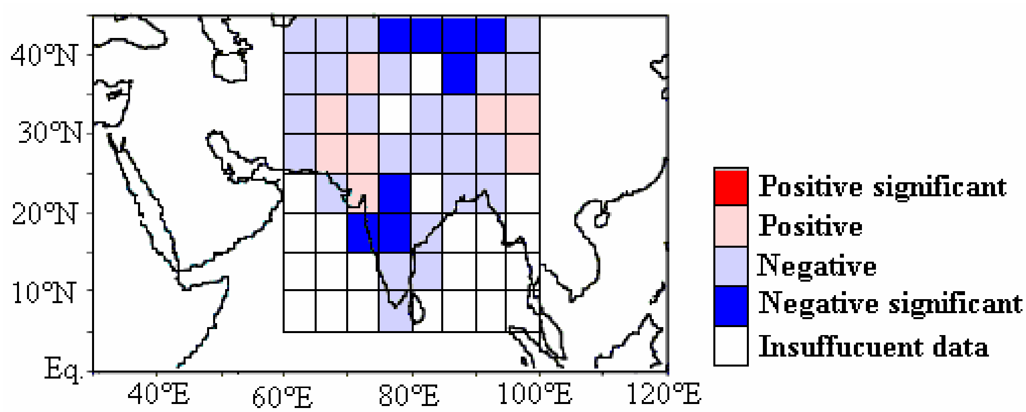


Fig. 6: Association of May NAO with temperature anomaly over 5° X 5° grid of the Indian Region (5°N-45°N, 60°E-100°E).

Thus, when ESI tendency is positive (negative) then it is linked to above-normal (below-normal) temperature anomaly over the Region (40°N-45°N, 85°E-100°E)and below-normal (above-normal) temperature anomaly over the Region (15°N-20°N, 80°E-85°E)in May. Moreover, during positive (negative) ESI tendency the phase of NAO in May is negative (positive) and it is linked with above-normal (below-normal) temperature anomaly over the Regions (40°N-45°N, 75°E-95°E)and (15°N-20°N, 70°E-80°E)in June. Thus, positive (negative) ESI tendency makes above-normal (below-normal) temperature anomaly over the Region (40°N-45°N, 85°E-95°E) in May and June. This Region is to the northern side of the normal position of upper air Tibetan anticyclone (SE of Tibetan Plateau) and warming over this Region may shift the Tibetan anticyclone at 200-hPa towards the northern side and hence reducing the rainfall activity over Indian sub-continent.

Open access e-Journal
Earth Science India, eISSN: 0974 – 8350
Vol. 4(III), July, 2011, pp. 159-170
http://www.earthscienceindia.info/

Prediction of Rainfall Departures over Region-1 and Region-2

We have developed a simple linear regression equation with ESI tendency as a predictor for predicting area weighted rainfall departures over Region-1 and Region-2. Recent 30-year period (1971-2000) is used for developing the models. The actual and estimated area weighted rainfall departures over Region-1 (model-1) and over Region-2 (model-2) are shown in Fig. 7 and Fig. 8 respectively. In both the models, the bias is found to be almost zero and root mean square error (RMSE) is less than the standard deviation of actual area weighted rainfall departure of respective Regions. The correlation coefficients between observed and estimated rainfall departure are 0.44 and 0.46 for Region-1 and Region-2 respectively. The performance of both the models is tested for independent period 2001-2006 and it is qualitatively found to be in accordance with the actual rainfall departure of respective Region. Out of six independent sample years five years are qualitatively well predicted by model-1 and model-2. Thus, along with another parameters affecting the rainfall activity over respective Regions ESI tendency may improve the skill of predicting rainfall over these Regions.

Conclusion

From this study following conclusions can be drawn:

1. The seasonal rainfall over core monsoon zone cannot be predicted with ESI tendency. It may be due to the large difference in time-scales of variability of ESI tendency and active/break spells of the monsoon rainfall, because the rainfall over this core monsoon zone is largely influenced by active/break spell as discussed by Goswami *et al.* (2003), Rajeevan *et al.* (2008) etc.
2. During positive (negative) ESI tendency the northeastern part of Tibetan Plateau will be warmer (cooler) in May and June.
3. ESI tendency can be used as the predictor for long-range forecasting of rainfall departures over Region-1and Region-2.

According to Flohn (1968), the anticyclone migrates in summer as far as SE Tibet because this part of the Tibetan Plateau (average elevation 4.5 km) acts as a source of heat. When ESI tendency is positive then the Region 40°N-45°N, 85°E-95°E will be warmer in May and June. This heating shifts the upper air Tibetan anticyclone to the northeastern side of its normal position, which shifts the tropical easterly jet to the north of the normal position. Therefore, as suggested by Chen and van Loon (1987), it reduces the strength of tropical easterly jet and Tibetan anticyclone gets weaken during warm summers over India and hence reduces the rainfall activity over India.

Acknowledgment: The authors are grateful to the Director, I.I.T.M. for providing necessary facilities for completing this study and to Head, Forecasting Research Division for encouragement and valuable suggestions. The authors are thankful to DST Government of India for funding.

Open access e-Journal
Earth Science India, eISSN: 0974 – 8350
Vol. 4(III), July, 2011, pp. 159-170
http://www.earthscienceindia.info/

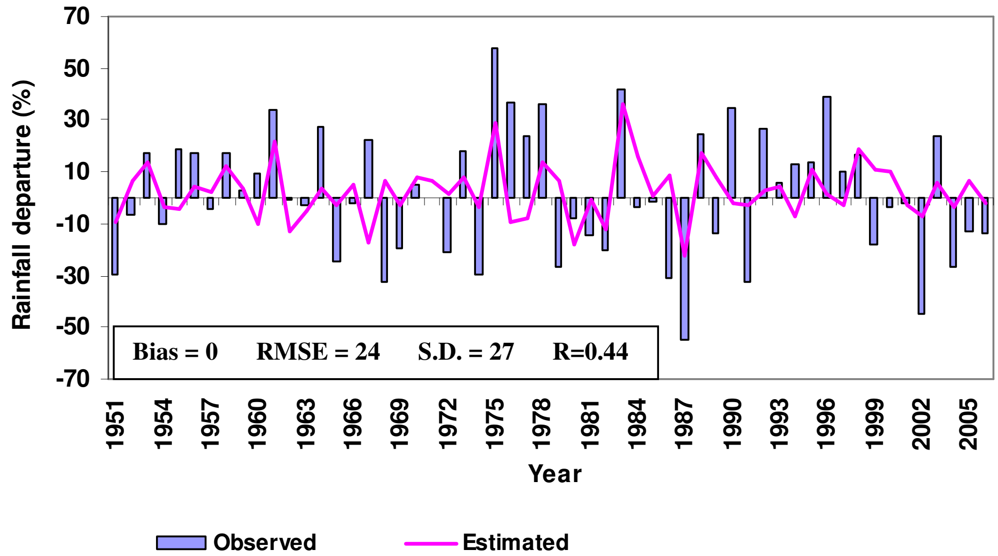


Fig. 7: Actual and estimated area weighted rainfall departure of Region-1.

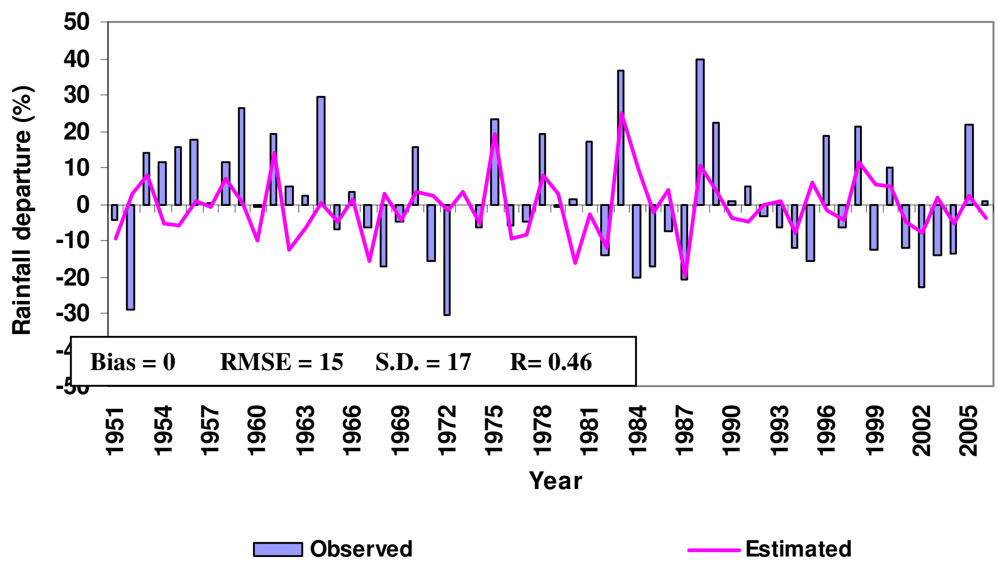


Fig. 8: Actual and estimated area weighted rainfall departure of Region-2.

References

Chen, T. C. and Van Loon, H. (1987) Interannual variation of tropical easterly jet. Monthly Weather Review, v. 115, pp. 1739-1759.

Flohn, H. (1968) Contribution to a meteorology of the Tibetan highlands. Department of Atmospheric Science, Colorado State University, Fort Collins**,** v. 130**,** pp.1-120.

Gowariker, V., Thapliyal, V., Sarkar, R. P., MandaI, G. S. and Sikka, D. R. (1989) Parametric and power regression models- new approach to long range forecasting. Mausam, v. 40, pp. 115- 122.

Goswami, B. N. , Ajayamohan, R. S. , Prince K. Xavier and Sengupta, D. (2003) Clustering of synoptic activity by Indian summer monsoon intraseasonal oscillations. Geophysical Research Letters, v. 30(8), 1431 doi:10.1029/2002GL016734

Goswami, B.N., Wu, G. and Yasunari, T. (2006) The Annual Cycle, Intraseasonal Oscillations, and Roadblock to Seasonal Predictability of the Asian Summer Monsoon. Journal of Climate—Special Section, v. 19, pp. 5078-5099.

Kakade, S. B. and Dugam, S. S. (2000) Simultaneous effect of NAO and SO on the monsoon activity over India. Geophysical Research Letters, v. 27, pp. 3501-3504.

Kakade, S. B. and Dugam, S. S. (2006) Spatial monsoon variability with respect to NAO and SO. J. Earth System Science, v. 115, pp. 601-606.

Krishna Kumar, K.0, Soman, M. K. and Rupa Kumar, K. (1995) Seasonal forecasting of Indian summer monsoon rainfall : A review. Weather, v. 50, pp. 449-467.

Krishnamurti, T. N., Bhalme, H. N. (1976) Oscillations of Monsoon System. Part I. Observational Aspect. Journal of Atmospheric Sciences, v. 33, pp. 1937-1954.

Kulkarni, Ashwini, Sabade, S. S. and Kripalani, R. H. (2009) Spatial variability of intra-seasonal Oscillations during extreme Indian monsoons. *International* Journal of Climatology, v. 29, pp. 1945-1955.

Murakami, T. (1987) Effects of the Tibetan Plateau. In: *C. P. Chang and T.N. Krishnamurti (eds.),* Monsoon Meteorology. Oxford University Press, pp. 235-270.

Raghavan, K. (1973) Tibetan anticyclone and tropical easterly jet. Pure and Applied Geophysics PAGEOPH, v. 110, pp. 2130-2142.

Rajeevan, M., Gadgil, S. and Bhate, J. (2008) Active and break spells of the Indian summer monsoon. National Climate Centre research report 6, pp. 1-46.

Rao, K. N. (1965) Seasonal Forecasting-India. WMO Tech. Note 66, pp. 17-30.

Thapliyal, V. (1986) Long-range forecasting of monsoon rainfall in India. World Meteorological Orgn., Geneva WMO/TD 87, pp. 723-732.

Verma, R. K. (1986) Predictive relationship between northern Hemispheric surface air temperature and Indian summer monsoon. (Long-Range Forecasting Research Report Series, No.6 Vol.-II) MWD/Technical Document, v. 87, pp. 798-806.

Verma, R. K., Subramaniam, K. and Dugam, S. S. (1985) Interannual and long term variability of the summer monsoon and its possible link with Northern Hemispheric surface air temperature. Proceeding of Indian Academy of Science (Earth Planetary Science), v. 94, pp. 187-199.

Walker, G. T. (1923) Correlation in seasonal variation of weather VIII: A preliminary study of world weather (World Weather-I). Mem. India Dept., v. 24, pp. 75-131.

Wu G. and Zhang, Y. (1998) Tibetan Plateau forcing and the monsoon onset over South Asia and the Southern China Sea. Monthly Weather Review, v. 126, pp. 913–927.

Wu, G., Xin, L., Qiong, Z., Jiangyu, M., Yimin, L. and Weiping, L. (2002) Progresses in the study of the climate impacts of the elevated heating over the Tibetan Plateau. Climate Environmental Research, v. 72, pp. 184–201.

Yanai, M. and Li, C. (1994) Mechanism of heating and the boundary layer over the Tibetan Plateau. Monthly Weather Review, v. 122, pp. 305-323.

Yanai, M., Li, C. and Song, Z. (1992) Seasonal heating of the Tibetan Plateau and its effects of the evolution of the Asian summer monsoon. Journal of the Meteorological Society of Japan, v. 70, pp. 189-221.

Ye, D. (1981) Some characteristics of the summer circulation over the Qinghai-Xizang (Tibet) Plateau and its neighborhood. Bulletin of American Meteorological Society, v. 62, pp. 14-19.

Yimin, L.I.U., Hoskins, Brian and Blackburn, Michael (2007) Impact of Tibetan Orography and Heating on the Summer Flow over Asia. J. Meteorological Society of Japan, v. 85B, pp. 1-19.