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Imprints of Teleconnection between ENSO and Climate Extremes in India

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Abstract

El Nino/Southern Oscillation (ENSO) remains the most important coupled ocean–atmosphere phenomenon to cause global climate variability on seasonal to interannual time scales. Therefore, an attempt is made in this study to analyze objectively defined indices of rainfall extremes over India, in terms of their frequencies and intensities, in relation to ENSO events, using daily station data for precipitation at stations well spread across India. An assessment of the association between cyclones crossing Indian coastline; and ENSO has also been carried out. The analysis reveals that ENSO is positively associated with annual count of dry spells but it is restricted only to the north and the interior where rainfall amount is less and negatively correlated with mean duration with more universal effect. ENSO is significantly correlated with the number of depressions crossing the Indian coast. The relationship between climate extremes and ENSO indicates potential for long-range prediction of these extremes.

Keywords

Linkage, Large Scale Phenomena, Climate Extreme, Monsoon, ENSO. Climate, Data Analysis, Monsoons, Natural Hazards.

Introduction

The extreme climate events such as heavy rainfall spells, tropical cyclones are linked to the large-scale circulation phenomena in their physical mechanism. The notion of conditional instability of the second kind (Ooyama, 1963, 1982; Charney and Eliassen, 1964) is one example of thermodynamic interactions between cumulus and large scale circulations. This notion was postulated to explain nonlinear intensification of a pre-existing weak, low level cyclonic circulation into a mature tropical cyclone, as a co-operative process between large scale diabatic heating and cumulus scale entrainment and detrainment. The physical linkage between the extreme climate events and large-scale circulation is of great use in terms of parameterization in numerical models. Also, since the large scale phenomena such as ElNINO and southern Oscillation (ENSO) are predicted and forecasted by national and international agencies few months to a year before the occurrence of the phenomena, these forecasts can be used in the prediction of the extreme climate events in the region if the linkage between the large scale phenomena and extreme climate events are well established.

In Indian region, by the 1900s investigators had identified two large scale

forcings important for predicting monsoon anomalies: Himalayan/Eurasian snow extent and the ENSO (Blanford, 1884, Walker, 1918). The El Nino/Southern Oscillation (ENSO) exemplify the dominant coupled ocean-atmosphere mode of the tropical Pacific (Cane, 1992). The oceanic component of this phenomenon, El Niño, and its atmospheric counterpart, Southern Oscillation, exhibit co-variability at 2-7 year time scales. However, there have been substantial variations in ENSO frequency, intensity and duration over the last century. On inter-annual time scales, a significant fraction of the global climatic variability can be associated with ENSO. In the Northern Hemisphere winter, up to 30% of the observed variance of the large-scale atmospheric circulation can be attributed to ENSO (Horel and Wallace, 1981; Trenberth et al., 1998). The global impacts of ENSO primarily stem from the changes in the strength and location of tropical Pacific convection that, in turn, trigger changes in the global atmospheric circulation (Cane and Clement, 1999). The ENSO extreme phases are often associated with major episodes of floods and droughts (e.g., Trenberth and Guillemot, 1996; Barlow et al., 2001) in many locations worldwide.

The Indian summer monsoon circulation influences more than 60% of world's population (Webster et.al., 1998) due to its large-scale impact on agriculture, water resources, power generation and overall economy (Mooley et.al., 1981; Mooley and Parthasarathy, 1983; Parthasarathy et.al., 1988). The contribution of agriculture to the Gross Domestic Product (GDP) has decreased substantially since independence and led to the expectation that the impact of the monsoon on the economy would have also decreased. However, a study of the variation of the GDP and the monsoon has revealed that the impact of severe droughts on GDP has remained between 2 and 5% of GDP throughout (Gadgil and Gadgil, 2006). The prediction of the interannual variation of Indian Summer Monsoon Rainfall (ISMR) particularly for the occurrence and nonoccurrence of the extremes (i.e. droughts and excess rainfall seasons) continues to be extremely important. The present skill of atmospheric and coupled models in predicting the Indian monsoon rainfall is not satisfactory, and the ability is particularly very poor as these models fail to predict the extremes (Gadgil et.al., 2005).

In the recent past, there has been an increasing effort to understand the causes of Indian rainfall variability in relation to large-scale atmospheric and oceanic circulation features. The association between large scale forcing such as ENSO and variations in ISMR has been studied by many authors (Pant and Parthasarathy, 1981; Mooley and Parthasarathy, 1983; Bhalme et al., 1983; Rasmusson and Carpenter, 1982, 1983; Shukla and Paolino, 1983; Parthasarathy and Pant, 1985; Gregory, 1989; Webster and Yang, 1992; Webster et.al., 1998; Gadgil et.al., 2007). Weakening of relationship between ENSO and monsoon has been observed (Kumar et.al., 1999). Present study enhances the wealth of literature in terms of approach and extension. The approach is discussed in the section entitled as data and methodology. Most of the studies carried out on tele-connection of ENSO in India are with extremes in monsoon. We have extended this to other extremes including cyclone crossing Indian coastline and heatwaves.

The remainder of the paper is organised as follows. Next section deals with the

data and methodology used in the study. Subsequent section presents the analyses and interpretation. Finally, conclusion with limitations and suggestions for future work is mentioned.

Data and Methodology

Daily rainfall data for various stations across India have been procured from India Meteorological Department Pune, India. Two characteristic of daily rainfall at stations viz. heavy rainfall event and dry spell in monsoon season have been considered. Heavy rainfall has been defined as the daily rainfall equal or greater than 5cm (Biswas and Bhadram, 1987; Dubey and Balakrishnan 1992). Dry day is the day for daily rainfall less than 1mm. The heavy rainfall event and dry spell have been taken the day or set of consecutive days with daily rainfall with their respective threshold. There are two reasons for combining consecutive days of heavy rainfall and dry day into a single event. First, we wanted to focus on events rather than rain/dry days, and to the extent that consecutive days of heavy rainfall are likely to correspond to the same weather pattern. Second, this approach allows us to explore characteristics such as the mean or maximum duration of these wet/dry spells. Data on cyclone have been extracted from the map of Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea, a 1996 publication of India Meteorological Department. Here cyclone is broadly classified into three categories based on wind speed and pressure – Depression (D), Storm (S) and Severe Storm (SS). The cyclone that crossed the Indian coastline of particular state has been determined with the help of a Geographical Information System.

When one deals with ENSO, a key issue is the choice of the characteristics of the phenomenon to be used for analysis. The monthly values of the Southern Oscillation Index (SOI), a commonly used measure of ENSO (e.g. Pan and Oort, 1983; Rasmusson and Carpenter, 1983; Hastenrath and Heller, 1977), have been used here. The all-India summer monsoon rainfall (ISMR) series is an area-averaged measure of total summer monsoon rainfall over India (Mooley and Parthasarathy, 1984a; Sontakke et. al., 1993). This series has been extensively used for analyses of monsoon variability (Parthasarathy, 1984; Mooley and Parthasarathy, 1984b; Pant et. al., 1988). The climate extreme data have been regressed against SOI and the significance of the slope of the regression line has been computed applying F-test. Correlation coefficient values between climate extremes and SOI have been computed to know the extent of linkage between them.

Analyses and Interpretation

Correlation values between the SOI and the annual counts and mean duration of heavy rainfall events reveal that most of the stations do not show significant correlation between SOI and the annual count of heavy rainfall events (Table 1). Only Jodhpur, Sawai Madhopur and Karwar have depicted significant relation between the two phenomena. It is also evident that most of the stations have depicted insignificant correlation between SOI and mean duration of the heavy rainfall events. Only Sawai Madhopur and Ongole have significant correlation between the two. Correlation coefficients between SOI and seasonal count and mean duration of dry spell at 32 stations across India depict that

Table - 1 : Results of Correlation Analysis between SOI and Heavy Rainfall Event Characteristics

S.N.	Station	Annual Count	Mean Duration
1	Delhi	0.21	0.09
2	Jodhpur	0.26	0.24
3	Gaya	-0.10	-0.03
4	Raipur	0.11	-0.08
5	Tejpur	-0.18	0.00
6	Alipur	-0.08	0.05
7	Pune	0.10	0.10
8	Goa	0.16	-0.03
9	Warangal	0.06	0.10
10	Vishakhapatnam	0.28	0.10
11	Kozikode	0.09	0.05
12	Arcot	-0.23	-0.03
13	Baroda	0.11	-0.06
14	Nagpur	0.21	-0.15
15	Damoh	0.23	-0.07
16	Sawai Madhopur	0.31	0.20
17	Azamgarh	0.10	0.04
18	Sambalpur	-0.06	0.00
19	Allahabad	0.04	0.00
20	Gonda	0.09	0.12
21	Bijapur	0.17	0.20
22	Amraoti	0.08	0.04
23	Belgaum	0.07	-0.01
24	Gulbarga	-0.04	0.07
25	Nalgonda	0.08	0.12
26	Kakinanda	0.12	-0.04
27	Ongole	-0.19	-0.30
28	Koraput	-0.02	-0.13
29	Karwar	0.24	0.00
30	Shimoga	-0.11	-0.09
31	Tanjavore	-0.07	-0.19
32	Hassan	-0.14	-0.09

Note: Bold values are significant at 5% level.

Table - 2 : Results of Correlation Analysis between SOI and Dry Spell Characteristics

S.N.	Station	Count	Mean Duration
1	Delhi	0.21	-0.29
2	Jodhpur	0.24	-0.29
3	Gaya	0.36	-0.39
4	Raipur	0.30	-0.43
5	Tezpur	-0.06	-0.04
6	Alipur	0.04	-0.27
7	Pune	0.26	-0.33
8	Goa	-0.21	-0.37
9	Warangal	0.23	-0.25
10	Vishakhapatnam	0.21	-0.25
11	Kozhikode	0.09	-0.19
12	Arcot	0.34	-0.29
13	Baroda	-0.16	0.03
14	Nagpur	0.24	-0.43
15	Damoh	0.22	-0.33
16	Sawai Madhopur	0.25	-0.29
17	Azamgarh	0.23	-0.11
18	Sambalpur	0.17	-0.25
19	Allahabad	0.22	0.02
20	Gonda	0.26	-0.35
21	Bijapur	0.06	-0.10
22	Amraoti	0.07	-0.26
23	Belgaum	-0.06	-0.18
24	Gulbarga	0.11	-0.10
25	Nalgonda	0.15	-0.17
26	Kakinanda	0.19	-0.27
27	Ongole	0.14	-0.16
28	Koraput	-0.01	-0.12
29	Karwar	-0.03	-0.36
30	Shimoga	0.08	-0.04
31	Tanjavore	0.12	0.01
32	Hassan	0.17	-0.20

Note: Bold values are significant at 5% level.

nearly half of the stations selected for the study show significant positive correlation between SOI and seasonal count of dry spell (Table 2). Most of the stations have an interior location (Fig. 1a). One also finds a north-south contrast and stations with significant positive correlations are mostly located in the north. Further, most of the stations depict significant negative correlation between SOI and mean duration of dry spell. The locations of these stations are in the interior (Fig. 1b). The north-south contrast is not, however, striking unlike in the case of the count. Here, it is noteworthy that the impact of ENSO on the mean duration of dry spell is more prominent than that on the seasonal count of the spell. The positive correlation of SOI with number of dry spells but negative correlation with duration is suggestive of the fact that number and duration are negatively related.

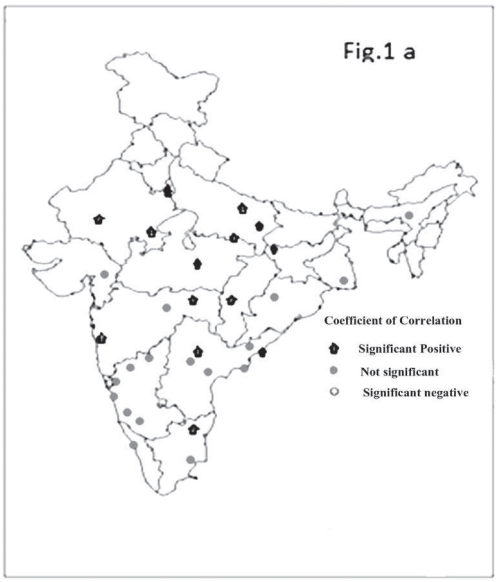

Fig.1a : Correlation coefficients between SOI and Count of Dry Spell.

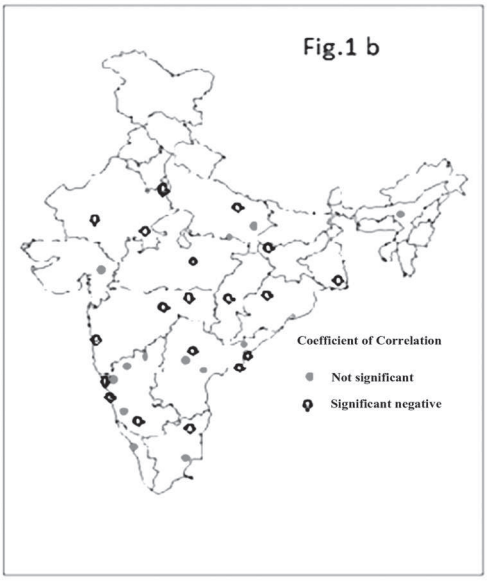

Fig.1b : Correlation coefficients between SOI and Duration of Dry Spell.

Total number of cyclones crossing the Indian coastline has been regressed with SOI indices. There is no significant correlation between the total number of cyclones crossing the Indian coastline and SOI (r= 0.15). Although, one finds a statistically significant correlation between SOI and total number of depressions (r= 0.26) even this correlation is not very high. It is also demonstrated by regression analysis between total number of depressions crossing the Indian coastline and SOI, is significant at 5% level (Fig. 2). The relationship between SOI and number of storms (r= 0.07) and severe storms (r = 0.01) is not statistically significant (Table 3); this is primarily because number of storms and severe storms is limited. Annual totals have also been calculated for the cyclones crossing the coastline of individual states.

Table - 3 : Cross correlation between cyclone, ISMR and SOI

	Total	**D-total**	**S-total**	**SS-total**	**AISMR**	**SOI**
Total	1					
D-total	0.72	1.00				
S-total	0.29	-0.12	1.00			
SS-total	0.32	0.10	-0.15	1.00		
AISMR	0.18	0.24	0.03	-0.03	1.00	
SOI	0.15	0.26	0.07	0.01	0.50	1.00

Note: Total implies total number of cyclone crossing the Indian coastline, D for Depression, S for Storm and SS for Severe Storm crossing the coastline of India. Bold values are significant at 5% level.

These totals are regressed against the SOI. Virtually no significant correlation has been found between the total annual number of cyclones crossing the coastline of various states and SOI. The analysis thus indicates that SOI is more influential in generating monsoon depressions. Further, a significant positive correlation (r = 0.50) between SOI and ISMR, reflects that monsoon is influenced positively with SOI. Since temperature indicator of ENSO such as sea surface temperature anomaly of Nino 3.4 region is negatively correlated with SOI, its linkage with ISMR is negative. Therefore, the ENSO phenomenon, which is most often generated by El-Nino, has negative impact on monsoon.

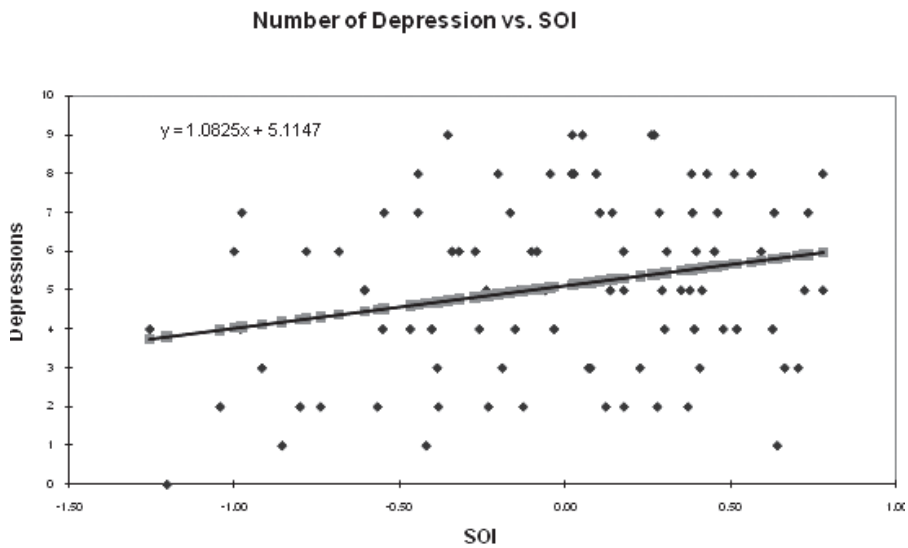

Fig.2 : Plot of Number of Depressions against SOI.

Correlation coefficient between SOI and heat spell over India (r = 0.24) shows virtually no significant relation. This is suggestive of the fact that other factors such as location with respect to water bodies and other micro-level phenomena including local winds, such as, Loo, deforestation and some anthropogenic interventions play more important role in heat spells to happen.

Conclusions

Since ENSO is predicted and forecasted by international and national agencies a few months to a year before the occurrence of this phenomena, it was thought, one could use these forecasts in the prediction of the extreme climate events in the region if the linkage between the large scale phenomena and extreme climate events are well established. The analysis carried out so far indicates that ENSO has a positive impact on annual count of dry spells but it is restricted only to the north and the interior where rainfall amount is less. Its impact on mean duration is negative and more universal. It is found to be correlated with the number of depressions crossing the Indian coast and this suggests that it can be a good predictor of monsoon rains. The study focuses on understanding only the pattern of association and not on understanding the mechanism behind such association through physical linkages. It is, therefore, necessary to extend the same for the better understanding of the physical mechanism behind the association of climate extremes in monsoon region with large scale phenomena such as ENSO.

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References

Barlow, M. Nigam, S. and Berbery, E. H. (2001): ENSO, Pacific Decadal Variability, and U.S. Summertime Precipitation, Drought, and Stream Flow. J. Climate, Vol. 14: 2105–2128.

Bhalme, H.N. Mooley, D.A. and Jadhav, S.K. (1983): Fluctuations in drought flood areas over India and relationships with the southern oscillation. Monthly Weather Review, Vol. 111: 86–94.

Biswas, B. and Bhadram, C.V.V. (1987): A study of heavy rainfall over Jaldhaka basin. Mausam, Vol. 38: 213-218.

Blanford, H. F. (1884): On the connexion of the Himalaya snowfall with dry winds and seasons of drought in India. Proc. Roy. Soc. London Vol. 37: 3-22.

Cane, M. A. and Clement, A. C. (1999): A role of the tropical Pacific coupled ocean-atmosphere system on Milankovitch and millennial timescales. Part II: Global Impacts. In Mechanisms of Global Climate Change at Millennial Time scales, P. U. Clark, R. S. Webb, and L. D. Keigwin (Eds.), Geophysical Monograph 112, American Geophysical Union, Washington, D.C., 373-383.

Cane, M. A. (1992): Tropical Pacific ENSO models: ENSO as a mode of the coupled system; In Climate System Modeling, K. E. Trenberth (Ed.), Cambridge University Press, 583-616.

Charney, J. G. and Eliassen, A. (1964): On the growth of the hurricane depression. J. Atmos. Sci., Vol. 21: 68-75.

Dubey, D.P. and Balakrishnan, T. K. (1992): A study of heavy and very heavy rainfall over Madhya Pradesh for the period 1977-1987. Mausam, Vol. 43: 326-29.

Gadgil, S. Rajeevan, M. and Nanjundiah, R. (2005): Monsoon prediction: Why yet another failure?. Curr. Sci. Vol. 88: 1389–1400.

Gadgil, Sulochana. and Gadgil, Siddhartha. (2006): The Indian Monsoon, GDP and Agriculture. Econ. Pol. Wkly., Vol. XLI: 4887–4895.

Gadgil, S. Rajeevan, M. and Francis, P.A. (2007): Monsoon variability: Links to major oscillations over equatorial pacific and Indian oceans. Current Science Vol. 93: 2 182-194.

Gregory, S. (1989): Macro-regional definitions and characteristics of Indian summer monsoon rainfall 1871–1985. International Journal of Climatology Vol. 9: 465–483.

Hastenrath, S. and Heller, L. (1977): Dynamics of climate hazards in northeast Brazil; Quarterly Journal of Royal Meteorological Society, Vol. 103: 77-92.

Horel, J. D. and Wallace, J. M. (1981): Planetary scale atmospheric phenomena associated with the Southern Oscillation; Mon. Wea. Rev., Vol. 109: 813-829.

Kumar, K. K. Rajagopalan, B. and Cane, M. A. (1999): On the weakening relationship between the Indian monsoon and ENSO. Science, Vol. 284: 2156-2159.

Mooley, D.A. Parthasarathy, B. Sontakke, N.A. and Munot, A.A. (1981): Annual rainwater over India, its variability and impact on the economy. Journal of Climatology, Vol. 1: 167-186.

Mooley, D.A. and Parthasarathy, B. (1983): Indian summer monsoon and El Niño. Pure and Applied Geophysics, Vol. 121: 339–342.

Mooley, D.A. and Parthasarathy, B. (1984a): Fluctuations of all-India summer monsoon rainfall during 1871-1978. Climatic Change, Vol. 6: 287-301.

Mooley, D.A. and Parthasarathy, B. (1984b): Variability of the Indian summer monsoon and tropical circulation features. Monthly Weather Review, Vol. 111: 967-978.

Ooyama, K. (1963): A dynamical model for the study of tropical cyclone development. Geofisica Internacional, Vol. 4: 187-198.

Ooyama, K. (1982): Conceptual evolution of the theory and modeling of the tropical cyclone. J. Meteor. Soc. Japan, Vol. 60: 369-380.

Pan, Y.H. and Oort, A.H. (1983): Global climate variations connected with sea surface temperature anomalies in the eastern equatorial Pacific Ocean for the 1958-1973 period. Monthly Weather Review, Vol. 111: 1244-1258.

Pant, G.B. and Parthasarathy, B. (1981): Some aspects of an association between the southern oscillation and Indian summer monsoon. Archives of the Meteorological and Geophysical Bioklimatological Series, Vol. 29: 245–252.

Pant, G.B. RupaKumar, K. Parthasarathy, B. and Borgaonkar, H.P. (1988): Long-term variability of the Indian summer monsoon and related parameters. Advances in Atmospheric Science, Vol. 5: 469-481.

Parthasarathy, B. (1984): Inter-annual and long-term variability of Indian summer monsoon rainfall. Proceedings of Indian Academy of Sciences (Earth Planet. Sci., Vol. 93: 371-385.

Parthasarathy, B. and Pant, G.B. (1985): Seasonal relationship between Indian summer monsoon rainfall and southern oscillation. Journal of Climate, Vol. 5: 369–378.

Parthasarathy, B. Munot, A.A. and Kothawale, D.R. (1988) Regression model for estimation of Indian food grain production from summer monsoon rainfall. Agricultural and Forest Meteorology, Vol. 42: 167–182.

Rasmusson, E.M. and Carpenter, T.H. (1982): Variations in topical sea surface temperature and surface wind fields associated with the southern oscillation–El Niño. Monthly Weather Review, Vol. 110: 354–384.

Rasmusson, E.M. and Carpenter, T.H. (1983): The relationship between eastern Equatorial Pacific sea surface temperatures and rainfall over India and Sri Lanka. Monthly Weather Review, Vol. 111: 517-528.

Shukla, J. and Paolino, D.A. (1983): The southern oscillation and long range forecasting of summer monsoon rainfall over India. Monthly Weather Review, Vol. 111: 1830–1837.

Sontakke, N.A. Pant, G.B. and Singh, N. (1993): Construction of all-India summer monsoon rainfall series for the period 1844-1991. Journal of Climatology, Vol. 6: 1807-1811.

Trenberth, K. E. and Guillemot, C. J. (1996): Physical Processes involved in the 1988 Drought and 1993 Floods in North America. Journal of Climate, Vol. 9: 1288–1298.

Trenberth, K. E. Branstator, G. W. Karoly, D. Kumar, A. Lau, N. C. Ropelewski, C. (1998): Progress during TOGA in understanding and modeling global teleconnections associated with tropical sea surface temperatures. Journal of Geophysical Research (Atmospheres), Vol. 103: 14291-14324.

Walker, G. T. (1918): Correlation in seasonal variations of weather. Quarterly Journal of the Royal Meteorological Society, Vol. 44: 223–224.

Webster, P.J. and Yang, S. (1992): Monsoon and ENSO: selectively interactive systems. Quarterly Journal of the Royal Meteorological Society, Vol. 118: 877–926.

Webster, P.J. Magana, V.O. Palmer, T.N. Shukla, J. Tomas, R.A. Yanai, M. and Yasunari, T. (1998): Monsoons: processes, predictability, and the prospects for prediction. Journal of Geophysical Research, Vol. 103: 451–14 510.

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