Relationship between Indian Ocean dipole mode and summer monsoon

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(Received 9 May 2007, Modified 22 October 2007)
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1. Introduction

The meteorologists have made attempts to predict the monsoon rainfall over Indian subcontinent since the beginning of the past century (Walker, 1910; 1924) which are still being pursued (Gowarikar et al., 1991; Singh & Pai, 1996; Singh, 1998). The main focus of such studies was to identify the suitable predictors for the development of statistical methods for the monsoon prediction. The phenomenon for predicting planetary scale air-sea interactions represented by El-Nino-Southern Oscillation (ENSO) was discovered by Bjerkenes (1969). The ENSO-monsoon relationship has been extensively studied by Sikka, 1980; Rasmussen & Carpenter, 1983; Shukla & Paolino, 1983; Chang & Krishnamurti, 1987; Singh et al., 2000; Singh, 2001 and others. Webster & Yang, 1992; Wang, 1995 and Kripalani & Kulkarni, 1997 have shown that ENSO-monsoon connections are very complex though the general type of relationships between ENSO and ISMR is known since long. Indian Ocean dipole mode (IODM) is the new focus of research (Webster et al., 1999; Saji et al., 1999; Behra et al., 1999; Iizuka et al., 2000; Kripalani and Kumar, 2004; Gadgil et al., 2007) for regional climate variability over the Indian subcontinent. IODM has been defined as the SST difference between the Sea Surface Temperature (SST) anomalies over the tropical western Indian Ocean area bounded by 50° E - 70° E, 10° S - 10° N and the tropical southeastern Indian ocean area bounded by 90° E - 110° E, 10° S - equator (Ashok, et al., 2001). Gadgil et al., 2007 have introduced the atmospheric component of IODM as EQUINOX and linked it to performance of monsoon. The IODM involves oscillation of SST between positive and negative phases. A positive phase means cooling of waters in the eastern Indian ocean which leads to droughts in Indonesian region and heavy rains in India whereas the negative phase of IODM brings warmer water and greater precipitation in the eastern near-equatorial
Indian Ocean region. The main objective of the present study is to examine the relationships of IODM, western and eastern poles with the monsoon onset over Kerala as well as monsoon rainfall distribution over India.

2. Data & methodology

The sub-divisionwise monthly and seasonal Indian summer monsoon rainfall data and the monsoon onset dates over Kerala for the period (1960-2002) published in the quarterly Journal Mausam in the article ‘Weather in India’ have been utilized. The time-series of monthly IODM index (IODMI) derived from GISST data have been used (Saji & Yamagata, 2003). SST data of western and eastern poles for the period 1960-1999 obtained from GISST data have also been utilized. The location of western and eastern poles of IODM are shown in Fig. 1.

Normally, the amplitude of IODM is maximum during spring (October-November). Thus the year-to-year variation in IODM index is maximum during October-November. During March-April the interannual variation is small which increases from May onwards and peaks in autumn. Three leadtime correlations between IODM indices & western and eastern poles’ SSTs with monthly and seasonal monsoon rainfall of each sub-division of India have been computed. To establish the relationship of IODM & onset date over Kerala two leadtime correlations pertaining to April & May have been computed. Correlations between the SSTs in western pole during April-May and onset date over Kerala have also been computed. For this purpose 1st June is considered as the normal onset date for counting the onset date anomaly, i.e., if onset date is 25th May the onset date anomaly is taken as -7 and if the onset date is 8th June it is taken as 7.

3. Results & discussion

3.1. Relationship between IODM and summer monsoon onset over Kerala

Fig. 2 shows that the correlations of onset date over Kerala with dipole index & western pole SST are positive which implies that the positive phase of dipole during April-May causes delayed onset of monsoon over Kerala. This is also supported by the correlations with SST in the western pole. Warmer SST anomalies in the western pole are associated with delayed monsoon onset. May SST of western pole is significantly correlated with monsoon onset having the Correlation Coefficient (CC) of +0.42, which is significant at the 99% level. It has been observed that SST anomalies in the western pole generally amplify during May (approximately two-third occasions).

3.2. Relationship between IODM and summer monsoon rainfall over different meteorological sub-divisions of India

To find out the relationships between IODM and summer monsoon rainfall over different sub-divisions, one/two/three months lag correlations between IODM indices and seasonal/monthly monsoon rainfall over each sub-division have been computed. However, the relationships between IODM and seasonal rainfall only have been emphasized and graphically presented.

3.2.1. Seasonal rainfall

3.2.1.1. 3 months lag relationships

It is seen from Fig. 3 that 3 months lag CC between IODM index and seasonal rainfall is highest for coastal Andhra Pradesh which is -0.5 (significant at the 99% level). The corresponding CCs for some other meteorological sub-divisions of peninsular India are: Rayalseema (-0.4) Telangana, Tamil Nadu & Pondicherry, north Interior Karnataka and south Interior Karnataka (-0.2). Outside peninsular India the significant CCs are for Marathwada and Vidarabha, west Rajasthan and Jammu & Kashmir (-0.3). Therefore, IODM Index of March can give indications of seasonal summer monsoon rainfall over the above mentioned meteorological sub-divisions of India.

3.2.1.2. 2 months lag relationships

It is seen from Fig. 3 that there exists a negative relationship between April IODM index and summer monsoon rainfall over peninsular India. The highest CCs are for Madhya Maharashtra, Rayalaseema and coastal Andhra Pradesh (-0.3) followed by Vidarbha, Telangana, Tamil Nadu & Pondicherry and Kerala (-0.2). Other
significant CCs are for west Rajasthan, Jammu & Kashmir, Bihar, Uttar Pradesh, gangetic West Bengal & NMMT which is -0.2. These CCs are significant at the 95% significance level.

3.2.1.3. 1 month lag relationship

Most of 1 month lag correlations are significant at the 95% level. Some of these are: NMMT (-0.3), Andaman & Nicobar Islands and Arunachal Pradesh (-0.2). Over peninsular India CCs for sub-divisions of coastal Andhra Pradesh, Rayalaseema, Tamilnadu & Pondicherry are -0.2.

3.2.2. Monthly rainfall

Three months lag CC between IODMI & June rainfall is maximum for Saurashtra and Kutch which is -0.4. The CCs for south interior Karnataka, coastal Andhra Pradesh and Marathwada is -0.2. Positive significant correlation is seen for sub-divisions of SHWB & Bihar Plains which is 0.3 whereas for peninsular India and Andaman & Nicobar islands CCs are negative. For July rainfall almost similar pattern is observed.

Two month lag correlations are higher than 3 month lag values. Not only this, the area of significant correlations is larger in the case of 2 months lag. The relations are consistent with 3 months lag. For July & August rainfall the correlations are not good except over peninsular India. For Andaman & Nicobar Islands all the three leadtime relations are consistent. The IODM indices of preceding 2 months can provide good indications of rainfall distributions over peninsular India during the withdrawal phase of the monsoon.

One month lag relations yield positive correlations between IODM index and June rainfall which are highly significant over the west coast of India.

For September month all the leadtime correlations are significant at the 95% level. It is seen that all the leadtime correlations show consistent results over peninsular India.

Fig. 2 shows that the correlation coefficients having magnitudes more or equal to +0.35 are significant at the 99% level and those with magnitudes more or equal to 0.25 are significant at the 95% level. Thus as shown in Fig. 3 the correlation between IODM and the seasonal monsoon rainfall over two sub-divisions of peninsular India, *i.e.*, coastal Andhra Pradesh and Rayalaseema (about 25% of the peninsular India) are significant at the 99% level. The correlations are significant at the 95% level for about 50% of the peninsular India.
3.3. **Relationships between SST in the eastern pole and monsoon rainfall**

3.3.1. **Seasonal rainfall**

It is seen from Fig. 4 that the SSTs in the eastern pole during April-May are positively correlated to ISMR over peninsular India. All the lead-time correlations are generally positive. The utility of relationships between SST in the eastern pole and monsoon rainfall seems to be limited to peninsular India only.

3.3.2. **Monthly rainfall**

For June rainfall over peninsular India positive correlations are observed. All the three lead-time correlations are consistent for peninsular India. Interestingly, July rainfall shows negative correlation with SST in eastern pole. Two months lag relations are more prominent for August rainfall. SST in the eastern pole yields a uniform pattern of relationship with rainfall over the sub-divisions of Madhya Maharashtra, Vidarabha, Marathwada, Telangana, north Interior Karnataka, south Interior Karnataka and Rayalaseema.

As shown in Fig. 4, the correlations between eastern pole of the dipole and the seasonal monsoon rainfall are significant at the 95% level for about 40% of the peninsular India.

3.4. **Relationship between SST in the western pole and monsoon rainfall**

It is seen from Fig. 5 that the SST in the western pole is positively correlated to seasonal monsoon rainfall over peninsular and western India (except Tamilnadu). March SSTs in the western pole can provide good indications of seasonal rainfall over Maharashtra.

Good correlations exist between SST in the western pole during June and rainfall over west coast & interior parts of peninsular India. During the strong western pole phase though the onset date over Kerala is delayed the monsoon activity during June is good over west coast and peninsular India.

Fig. 5 shows that the correlations between the western pole of dipole and seasonal monsoon rainfall are significant at the 99% level for Andaman & Nicobar
Lag correlations between western pole and seasonal rainfall are significant at the 95% level for Tamilnadu and north Interior Karnataka.

4. Conclusions

The study has brought out the following results:

(i) Positive/negative phase of Indian ocean dipole mode and warmer/colder SSTs in the western pole during April-May cause delayed/early onset of monsoon over Kerala.

(ii) The Indian ocean dipole phenomenon seems to influence the summer monsoon activity over the peninsular India more as compared to that over the central and northern parts of India. Negative phase of IODM during March-April, i.e., stronger eastern pole is associated with enhanced seasonal summer monsoon rainfall over peninsular India. The correlations are significant at the 99% level for about 25% of the peninsular India.

(iii) The Indian ocean dipole mode index of preceding one/two months, i.e., July and August can provide good indications of summer monsoon activity over peninsular India during the withdrawal of monsoon, i.e., September.

(iv) Sea surface temperatures in the western pole during March-April are associated with enhanced monsoon rainfall over Kerala, Karnataka and Andhra Pradesh during the onset phase of monsoon, i.e., June. The correlations are significant at the 99% level for Andaman & Nicobar islands and Lakshadweep and at the 95% level for Tamilnadu and north Interior Karnataka.

Acknowledgements

The authors are thankful to the Executive Director, Environment Monitoring and Research Centre (EMRC) for having agreed to include the studies on the relationship of Indian Ocean dipole mode phenomenon with the regional climate in the climate research programme of EMRC. Smt. Vandana Aggrawal and Smt. Premmlata Kataria, Scientific Assistants of Climate Research Unit (CRU) of Environment Monitoring and Research Centre, India Meteorological Department, New Delhi are thanked for their assistance in the preparation of the manuscript.

References

Ashok, K., Guan, Z. and Yamagata, T., 2001, “Impact of the Indian ocean dipole on the relationship between the Indian monsoon rainfall and ENSO”, Geophys. Res. Lett., 28, 4499-4502.

Behera, S. K., Krishnan, R. and Yamagata, Y., 1999, “Unusual ocean atmospheric conditions in the tropical Indian ocean during 1994”, Geophys. Research Lett., 26, 3001-3004.

Bjerknes, J., 1969, “Atmospheric teleconnections from the equatorial Pacific”, Mon. Wea. Rev., 97, 163-172.

Chang, C. P. and Krishnamurti, T. N., 1987, “Monsoon Meteorology Oxford University Press”, Oxford, p544.

Gadgil, S., Rajeevan, M. and Francis, P. A., 2007, “Monsoon variability: Links to major oscillations over the equatorial Pacific and Indian oceans”, Curr. Sci, 93, 182-194.

Gowardi, V., Thapaliyal, V., Kulshreshtha, S. M., Mandal, G. S., Sen Roy, N. and Sikka, D. R., 1991, “A power regression model for long range forecast of southwest monsoon rainfall over India”, Mauam, 42, 125-130.

Iizuka, S., Matsuura, T. and Yamagata, T., 2000, “The Indian Ocean SST dipole simulated in a coupled general circulation model”, Geophys. Res. Lett., 27, 3369-3372.

Kripalani, R. H. and Kulkarni, A., 1997, “Rainfall variability over southeast asia connections with Indian monsoon and ENSO extremes; new perspective”, Int. J. Climatol., 17, 1155-1168.

Kripalani, R. H. and Kumar, P., 2004, “Northeast monsoon rainfall variability over south peninsular India vis-à-vis the Indian ocean dipole mode”, Int. J. Climatol., 24, 1267-1282.

Rasmussen, E. M. and Carpenter, T. H., 1983, “The relationship between easter equatorial Pacific sea surface temperature and rainfall over India and Sri Lanka”. Mon. Wea. Rev., 111, 517-528.
Saji, N. H., Goswami, B. N., Vinayachandran, P. N. and Yamagata, T., 1999, “A dipole mode in the tropical Indian Ocean”, *Nature*, **401**, 360-363.

Saji, N. H. and Yamagata, T., 2003, “Possible impacts of Indian Ocean dipole mode events on global climate”, *Climate Research*, **25**, 151-160.

Shukla, J. and Paolino, D. A., 1983, “The southern oscillation and long range forecasting of the summer monsoon rainfall over India”. *Mon. Wea. Rev.*, **111**, 1830-1837.

Sikka, D. R., 1980, “Some aspect of the large scale fluctuations of summer monsoon rainfall over India in relationship to fluctuations in the planetary and regional scales circulation”, *Proc. Ind. Acad. Sci. (Earth and Planetary Sci.)*, **89**, 179-195.

Singh, O. P. and Pai, D. S., 1996, “An oceanic model for the prediction of SW monsoon rainfall over India,” *Mausam*, **47**, 91-98.

Singh, O. P., 1998, “The association between the north Indian ocean and summer monsoon rainfall over India”, *Mausam*, **49**, 325-330.

Singh, O. P., Ali Khan, T. M. and Rahman, S., 2000, “Changes in the frequency of tropical cyclones over the north Indian ocean”, *Meteorol. Atmos. Phys.*, **75**, 11-20.

Singh, O. P., 2001, “Multivariate ENSO Index and Indian monsoon rainfall: Relationships on monthly and sub-divisional scales”, *Meteorol. Atmos. Phys.*, **78**, 1-9.

Walker, G. T., 1910, “Correlations in seasonal variations of weather”, *Memories of India Meteorological Deptt.*, **21**, 22-45.

Walker, G. T., 1924, “Correlations in seasonal variations of weather, A further study of world weather (World Weather 11)” *Memoirs of India Met. Deptt.*, **24**, 275-332.

Wang, B., 1995, “Interdecadal changes in El Nino onset in the last four decades”, *J. Climate*, **8**, 167-285.

Webster, P. J. and Yang, S., 1992, “Monsoon and ENSO, selectively interactive systems”, *Quart. J. R. Meteor. Soc.*, **118**, 877-926.

Webster, P. J., Moore, A. M., Loschnigg, J. P. and Leben, R. R., 1999, “Coupled ocean-atmosphere dynamics in the Indian Ocean during 1997-98”, *Nature*, **401**, 356-360.