e-Journal Earth Science India, Vol. I (III), 2008, pp. 219-228
http://www.earthscienceindia.info/

Use of Interactions between NAO and MJO for the Prediction of Dry and Wet Spell in Monsoon Season

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Abstract

The Indian summer monsoon exhibits prominent 30-40 day fluctuations with "active" periods of heavy rain interrupted by dry periods *i.e.* "Breaks". The circulation anomalies associated with active/break monsoon cover the entire Indian Ocean remote tropics and North Pacific Ocean. A prolonged dry/wet period will result in severe drought/flooding, which have profound influences on the south Asia water cycle, agriculture and societal activity of more than one billion people. The atmospheric general circulation models have great difficulty in simulating the Intra-seasonal oscillation (ISO). Therefore, it is necessary to study the empirical relationship between various atmospheric processes, which are responsible for the ISO. In this paper, the analysis of North Atlantic Oscillation Index (NAOI) and Madden Julian Oscillation Index (MJOI) on daily scale is carried out in relation to daily Indian summer monsoon rainfall (June-September). The analysis is carried out for the period 1979-2001. Since the potential predictability limit for monsoon break is about 20 days, the 20 days running lag/lead correlation analysis between the NAOI and MJOI is found out for each year. It is observed that 20-day lag relationship between NAO and MJO is inverse and significant (0.1 level) and this relationship remains negative throughout the break monsoon period and in active phase it reverses. This twenty days lag relationship between NAO and MJO is potential predictor for break/ active monsoon conditions over the Indian region. The analysis is verified for major drought year 2002.

Introduction

In spite of governing industrialization, Indian economy still depends upon the rain-fed agricultural production. Moreover, the summer monsoon rainfall is also important for hydroelectric power generation and achieving drinking water requirements. Therefore, performance of the southwest monsoon over India plays a very crucial role in affecting the quality of life in Indian sub-continent. The southwest monsoon season (June-September) accounts for 80-90% of the annual rainfall of the country, out of these four months, more than 60% of the seasonal rainfall occurs during July and August, but if during this period the frequency of dry/wet spell prolonged it affects the agriculture production and create drought/floods situations. In 2002 July and 2004 monsoon season the prolonged dry spells affect the entire monsoon seasonal rainfall. Therefore, rainfall during the months of July and August; particularly in months of July (since more than 60% of seasonal rainfall occurs during July and August) which is the rainiest month has a decisive role in determining the over all performance of the southwest monsoon and its subsequent impacts. Most of the operational and experimental forecasts based on statistical and dynamical models (Rajeavan, 2001) are unable to predict such a large-scale deficiency in July 2002. It has opened new challenges for forecasters/ researchers to examine the monsoon verifiability with new precursors and techniques for the prediction of dry/wet spells in monsoon. However, the state of art atmospheric general circulation models has great difficulty in simulating the monsoon cycle (Waliser *et al.,* 2003).

The active/break cycle in Indian summer monsoon rainfall is extensively studied by various scientists *viz.* Ramaswamy (1962); Krishnamurti and Bhalme (1976); Sikka and Gadgil (1980) ; Goswami and Shukla, (1984); Cadet and Daniel (1988) ; Gadgil and Asha (1992); Krishnan *et al.* (2000); Goswami and Mohan (2001); Annamalai and Slingo (2001); De and Mukhopadhyay (2002); Gadgil and Joseph (2003); Goswami and Xavier (2003); Srivastava *et al.* (2002) and many others. Recently, there has been growing interest in "sub-seasonal" forecast that have lead times on the order of weeks. The basis for developing and exploiting sub-seasonal predictions largely resides with phenomena such as NAO, MJO (Madden,1986, Madden and Julian, 1971;1994), Pacific North American (PNA) pattern, mid-latitude blocking and the memory associated with soil moisture, as well as modeling techniques that rely on both initial conditions and slowly varying conditions (*e.g.* tropical pacific SST).

The Indian summer monsoon exhibits prominent 30-40 day fluctuations with "active" periods of heavy rain interrupted by dry periods *i.e*. "Breaks" (Gadgil, 2003; Krishnamurti and Bhalme,1976). Active and break episodes, characteristics of sub-seasonal variation of the Indian summer monsoon are associated with increased (decreased) rainfall over central and western India and decreased (Increased) rainfall over southern peninsula and eastern India (Singh *et al.,* 1992 ; Krishnamurthy and Shukla 2000). The circulation anomalies associated with active/break monsoon cover the entire Indian Ocean and influence remote tropics and North Pacific Ocean (Webster *et al.,*1998). The intra-seasonal variation of rainfall (active-break cycle) is strongly coupled to ISO (Hartmann and Michelson, 1989; Webster *et al.,* 1998; Sperber *et al.,* 2000; Goswami and Mohan 2001). A prolonged dry/wet period will result in severe drought/flooding, which have profound influence on the south Asia water cycle, agriculture and societal activity of over more than one billion people. The southwest monsoon season (June-September) accounts for 80-90% of the annual rainfall of the country, out of these four months, more than 60% of the seasonal rainfall occurs during July and August, but if during this period the frequency of dry/wet spell prolonged it affects the agriculture production and possible drought/flood situations may occur. The prolonged dry spells in 2002 and 2004 affects the entire monsoon rainfall. Most of the operational and experimental forecasts based on statistical and dynamical models are unable to predict such a large-scale dry phase in July 2002 (Rajeavan 2001). It has opened a new challenge for forecasters/ researchers to examine the monsoon verifiability in new perspective, precursors and techniques for the prediction of dry/wet spells in monsoon. However, the state of art is atmospheric general circulation models has great difficulty in simulating the monsoon cycle (Waliser *et al.,* 2003). Therefore, it is necessary to study the empirical relationship between various atmospheric processes, which are responsible for the ISO.

Previous studies have established that the active/ break conditions are triggered by organized northward propagation of heavy precipitating or cloud free zones from the equatorial region towards the continental landmass (*e.g.* Yasunari, 1980; Sikka and Gadgil,1980). However, a question where and how the convective anomalies that bring about active and break conditions are generated? is remained unanswered. There is some support for the idea that the upper-level divergent waves associated with MJO that circumnavigate the globe, could re-initiate convective anomalies over the Indian Ocean (*e.g.* Lorenc, 1984, Lau and Chan, 1986). However, Salby and Hendon (1994) showed that the decorrelation time of MJO is less than 1 cycle. Hence, one event tend not to follow another. During boreal summer, the equatorial eastward propagating MJO weakens substantially (Hendon and Salby, 1994) and some northward propagating episodes are independent of MJO (Wang and Rui, 1990). Whether we could get signal from NAO about the weaking of the eastward propagating MJO, over the Indian Ocean remains to be examined to predict active/break cycle in monsoon season. The North Atlantic Oscillation is most important mode of variability in northern Hemisphere. It simply measures the strength of the westerly winds blowing across the North Atlantic Ocean between 40°N and 60°N. Although originally defined in terms of a regional see saw of sea-level pressure between the Icelandic low and Azores high, it is not a regional phenomenon but has hemisphere extent (Wallace, 2000; Hurell, 1997). NAO is characterized by strong month to month and year to year variability but also has some decadal trends or inter-decadal variability (Osterineier and Wallace 2003; Hurell,1995). Many scientists (Dugam *et al.,* 1997; Kakade and Dugam, 2000; Chang *et al.,* 2001; Rajeevan, 2002; Goswami *et al.,* 2006) study the links between NAO and Indian summer monsoon on inter-annual and decadal time scale.

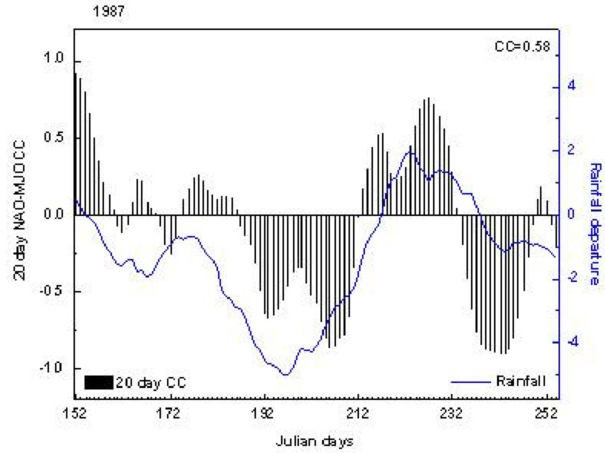
Matthews and Kiladis (1999, 2000) have proposed tropical-extra-tropical interaction as a possible mechanism for the initiation of the convective cycle of MJO in the Indian Ocean. Propagation of extra tropical waves in to the tropical Indian Ocean region has been shown to initiate the MJO in case studies (Hsu *et al.,* 1990) and simple modeling studies (Blade and Hartmann, 1993). It is known that the tropical-extra-tropical interaction through NAO and Pacific North American (PNA) pattern and coupling between the NAO and MJO through the upper level divergent wave that circumnavigate the globe, which could re-initiate convective anomalies over Indian Ocean (Wang *et al.,*2000). Now the question is "whether this divergent wave is perturbed by large-scale middle-latitude oscillation like NAO?" and can this relationship is useful for monitoring the dry/wet episode during the monsoon.

Data details

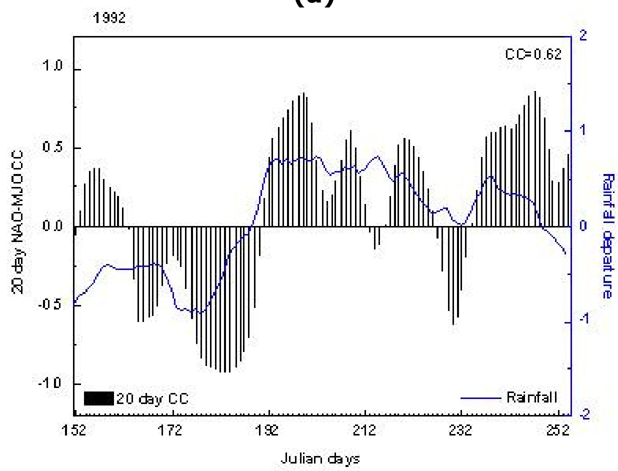
The daily Madden Julian Oscillation index time series for the period 1979 to 2001 is taken from the Eric Maloney of Oregon State University. They have constructed these indices from the first 2 principal components of the band pass filtered 30-90 days 850 hPa zonal wind over the region 5°N-5°S, from the National Centers for Atmospheric Research Reanalysis. Daily North Atlantic Oscillation index data have been taken from the website http://www.cpc.ncep.noaa.gov/ for the same period. NCEP/NCAR reanalyzed monthly mean Outgoing Long Radiation (OLR) for 1958-2003 and divergences at 200hPa level data for 1958-1996 have been used. We have used the daily rainfall data at 1°X1° resolution from the Indian Meteorological Department (IMD), based on 1803 stations (Rajeevan *et al.,* 2006) for the period 1951-2000.

Discussion

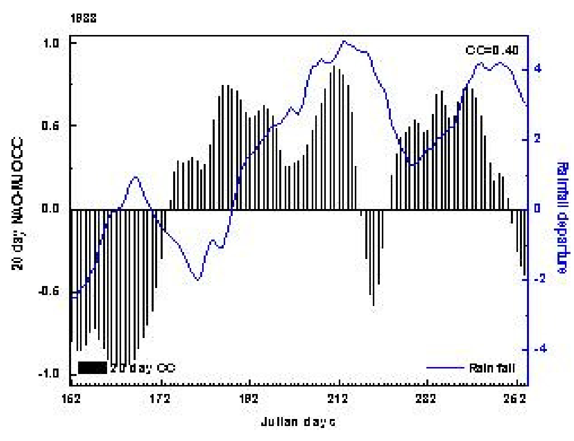
We have computed the 20-day lag-lead correlation between daily NAO and MJO index data for the monsoon period (June-September) since the potential predictability limit for monsoon break is about 20 days. The analysis is carried out for 23 years (1979-2001). This lag-lead correlation analysis is compared with the daily Indian summer monsoon rainfall. Fig.1 (a, b, c) shows the 20-day running lag-lead relationship between NAO and MJO and its association with the 20-day mean rainfall anomalies for 1987 (drought year), 1997 (normal year) and 1988 (flood year). From the figure, it is observed that prior to the break (active) spell of monsoon rainfall the relationship between NAO and MJO is negative (positive) respectively. It is observed that 20-day lag relationship between NAO and MJO is inverse and significant (0.1% level) and this relationship remains negative throughout the break monsoon period and vice versa. This 20-day lag relationship between NAO and MJO may be used as potential predictor for dry/wet spells monsoon condition over Indian region. The smooth running line represents the 20 day running mean rainfall anomalies and vertical bar represents lag-lead co relationship between daily NAO and daily MJO during the monsoon period.



(a)



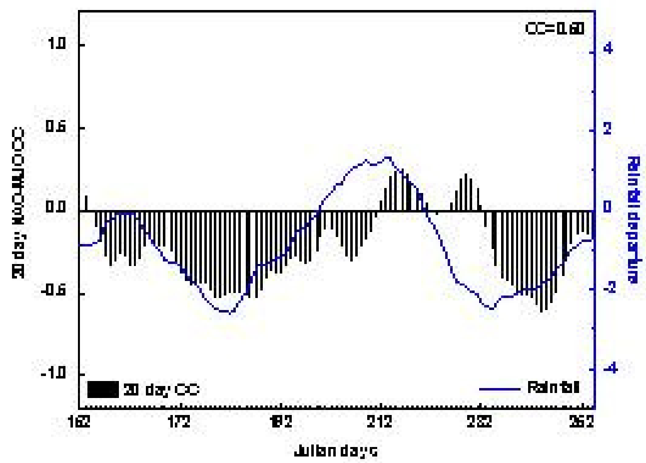
(b)



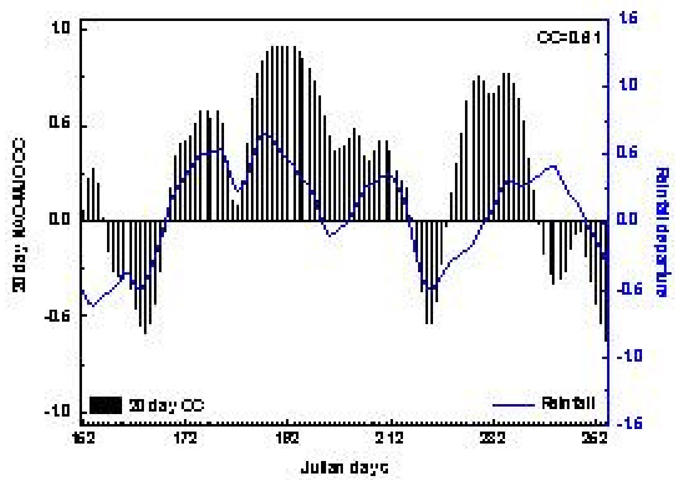
(c)

Fig.1: Association of 20-day lag-lead relationship between NAO and MJO with 20-day mean rainfall anomalies in monsoon season (June-September) (a) for the drought monsoon year1987 (b) for Normal monsoon year 1997 (c) for excess monsoon year 1988.

The composite analysis for all drought years (1979, 1982, 1985, 1986 and 1987) and flood years (1983, 1988 and 1994) is also shown in fig. 2 (a, b). It is seen that 20-day lag-lead relationship of NAO and MJO with 20-day mean rainfall anomalies is going almost hand in hand.



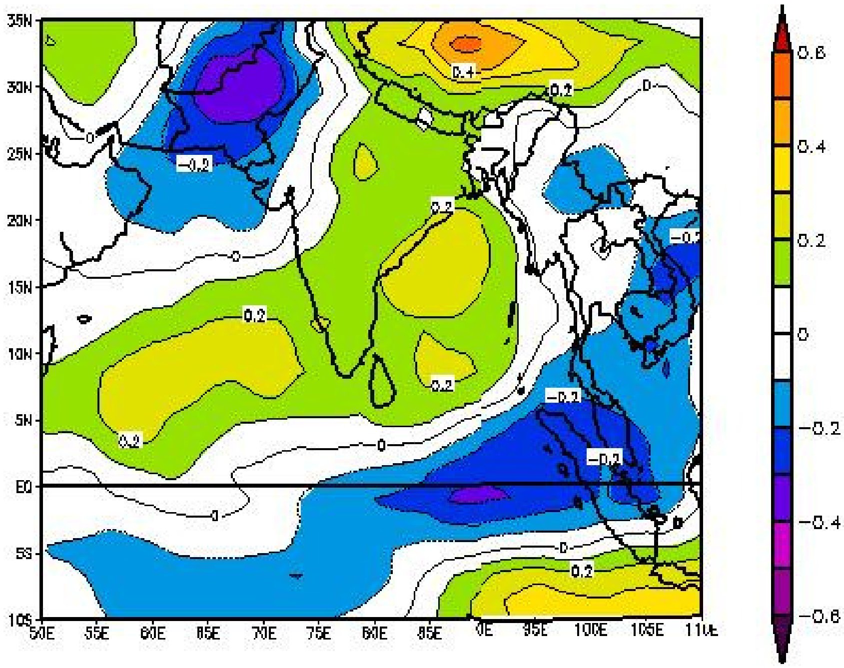
(a)



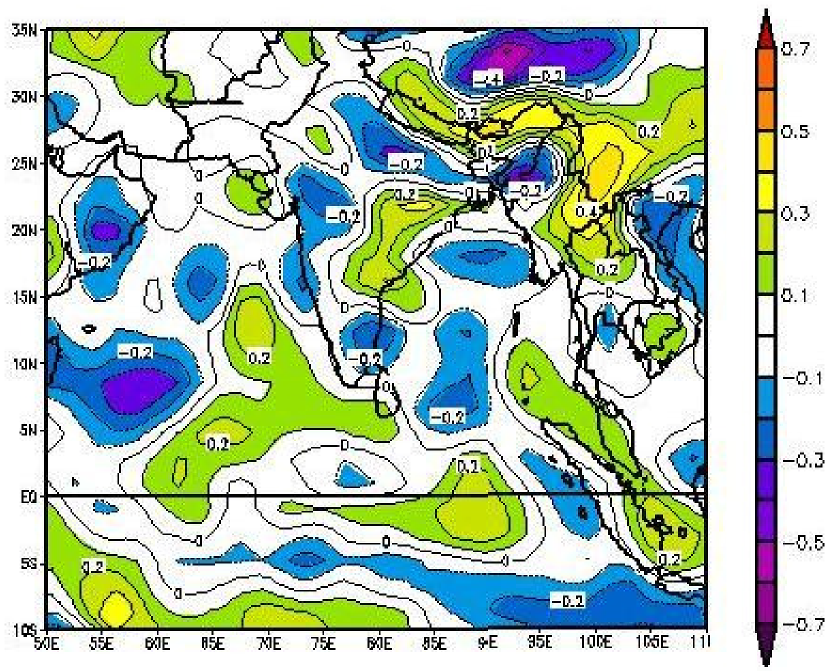
(b)

Fig.2: (a) Association of 20-day lag-lead relationship between NAO and MJO with 20-day mean rainfall anomalies in monsoon season (composite analysis of drought years) and (b) flood monsoon years. The smooth running line represents the 20 day running mean rainfall anomalies and vertical bar represents lag-lead co relationship between daily NAO and daily MJO during the monsoon period

It is known that there is tropical - extra-tropical interaction through NAO and Pacific North American (PNA) pattern. It is known that there is a coupling between the NAO and MJO, through the upper level divergent wave that circumnavigates the globe (Wang *et al.,* 2000 ; Ferranti *et al.,* 1990]. This could re-initiate convective anomalies over Indian Ocean. The lag correlation analysis between the NAO and OLR and divergence at 200 hPa for the period 1958-2003 by NCEP/NCAR reanalysis data derived from the observations taken by polar–orbiting National Oceanic and Atmospheric Administration (NOAA) satellites explains the tropical-extra-tropical interaction (between NAO and MJO) and its association with rainfall activity during the monsoon period. Fig.3 (a, b) depicts the same. From this, it is seen that during the positive phase of NAO upper level divergence at 200hPa over Indian land/ocean region is negative. This means that when the NAO is stronger than normal upper level divergence field is weak, which affects the convention over Indian region.



(a)



(b)

Fig.3: (a) The lag-lead relationship between NAO and Outgoing Long Radiation for the period 1958-1996 during the monsoon season (June- September) (b) The lag-leads relationship between NAO and divergence at 200 h Pa during monsoon season for period 1948-2003. Contours are correlation coefficients.

Probable physical linkage for using this relationship for predicting the dry/wet spell in monsoon period could be like this: the active/break monsoon conditions are triggered by organized northward propagation of heavy precipitating or cloud free zones from the equatorial regions towards the continental land mass (Sikka and Gadgil, 1980).This northward propagating mode (NPM) over the Indian monsoon region was weaker (stronger) during drought (flood) (Krishnan *et al.,* 2000). It is also known that the MJO interacts with the NPM in the Indian monsoon region (Matthews and Kiladis, 1999). It is plausible that the different phases of NAO modulate the temperature gradients cold/warm in upper troposphere [Goswami *et al.,* 2006]. Hence, it might be responsible for the increase in the period of the NPM. A longer period of NPM could possibly lead to longer monsoon break periods causing the major drought conditions and vie versa.

Conclusions

From this study following conclusions can be drawn:

1. 20-day lag-lead relationship between NAO and MJO is inverse and almost remains stable at the beginning and during the dry spell. While, it is direct and almost stable at the beginning and during the wet spell.
2. Lag-lead relationship analysis between NAO and OLR and 200 hPa divergence field over Indian region suggested that when NAO is stronger (weaker) then the OLR anomaly over the Indian region is positive (negative), which suppress (enhance) the convection.
3. This empirical association between them may be useful for prediction of dry/wet spell during the monsoon period.

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Acknowledgment*:* The author is grateful to Prof. B.N. Goswami, Director, I.I.T.M. for providing necessary facilities for completing this study and to Dr. P. N. Mahajan, Head, Forecasting Research Division, for his encouragement and valuable suggestions. Thanks are due to the NOAA/ESRL Physical Sciences Division, Boulder Colorado for their Web site at http://www.cdc.noaa.gov/ and India Meteorology Department for providing the rainfall data.

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