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Prediction of summer monsoon rainfall over northwest region of India using an OLR index

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सार – यद्यपि समूचे देश की मानसून वर्षा (जून से सितम्बर) की विभिन्नताओं में कुछ लचीलापन का पता चलता है परन्तु देश के उत्तरी पश्चिमी भागों के कुछ छोटे क्षेत्रों में हुई वर्षा में असाधारण विभिन्नताएं देखने को मिलती है। इस शोध–पत्र में, उत्तरी अटलांटिक महासागर के भागों में मई के महीने के दौरान उत्तरी अटलांटिक दोलन (एन. ए. ओ.) से संबंद्ध औसत क्षेत्र ओ. एल. आर. विसंगति सूचकांक की सहायता से उत्तरी पश्चिमी भारत में मौसमी वर्षा के अंतर का पूर्वानुमान करने का प्रयास किया है । इस अध्ययन में 1979 से 2000 की अवधि के आंकड़ों से विकसित ओ. एल. आर. विसंगति सूचकांक का प्रयोग करते हुए एक सरल समाश्रयण निदर्श विकसित किया तथा क्रॉस वैलिडेशन तकनीक से इस निदर्श का आकलन किया गया । इस निदर्श (9.73) की मूल माध्य वर्ग (आर. एम. एस.) त्रुटि, उत्तरी पश्चिमी भारत की वर्षा के मानक विचलन (17.51) से काफी कम रही जिससे इस निदर्श की क्षमता का पता चलता है ।

ABSTRACT. Although, monsoon rainfall (June-September) over the country as a whole has shown some resilience for variations, it has shown remarkable variations over smaller regions *viz*. over the Northwestern parts of the country. This study is an attempt to predict seasonal rainfall departure over the Northwest India with the help of an “area averaged OLR anomaly index” associated with the North Atlantic Oscillation (NAO) over parts of North Atlantic Ocean during May. Using the OLR anomaly index developed in this study for the period 1979-2000, a simple regression equation was developed and the performance of the model was evaluated through the “Cross validation” technique. The Root Mean Square (RMS) error of the model (9.73) was much less than the standard deviation (17.51) of the rainfall over NW India, indicating the skill of the model.

Key words – Long range forecast, SST, Indian monsoon, Regression analysis.

1. Introduction

Southwest monsoon rainfall over India, accounts for 75% to 90% of the annual rainfall over different parts of the country and has a profound impact on our agriculture based economy. It also plays a crucial role in maintaining water resources and power generation. A study by Parthasarathy *et al.*, (1988) has revealed that total agricultural production in a year is heavily dependent on the amount of rainfall received. Therefore, prediction of seasonal monsoon rainfall over India has its own significance especially for the long term planning. Mean monsoon rainfall over India as a whole during June-September is 88 cm and in spite of noticeable year-to-year variations, it does not show appreciable change (coefficient of variation being 10%) from the mean value. Yet, the behaviour of the monsoon over the years has been a mystery filled manifestation of combined effect of varying oceanic and atmospheric responses of the Sun’s radiation.

To unravel this mystery, attempts are continuing and much progress has been made regarding its understanding and prediction from the early days of Blanford (1884). There are several studies examining its interannual/ intraseasonal variations, its modulation by sea surface temperatures (SST) of different oceans, energy exchanges through different modes of oscillation of varying periodicity and interactive mechanism of troposphere and stratosphere. Studies, linking Indian summer monsoon with ENSO [Rasmusson and Carpenter (1983)], Eurasian snow cover [Kripalani *et al.*, (1996), Bamzai and Shukla (1999)], the role of mountains *viz*. Tibetan plateau [Hahn and Manabe (1975)], and role of North Atlantic Oscillation (NAO) through land surface temperature anomalies over northwest Europe [Rajeevan *et al.*, (1998), Chang *et al.*, (2001)] are to be specially mentioned. Several operational models (mainly statistical) based on indices developed in these studies were examined for the prediction of Indian Summer Monsoon Rainfall (ISMR).

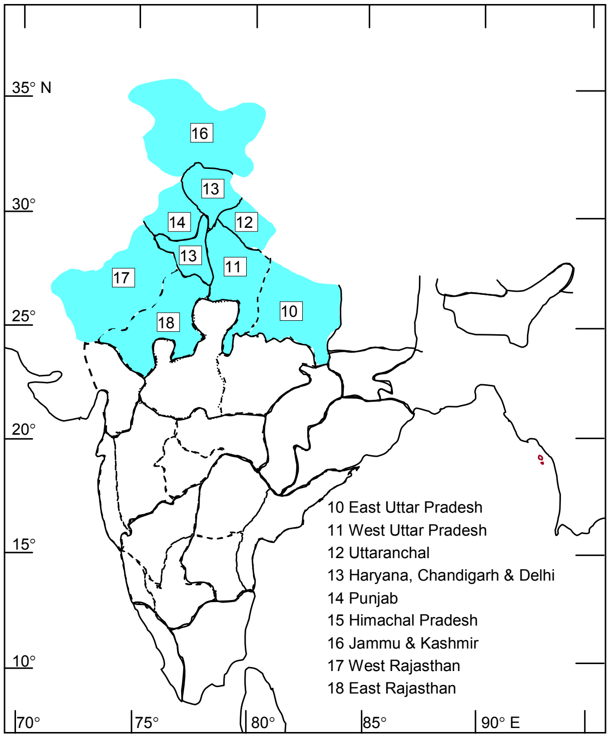

Fig. 1. Meteorological sub-divisions of northwest India

However, secular variations between the predictors and ISMR have been noticed, [Parthasarathy *et al.*, (1991), Hastenrath and Greischer (1993)]. Therefore, search for physically linked potential predictors is a continuous process.

With the growing demands of users and macroscale planners, down scaling of models for small homogeneous regions was also attempted. For the purpose, IMD (based on the mutual correlation observed in the rainfall over different subdivisions) has divided the country (consisting of 36 meteorological subdivisions) into three homogeneous regions. Characteristics of monsoon rainfall within the region are almost similar. Rainfall over the different subdivisions in a particular homogeneous region is significantly and positively correlated. But, on these smaller homogeneous spatial scales, particularly over the northwest region (comprising of nine meteorological subdivisions), interannual variation is quite significant and coefficient of variation is as high as 20% of the mean value. This is mainly due to large variation in the rainfall over its constituent subdivisions. Rainfall over the eastern Uttar Pradesh has 21% of coefficient of variation while, it is 36% over the west Rajasthan. The uncertainty in the monsoon rainfall (due to very high variation) over Northwest region is a cause of concern and poses a challenging task for the prediction.

Recently, Srivastava, *et al.*, (2002) have found that OLR values over the parts of North Atlantic Ocean during May have a significant positive correlation with ISMR. It was also observed that the North Atlantic Oscillation (NAO), a see-saw in the surface pressure anomalies over the large parts of northwest and southeast Europe during winter (Walker & Bliss, 1932) primarily governs this OLR field by modulating Sea Surface Temperatures (SST).

NAO Index is defined/measured by the difference of sea level pressure anomalies of Azero high and Icelandic low. NAO modulates large scale circulation patterns (Marshall *et al.,* 2001) over different parts of the globe and particularly over the Europe. NAO also induces SST changes over parts of North Atlantic Ocean which peak during summer (Rogers & van Loon, 1979). It may be mentioned that NAO modulated anomalies in SST are observed over the cold regions and therefore OLR and SST fields are found to be positively correlated.

In this study, an area averaged OLR anomaly index over a broader region of the North Atlantic Ocean during May, based on the study of [Srivastava *et al.,* (2002)], has been developed and its usefulness in predicting monsoon rainfall over the Northwest region has been examined.

2. Data and methodology

For this study, we have used monthly mean OLR data derived from the observations taken by polar orbiting NOAA satellites. These data are available at 2.5° × 2.5° resolution for the period 1979-2000. These data and seasonal sea level pressure and wind anomalies at 850 hPa were obtained from NCEP, USA. The percentage departure of seasonal rainfall over the NW region and ISMR for monsoon season (June-September) for the period 1979-2000 was taken from the National Data Centre, Pune (NDC) of the India Meteorological Department.

We have calculated correlation coefficients of monthly OLR anomalies over the Atlantic Ocean during May and the percentage departure of seasonal (monsoon) rainfall over the NW homogeneous region for examining spatial pattern of correlation. Further, an OLR anomaly index averaged over the area bound between 32.5° N to 40.0° N and 65.0° W to 57.5° W, has been derived and its usefulness for predicting the monsoon rainfall over northwest India has been examined. It may be mentioned that different OLR indices from the area of high correlation were made and the index found to have highest correlation with the monsoon rainfall of the NW region, was selected for the study. Finally, in a particular year

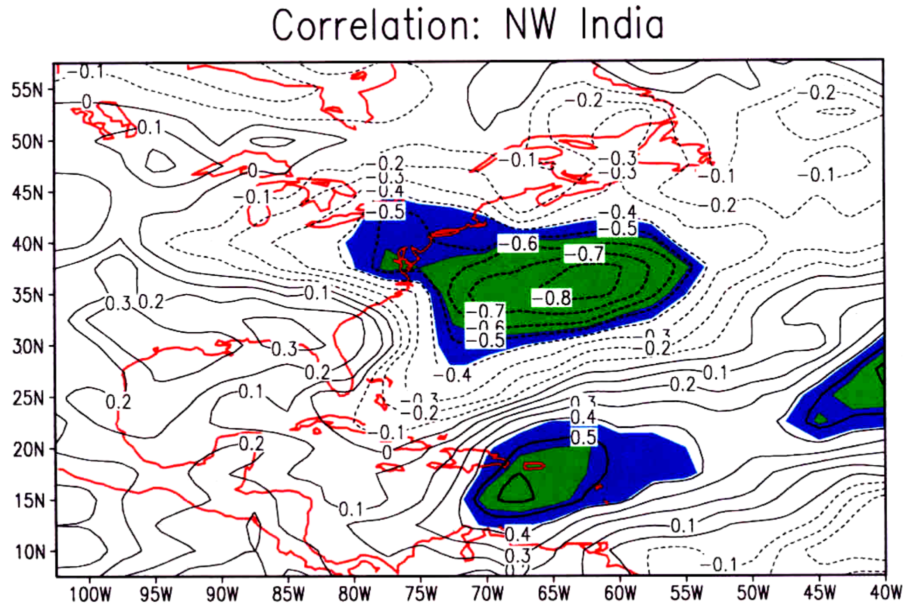

Fig. 2. Spatial pattern of correlation between May OLR anomalies and NWMR anomalies for the period 1979-2000. Area of 95% (99%) significance level is shaded light (dark)

(forecast) was estimated by fitting a regression line between monsoon rainfall of NW region and the OLR anomaly index and using the `Cross validation technique'.

3. Results and Discussions

Homogeneous meteorological subdivisions of NW India are shown in Fig. 1.

Fig. 2 shows the spatial pattern of correlation coefficients between OLR anomalies during the month of May and monsoon rainfall over the NW region. Correlation coefficients which are significant at the 5% (1%) level are shaded light (dark). It can be seen that OLR anomalies over a large area (bound between Lat. 30° N - 45° N, Long. 80° W - 30° W) of the western parts of North Atlantic Ocean (just east off the American Coast) are negatively correlated with monsoon rainfall over the NW region. Maximum magnitude of the correlation exceeds even 0.84 (significant at the 0.1% level and explaining more than 70% variation). Just south of this area, an area with positive correlations is also observed. The strength and aerial extent of positive correlations are however smaller compared to the negative correlations. The spatial pattern reveals a north-south dipole like structure of correlation over the Atlantic Ocean with the monsoon rainfall over the NW region. Similar changes (dipole like) in the SST field were found to be introduced by the NAO (Rogers & van Loon, 1979) and again confirmed by the study of Kushnir, (1994) ; Kapala, *et al*., (1998).

The OLR field (anomaly) for the month of May over parts of North Atlantic Ocean, sea level pressure anomalies (June to September) and vector wind anomalies at the 850 hPa level (June to September) over the Indian region for the two contrasting bad and good monsoon years, 1979 and 1983 are shown in Fig. 3. It may be seen that in 1979, OLR anomalies over the concerned parts of North Atlantic Ocean are positive while seasonal pressure anomalies are more positive and anomalous easterlies prevail over the peninsular India which indicate a weak monsoon condition. Similarly, in the year 1983 OLR anomalies are negative, seasonal pressure anomalies are only slightly positive and westerly anomalies prevail over the peninsular India which indicates a normal/good monsoon condition. Thus, inverse relationship between the OLR anomalies and zonal wind anomalies at 850 hPa, sea pressure surface anomalies is clearly evident.

We have further calculated correlation coefficient between OLR anomaly index averaged over the area

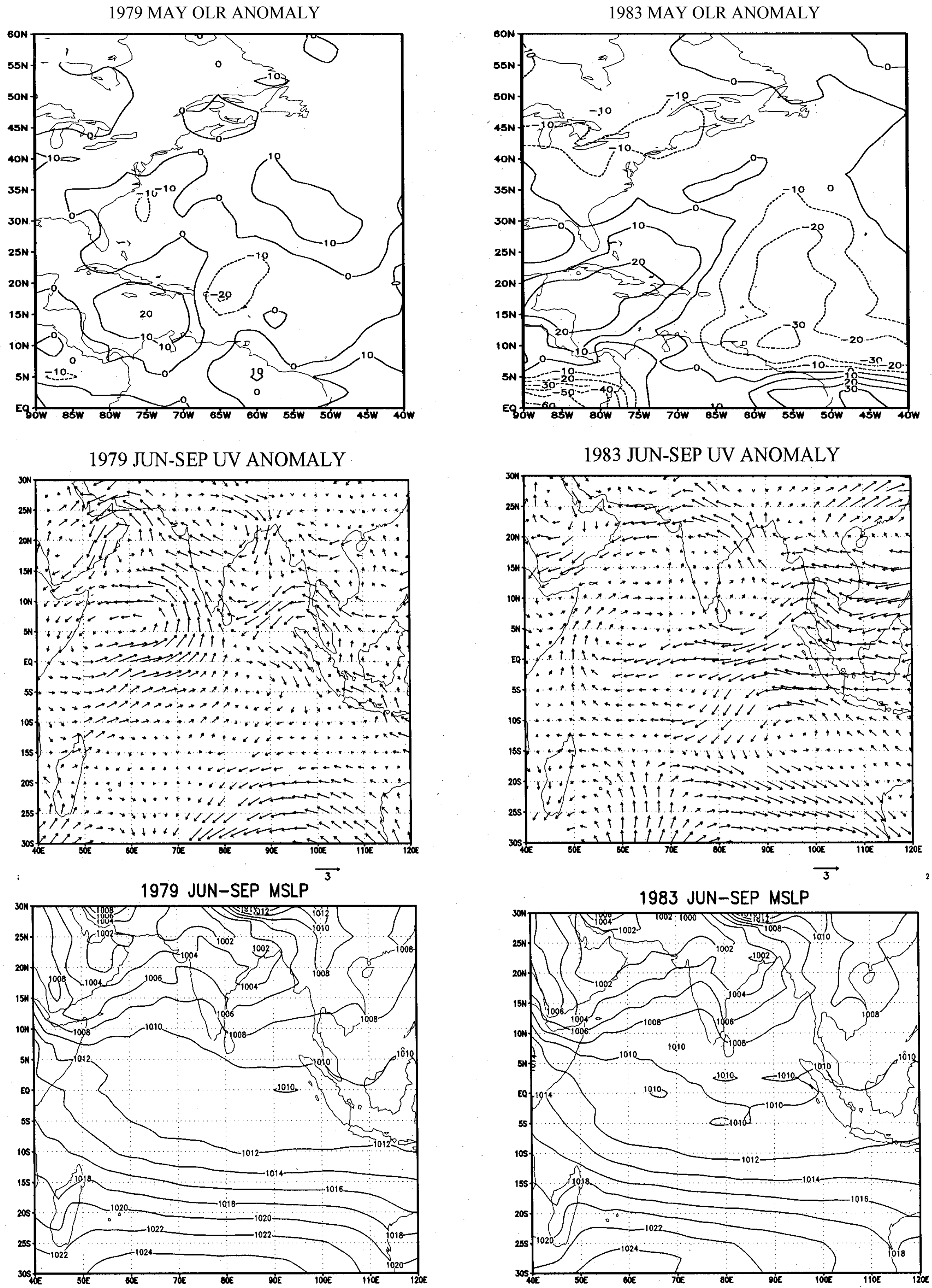

Fig. 3. OLR anomalies over the north Atlantic Ocean, seasonal vector wind anomaly at 850 hPa level and seasonal sea level pressure anomalies for the two contrasting monsoon years, 1979 & 1983

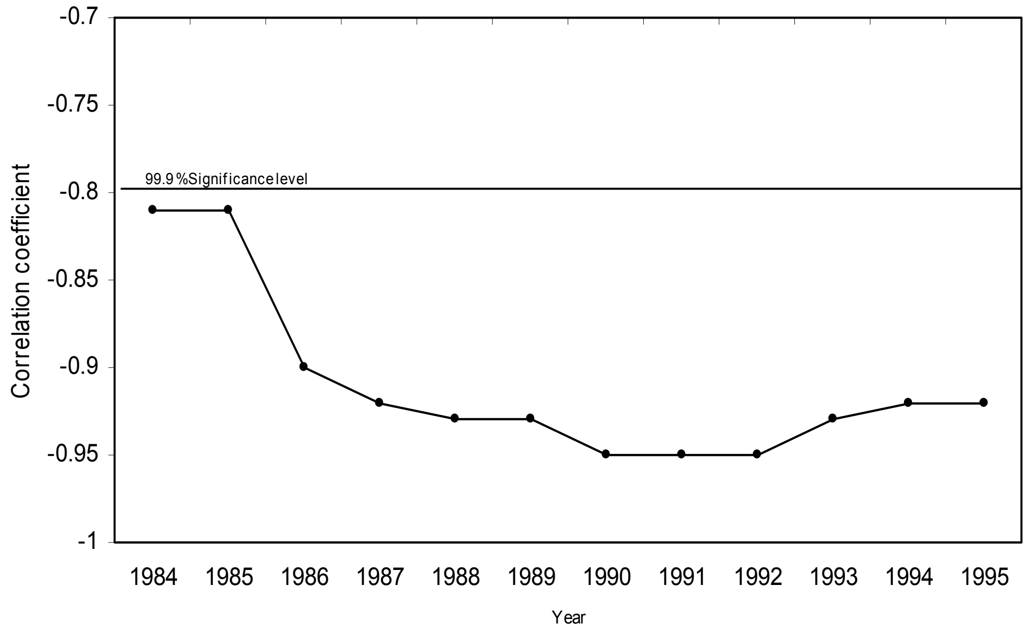

Fig. 4. 11-year sliding correlation coefficient of the area averaged OLR anomaly index and percentage departure of NWMR for the period 1979-2000

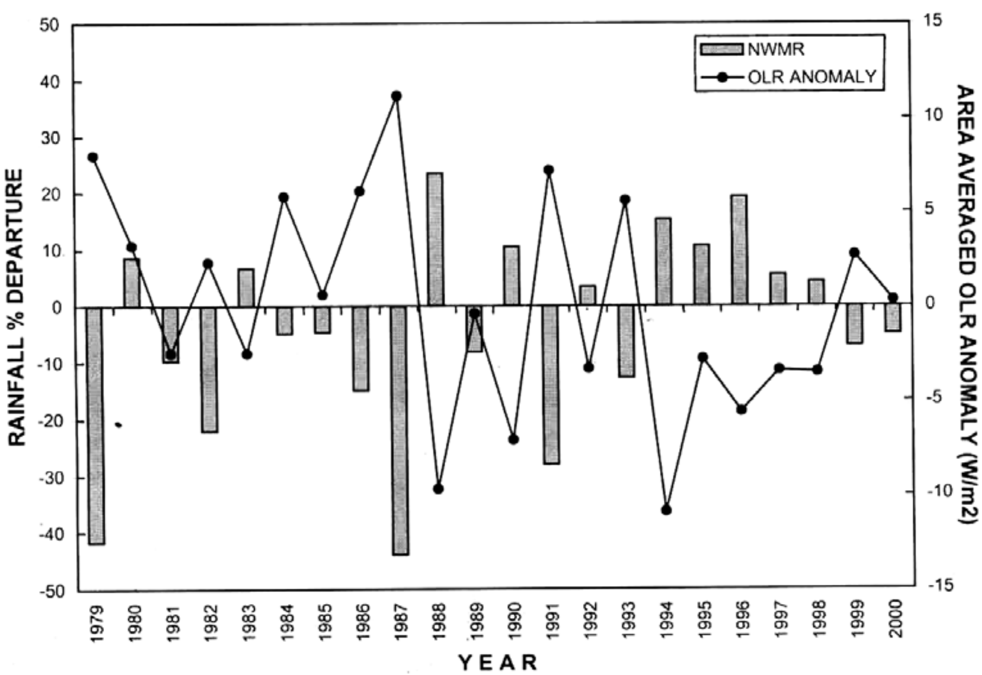

Fig. 5. Time series of area averaged OLR anomaly index and percentage departure of NWMR for the period 1979-2000

bound between 35.0° N to 37.5° N and 62.5° W to 57.5° W to examine its usefulness as a predictor for the monsoon rainfall over NW region. This index of OLR anomaly has a correlation of -0.86 with the monsoon rainfall over NW region, which is statistically significant at the 0.1% level. The 11 year moving correlations between the two were also found to be significant (Fig. 4) at the 0.1% level throughout the period (1979-2000), indicating the stability and usefulness of the parameter. The time series of the OLR anomaly index and the monsoon rainfall departure over NW region for the period 1979-2000 are shown in Fig. 5. When monsoon rainfall over NW India was above (below) normal consecutively for 5 (4) years during 1994-98 (1984-87), this index was

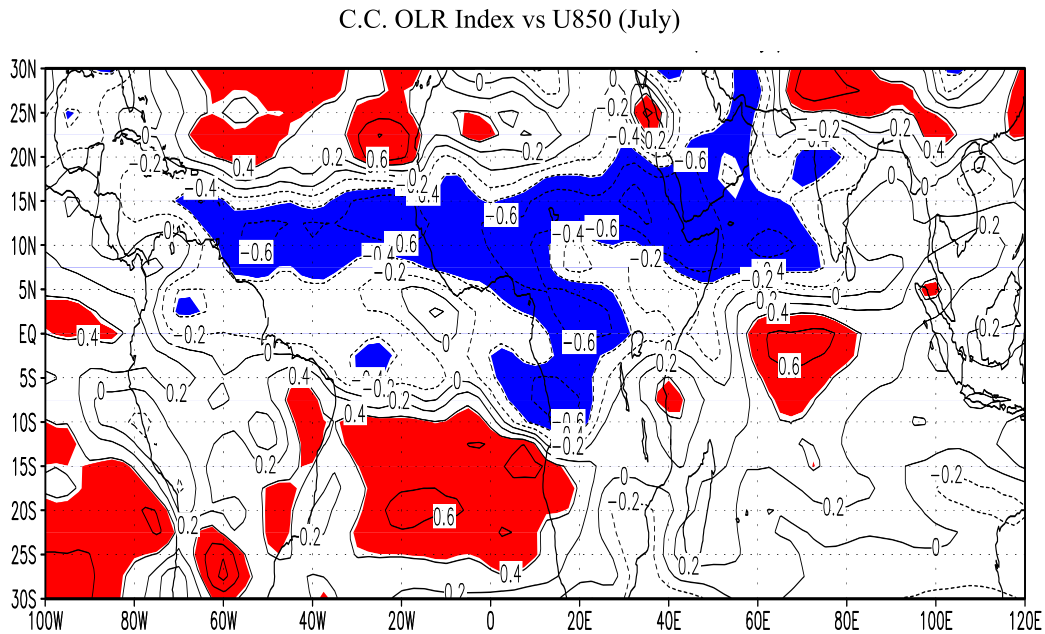

Fig. 6. Spatial correlation pattern between the OLR anomaly index (May) and 850 hPa zonal wind for the month of July (period 1979-2000). Negative (positive) correlation significant at 95% level are shaded light (dark)

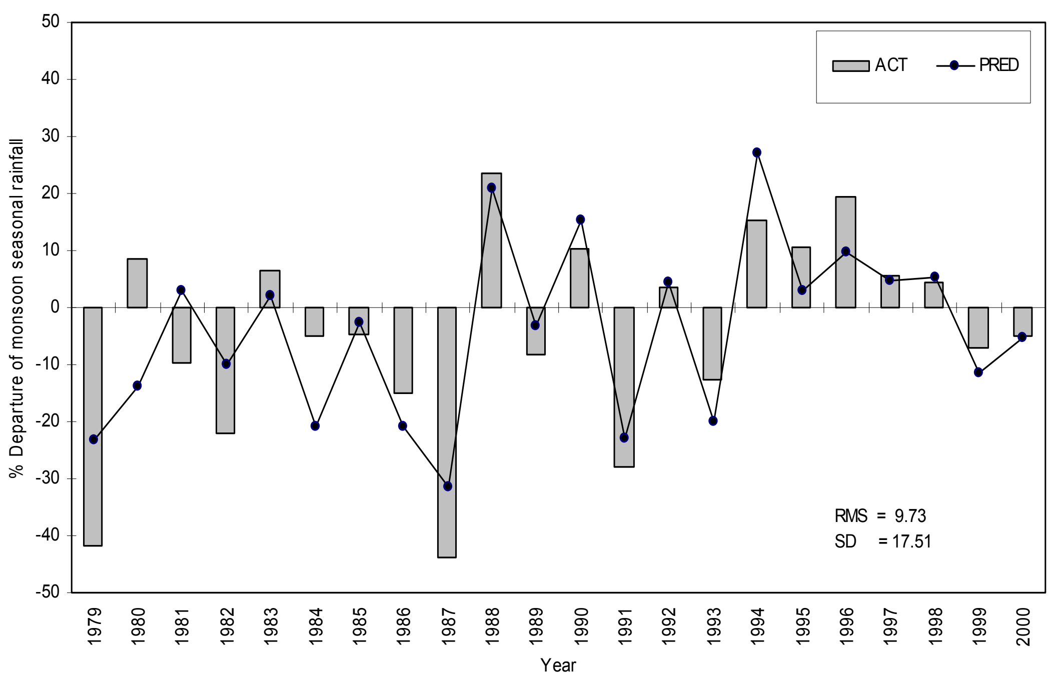

Fig. 7. Percentage departure of seasonal (monsoon) rainfall over northwest region

negative (positive). Similarly, in other years also monsoon rainfall over NW region and index can be seen in opposite phase. Thus, the OLR anomaly index, over the Atlantic Ocean, appears to be a promising one, as a predictor for the long range forecast's of the monsoon rainfall over NW region.

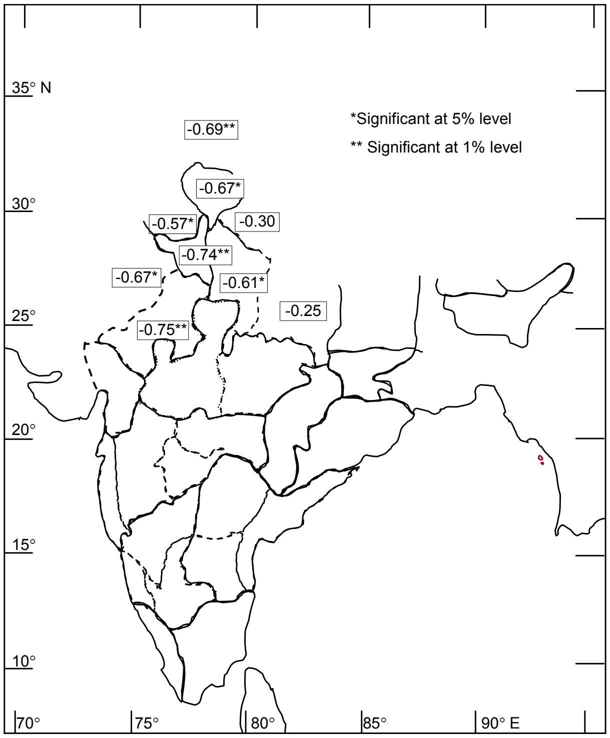

Fig. 8. Correlation coefficient between OLR anomaly index and percentage departure rainfall of subdivision of northwest India

We have also calculated the correlation co-efficients between this OLR index, seasonal (June – September) sea level pressure difference between Thiruvananthapuram and Mumbai and 850 hPa zonal wind during July to examine its relation with the pressure and wind fields over the Indian region. Correlation co-efficient between the seasonal pressure difference and the index was found to be -0.67 for the period 1979-2000 which is significant at the 1% level. This implies that when OLR anomaly index is positive, pressure gradient along the west coast of India is likely to be weak, an indicative of subdued monsoon condition. Similarly, correlation pattern between the index and the zonal wind field during July is shown Fig. 6. It shows that positive OLR anomaly index is associated with easterly wind anomalies (negative correlation) right from the Atlantic Ocean to west Arabian Sea across Africa. Positive OLR anomaly index over the North Atlantic Ocean is associated with easterly wind anomalies over Arabian Sea and westerly wind anomalies over the South Indian Ocean in the month of July. This implies that when the OLR anomaly index is positive, southeasterly monsoon winds, south of equator and southwesterly monsoon winds over Arabian Sea become weaker. It may be mentioned that July is the rainiest month over India during the monsoon season. Weaker southeasterly winds south of equator and southwesterly winds over Arabian Sea may ultimately weaken the cross equatorial flow and the monsoon flow over the Arabian Sea leading to reduced rainfall activity over India.

It may be mentioned that NAO has been found to have an increasing trend in recent years [Hurrell *et al.*, (2001)] and a study by Chang *et al.*, (2001) has indicated that this trend might have caused normal monsoon rainfall over India, even during recurrent and prolonged ENSO events in the last decade.

We have attempted to use the index for prediction, using the `Cross validation method' and fitting a regression equation using data set. 'Cross validation method' [Manly, (1994)] is used to establish expected skill on independent future data, in which each of the years to be verified has been held out for fitting regression lines and then used as a forecast target. Results are shown in Fig. 7. The standard deviation (S.D.) of monsoon rainfall over NW region is 17.51 while the Root Mean Square (RMS) error of the predicted values is 9.73. This is indicative of a good skill of the model. It can also be seen that out of 22 years, on 20 occasions (except for the year 1980) actual rainfall was within reasonable limit of the predicted value.

We have also calculated correlation coefficients between the OLR anomaly index and seasonal percentage rainfall of individual meteorological subdivisions of NW region and the results are shown in Fig. 8. It may be seen that correlation of 7 out of 9 subdivisions (excluding Uttaranchal and east Uttar Pradesh) with the OLR anomaly index is highly significant. Thus, this index can be used as a predictor for predicting seasonal monsoon rainfall even on a meteorological sub-divisional scale (much lower spatial scale) of NW region.

4. Conclusion

(*i*) OLR anomaly over the North Atlantic Ocean during May has a significant correlation with the seasonal rainfall over Northwest India.

(*ii*) 'OLR anomaly index' as defined in the study appears to be a potential predictor of seasonal rainfall departure over Northwest region. RMS error of predicted values based on this single parameter for 22 years is 9.73 which is much less than the S.D. (17.51) of the observed rainfall during the same period. The skill is comparable to any other statistical model.

(*iii*) The index in conjunction with some other parameters can be used for predicting seasonal rainfall departure even in individual meteorological subdivisions of Northwest India.

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References

Bamzai, A. S. and Shukla J., 1999, “Relationship between Eurasian snow cover, snowdepth and the Indian Summer Monsoon : An observational study”, *J. of Climate*, **12**, 3117-3132.

Blanford, H. F., 1884, “On the connection of the Himalayan snowfall and seasons of droughts in India”, *Proc.Roy.Soc. London*, **37**, 3-22.

Chang, C. P., Harr, P. and Ju, J., 2001, “ Possible roles of Atlantic circulation on the weakening Indian monsoon rainfall – ENSO relationship”, *J. Climate*, **14**, 2376-2380.

Hahn, D. and Manabe, S., 1975, “The role of mountains in the south Asian monsoon circulation”, *J. Atmos. Sci*., **33**, 2461-2463.

Hastenrath, S. and Greischer, L., 1993, “Changing predictability of Indian monsoon rainfall anomalies”, *Proc.Indian.Acad. Sciences, (Earth. Planet. Sci.)*, **102**, 35-47.

Hurrell, W., Kushnir, Y. and Visbeck, M., 2001, “The North Atlantic Oscillation”, *Science*, **291**, 5504, 603-605.

Kapala, A. M., Machel and Flohn, H., 1998, “Behaviour of the centers of action above the Atlantic since 1881. Part II : Association with regional climate anomalies”, *Int. J. Climatol*., **18**, 23-36.

Kripalani, R. H., Singh, S. V., Mandal, B. N. and Thapliyal, V., 1996, “Empirical study on Nimbus-7 snow and Indian summer monsoon rainfall”, *Int. J. of Climatol*., **16**, 23-24.

Kushnir, Y., 1994, “Inter-decadal variations in North Atlantic sea surface temperature and associated atmospheric conditions”, *J. Climate*, **7,** 143-157.

Manly, B. F. J., 1994, “Multivariate statistical methods, A primer”, CRC OPress, Boca Raton; Chapman and Hall.

Marshall, J., Kushnir, Y., Battisti, D., Chang, P., Czaja, A., Dickson, R., Hurrell, J., Cartney, M.Mc, Saravanan, R. and Visbeck, M., 2001, “North Atlantic Climate Variability : Phenomena, Impacts and Mechanisms : A Review interannual time scale; North Atlantic Oscillation; Climate variability”, *International Journal of Climatology*, **21,** 15, 1863-1898.

Parthasarathy, B., Munot, A. A. and Kothawale, D. R., 1988, “Regression model for estimation of Indian foodgrain production from Summer Monsoon Rainfall”, *Agricultural and Forest Meteorology*, **42**, 167-182.

Parthasarathy, B., Kumar, K. Rupa and Munot, A. A., 1991, “Evidence of secular variations in Indian summer monsoon rainfall-circulation relationships”, *J. Climate*, **4,** 927-938.

Rajeevan, M., Pai, D. S. and Thapliyal, V., 1998, “Spatial and temporal relationships between global land surface air temperature anomalies and Indian summer monsoon rainfall”, *Meteorol. Atmos. Phys*., **66**, 157-171.

Rasmusson, E. M. and Carpenter, T. H., 1983, “The relationship between the eastern Pacific sea surface temperature and rainfall over India and Sri Lanka”, *Mon. Wea. Rev*., **111**, 354-384.

Rogers, J. C. and Loon, H. van, 1979, “The see saw in winter temperature between Greenland and Northern Europe Part II : Some oceanic and atmospheric effects in middle and high latitude”, *Mon. Wea. Rev*., **107,** 509-519.

Srivastava, A. K., Rajeevan, M. and Kulkarni Ruta, 2002, “Teleconnection of OLR and SST anomalies over Atlantic Ocean with Indian summer monsoon”, `*Geophysical Research Letters'*, **29**, 8, 125.1-125.4,

Walker, G. T. and Bliss, E. W., 1932, World Weather V. Mem., *Roy. Meteor. Soc*., **4**, 53-84.