Variability of Indian summer monsoon: Relationship with surface air temperature anomalies over northern hemisphere

R. K. VERMA

Indian Institute of Tropical Meteorology, Pune

(*Received 20 November 1991, Modified 8 September 1992*)

सार — उत्तरी गोलार्ध में वायु के सतही तापमान की विसंगतियों के साथ मानसून के दूरसंयोजनों की पहचान के लिए महीनों की विभिन्न अवधियों के (अर्थात् मानसून से पहले, मानसून के दौरान तथा बाद में आने वाले महीनें) ग्रिडिड सतही वायु तापमान के आंकड़ों के साथ मानसून-सूचकांक (एम आइ) के तीस वर्षों (1950–79) की समय श्रृंखला सहसंबंधित की गई है ।

मानसून वर्षा के सांख्यिकी दृष्टि से सार्थक संबंध दिखाने वाले तीन महत्वपूर्ण क्षेत्रों में से दो क्षेत्र उत्तरी अमेरिका तथा यूरेशिया में 40° उ०- 70° उ० के उच्चतर अक्षांशीय इलाके में है । जो कि उत्तरी शीतकाल, विशेषकर जनवरी और फरवरी के दौरान, तापमान के साथ सकारात्मक सहसंबंध दिखाते हैं । तीसरा क्षेत्र भारत के उत्तर-पश्चिम में तथा समीपवर्ती पाकिस्तान में स्थित है । इस क्षेत्र में अप्रैल तथा मई के मानसून पूर्व महीनों में अधिकतम सकारात्मक सहसंबंध का पता चला है। ये संबंध यह बताते हैं कि अपेक्षाकृत टंडा उत्तरी गोलार्ध कतिपय महत्वपूर्ण क्षेत्रों में शीत/बसंत ऋतु से पहले की ऋतुओं के दौरान भारत में सामान्यतः सामान्य से कम ग्रीष्म मानसून वर्षा एवं इसकी विलोम स्थिति से संबद्ध है जो मानसून के दीर्घ अवधि पूर्वानुमान के लिए उपयोगी हो सकता है ।

एशियाई और अफ्रीकी मानसून जो कि उत्तरी उष्ण कटिबंध में दो बड़े क्षेत्र है, जिनका तापमान ग्रीष्म मानसून ऋतु की संगामी तथा बाद की ऋतुओं के दौरान मानसूनी वर्षा के साथ प्रबल नकारात्मक सहसंबंधों को प्रकट करता है । तथापि मानसून के बाद लगभग दो ऋतुओं की लंबी अवधि तक इस संबंध का उष्णकटिबंधीय जलवायु पर बने रहना ई एन एस ओ (एलनीनो दक्षिणी दोलन) के प्रबल प्रभाव को दर्शाता है ।

ABSTRACT. Thirty year (1950-79) time series of Monsoon Index (MI) is correlated with the gridded surface air temperature data over northern hemisphere land at various time lags of months (*i.e.,* months preceding, concurrent and succeeding to the monsoon season) to identify teleconnections of monsoon with the northern hemisphere surface air temperature anomalies.

Out of three key regions identified which show statistically significant relationship of monsoon rainfall, two regions are in the higher latitudinal belt of 40°N-70°N over North America and Eurasia which show positive correlations with temperatures during northern winter; particularly during January and February. The third region is located over northwest India and adjoining Pakistan, where the maximum positive correlation is observed to occur during the pre-monsoon months of April and May. These relationships suggest that cooler northern hemisphere during the preceding seasons of winter/spring over certain key regions are generally associated with below normal summer monsoon rainfall over India and *vice-versa* which could be useful predictors for long-range forecasting of monsoon.

There are two large regions in the northern tropics, namely, Asian and African monsoons whose temperatures reveal strong negative correlations with monsoon rainfall during the seasons concurrent and subsequent to the summer monsoon season. However, persistence of this relationship for longer period of about two seasons after the monsoon, suggests the dominant influence of *ENSO* (*El-Nino-Southern Oscillation*) on tropical climate.
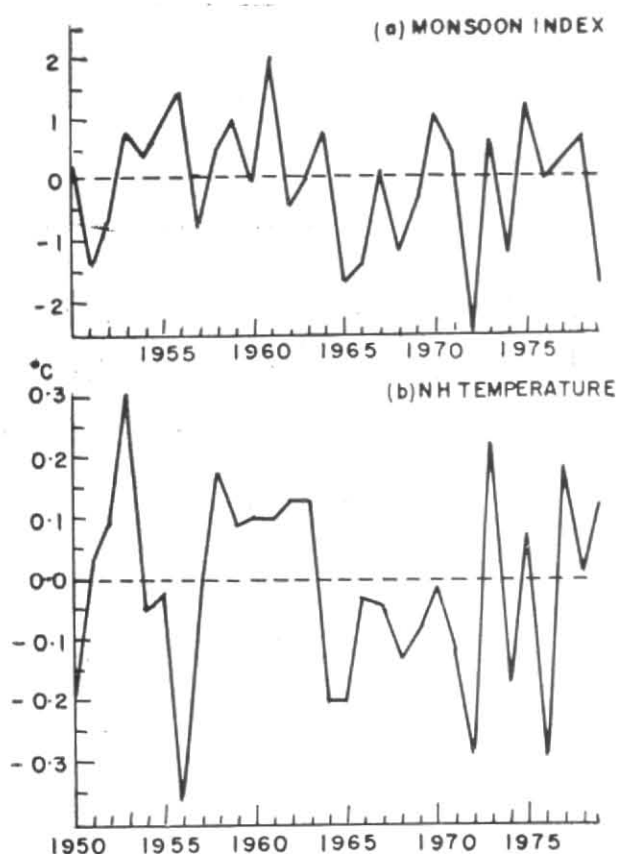
Key words — Indian summer monsoon, Northern hemisphere temperature, Inter-annual variability, Teleconnections, Long-range forecasting, Correlations, ENSO.

1. Introduction

Southeast Asian summer monsoon is one of the most important component of the global climate system. During recent decades the global climate in general and the monsoons in particular have shown considerably large year-to-year variability (Verma 1990). There is a growing body of modelling and observational evidence which suggests that the slowly varying boundary conditions at the earth's surface (such as surface temperatures, soil moisture, sea ice and snow) can influence the inter-annual variability of atmospheric circulation (Charney and Shukla 1981,

Shukla 1986). Role of greater continentality of northern hemisphere on the intensity of seasonal fluctuations is also relevant (Oort 1983).

An earlier study by Verma *et al.* (1985) demonstrated a statistically significant positive relationship between summer monsoon precipitation over India and the averaged northern hemispheric (NH) surface air temperature-maximum correlation being shown with the preceding January-February temperature anomalies. It was for the first time that monsoon was shown to have significant relationship with a meteorological parameter on the hemispheric scale. This

Figs. 1(a&b). Standardized rainfall departure values of Indian summer monsoon, (a) [MI] and (b) annual mean temperature anomaly series averaged for the northern hemisphere from 1950 to 1979

brings in focus the fact that the monsoon is a thermally driven circulation whose year-to year variability, to a considerable extent, will depend upon the overall surface air temperature anomaly of NH, much ahead of the establishment of the circulation. However, spatially averaging the thermal forcing on to the scale of an hemisphere suffers from the risk of obscuring the specific area(s) which might be playing more dominant role. Hence, it was necessary to look into the spatial variability of the relationship also, which would not only identify the key regions in the teleconnection between monsoon and NH land surface temperatures but also bring into deeper focus the mechanism of monsoon variability on interannual scale. The present study deals with the spatial analysis of the relationship over NH land. Correlation maps are presented in respect of months starting from two seasons preceding to summer monsoon season and continuing up to three seasons following the monsoon [i.e., from Dec (−1) through May (+1) with respect to monsoon-year].

2. Data and analysis procedure

Indian summer monsoon precipitation data is taken from Mooley and Parthasarathy (1984). The rainfall departure value is standardized by the long-term standard deviation and denoted as MI (Monsoon Index). The series is shown in Fig. 1(a).
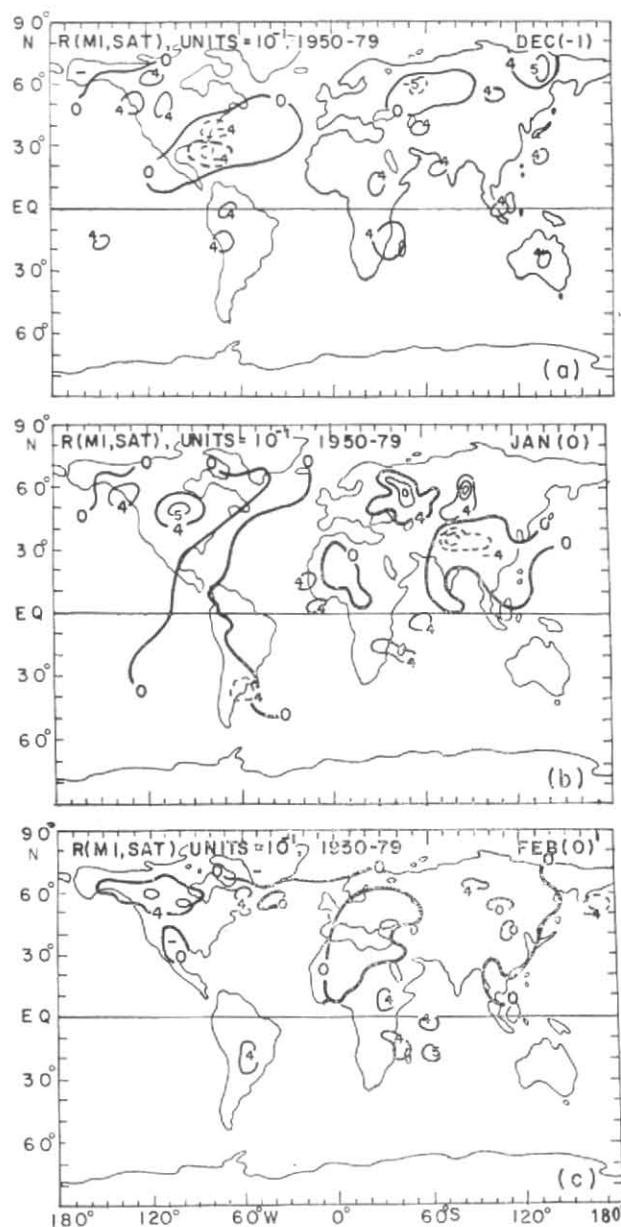
Figs. 2 (a-c). Correlation coefficient (× 10) of the Indian summer monsoon rainfall (MI) with monthly mean surface air temperature anomalies for winter months, (a) Dec (−1), (b) Jan (0) and (c) Feb (0) preceding to monsoon. Contour interval is 2.0 with negative values dashed. Significant correlations at more than 95% level are numbered. (Data period : 1950-1979)

The mean monthly surface air temperature anomalies for northern hemisphere, compiled at Climate Research Unit, University of East Anglia, Norwich, UK, for the period 1851-1984, were made available at GFDL through the courtesy of Dr. P.D. Jones. Details on the data source and analysis methods used are described in Jones et al. (1986). The annual mean temperature anomaly series averaged for the NH during the period 1950-1979 are shown in Fig. 1(b) along with MI series.
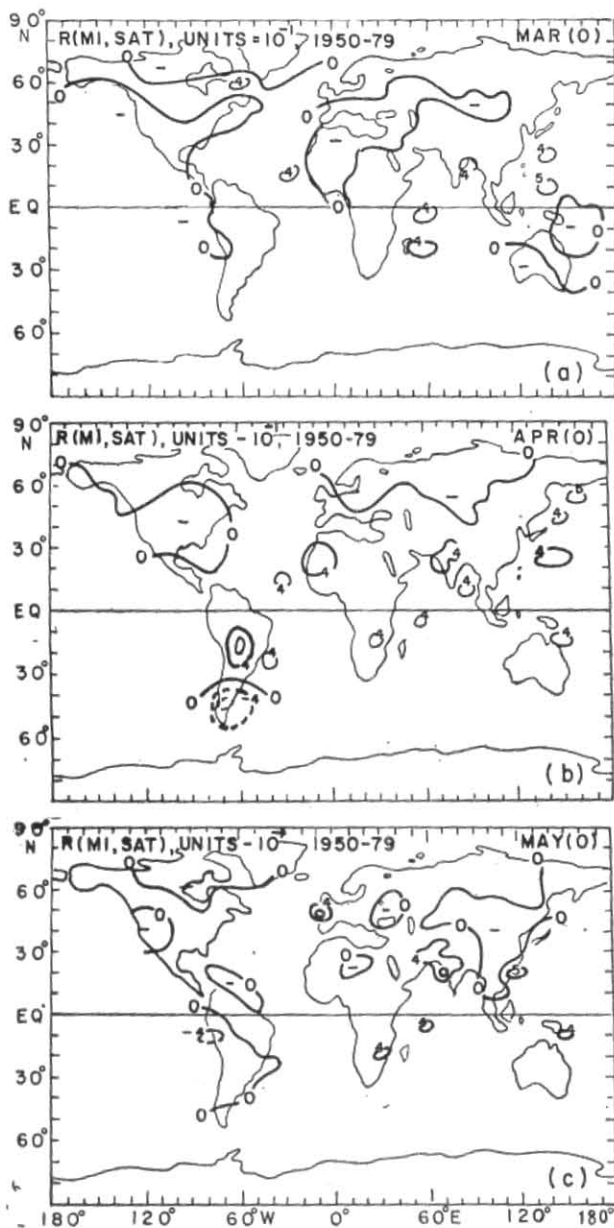
Figs. 3 (a-c). As Fig. 2 but for temperature anomalies for spring months, (a) Mar (0), (b) Apr (0) and (c) May (0) preceding to monsoon

The data series of the period 1950-1979 are used to compute correlations between the monsoon index (MI) and the surface air temperature anomalies at each grid-point with different lags. A total of 30 correlation maps were produced — one each for the month from January of the preceding year through June of the following year, with respect to the monsoon—year. Only selective and more relevant maps are presented and discussed in the present paper. Isolines of correlation coefficients × 10 are drawn on the world base maps. Negative (positive) contours are depicted by dashed (continuous) lines. Significant correlations at more than 95% level are numbered. On the global base maps used in the present study, analyses are extended into the southern hemisphere also as some temperature data from the southern

hemisphere land were also available. Correlations over some regions such as Peru coast, South Africa and northeast Australian region show significant strength. However, we confine our discussions to northern hemisphere, in the present study.

## 3. Relationship of monsoon with NH surface air temperature anomalies over land

3.1. Correlations with temperatures preceding to monsoon

Proceeding in monthly time sequence we first depict relationship of summer monsoon precipitation during June to September with NH surface air temperature during the months preceding to monsoon, viz., Dec(—1) through May (0). Fig. 2 shows the winter months (DJF) and Fig. 3 the spring months (MAM). These maps help identify the key regions over NH land having teleconnections with the Indian summer monsoon wherever correlations are significantly high over a relatively large contiguous area. These teleconnections will not only help in predicting and monitoring the monsoon but also in understanding the mechanism of its variability.

Three key regions are identified in the analysis of relationship of monsoon with preceding months surface air temperature over northern hemisphere. Two of the regions are located in the higher latitudinal belt of North America and Eurasia, which show positive correlations ranging from 0.4 to 0.6 (significant at more than 95% level) during the months from Dec (—1) through Feb (0) —more so during Jan (0) and Feb (0). The latitude belt corresponds to roughly from 40°N to 70° N over the two large land masses of northern hemisphere. The relationship suggests that significantly cooler winters, particularly during January and February, are generally associated with below normal summer monsoon rainfall activity over India and vice versa.
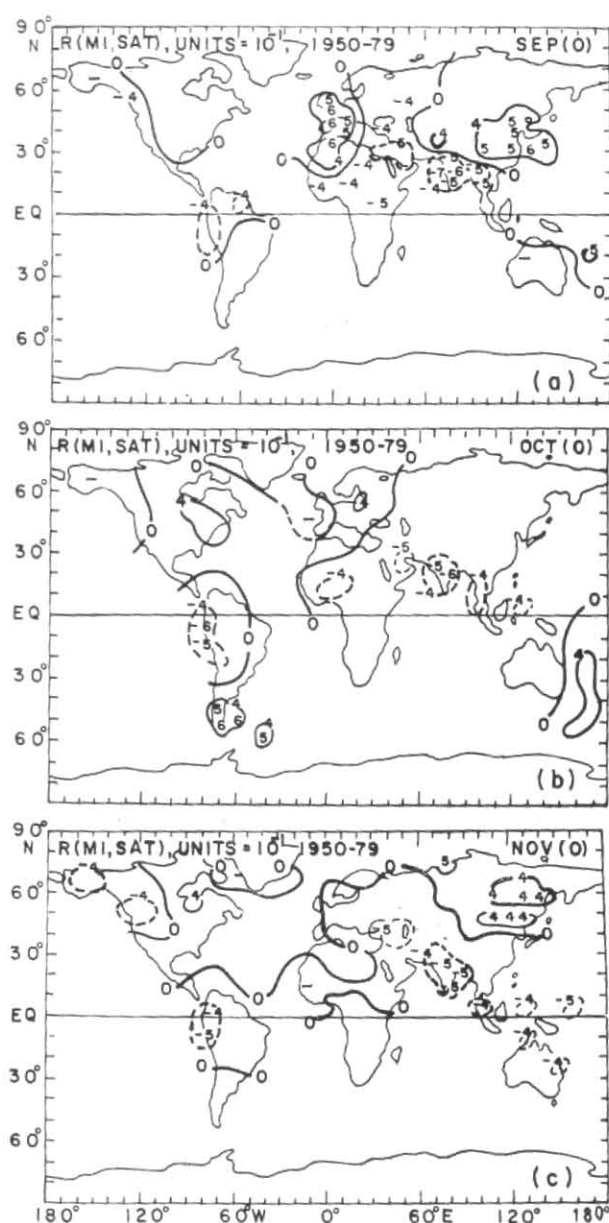
The third region is located over northwest India and adjoining Pakistan. Sense of the relationship is same, i.e., positive but the phase has advanced compared to what was observed over higher latitudes. The maximum correlation is observed to occur during the pre-monsoon months of April and May [Figs. 3 (b & c)].

The physical mechanism for such a relationship may be explained keeping in view the fact that the Asian summer monsoon is basically a thermally driven meridional circulation. The meridional thermal contrast is generated by the ocean-continent configuration of Asian land mass and the Indian ocean to its south. Continentality of northern hemisphere clearly reveals that continents of northern hemisphere lie mainly between 40° N and 70° N or this belt comprises of more land surface than ocean surface (Sellers 1965).
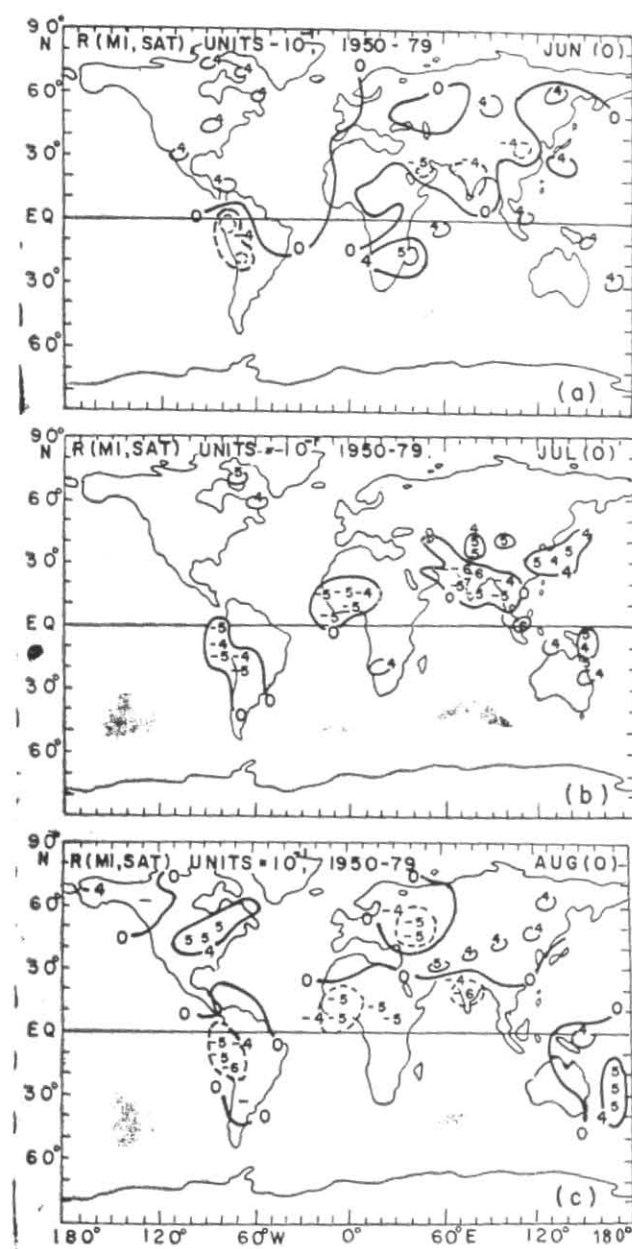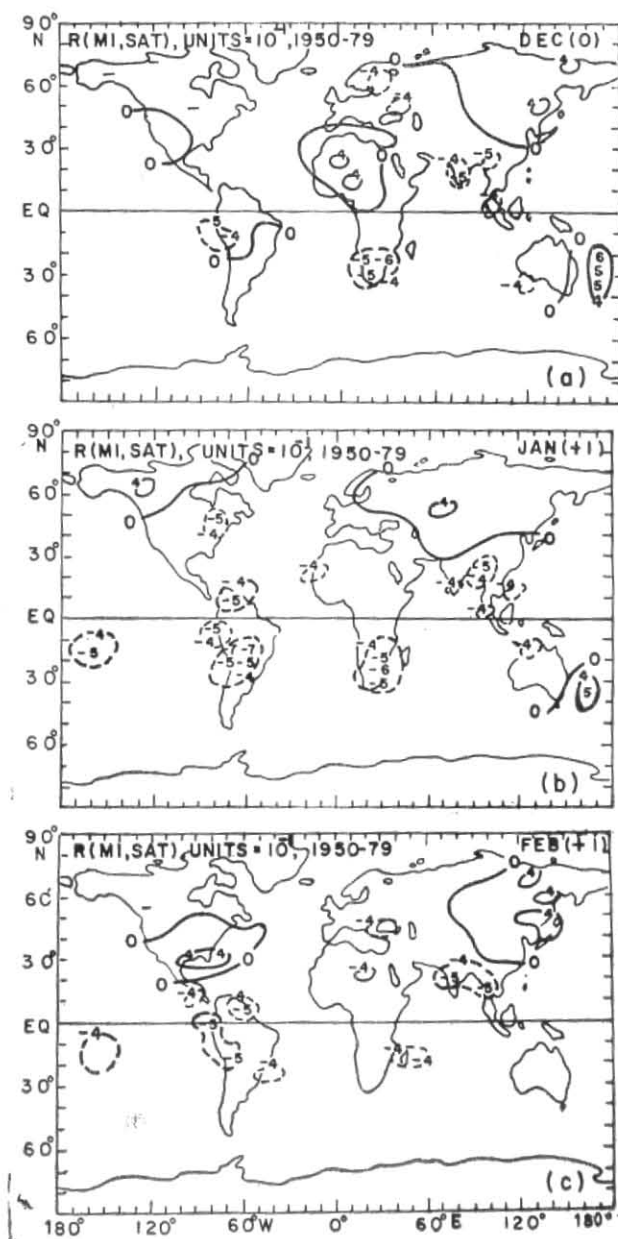
Figs. 4(a-c). As Fig. 2 but for temperature anomalies for summer
months, (a) Jun (0), (b) Jul (0) and (c) Aug (0)
concurrent to monsoon

Figs. 5(a-c). As Fig. 2 but for temperature anomalies for
autumn months, (a) Sep (0), (b) Oct (0) and (c)
Nov (0) subsequent to monsoon

The intensity of seasonality of a planetary circulation (such as Hadley circulation) will also depend upon the land-ocean ratio in zonal belts because of the largely differing thermal properties of land and ocean. Higher the land-ocean ratio in a zonal belt, larger the forcing on the seasonality in the planetary circulation from that belt. Hence, relatively, the largest thermal control on the monsoon circulation will be exerted from the belt of 40° N-70° N which has the maximum land-to-ocean ratio in the northern hemisphere. The temperature anomaly of the land surface over this belt will exert considerable influence on the

strength of the monsoon circulation. But how to explain the lag between the winter temperature anomaly and the summer monsoon activity ? The possible explanation may be as follows : The greater continentality of NH belt of 40° N-70° N will make the winter over this belt very cold compared to warmer tropical and equatorial belt and will thus generate strong meridional temperature gradient resulting in strong westerlies. During spring the temperature gradient tends to weaken and the wind field too slackens. In early summer months the temperature gradient even reverses because of hot continents and cooler oceans. From the point of view of year-to-year variability of the climate system, the temperature anomaly over this belt during the winter months or the season of the maximum temperature gradient, assumes greater importance.

Figs. 6(a-c). As Fig. 2 but for temperature anomalies for winter months, (a) Dec (0), (b) Jan (+1) and (c) Feb (+1) subsequent to monsoon

The strong positive correlation of surface air temperature observed during April and May over northwest India and adjoining Pakistan with the summer monsoon rainfall of India may suggest that the winter-temperature anomaly of higher latitudinal belt of NH spreads to southern latitudes during the spring. However, its relevance to Indian summer monsoon is confined in space and time — to northwest India and adjoining Pakistan region and to pre-monsoon months of April and May. Importance of the local thermal anomaly during the pre-monsoon months in influencing the monsoon was earlier revealed in the studies by Verma (1980, 1982).
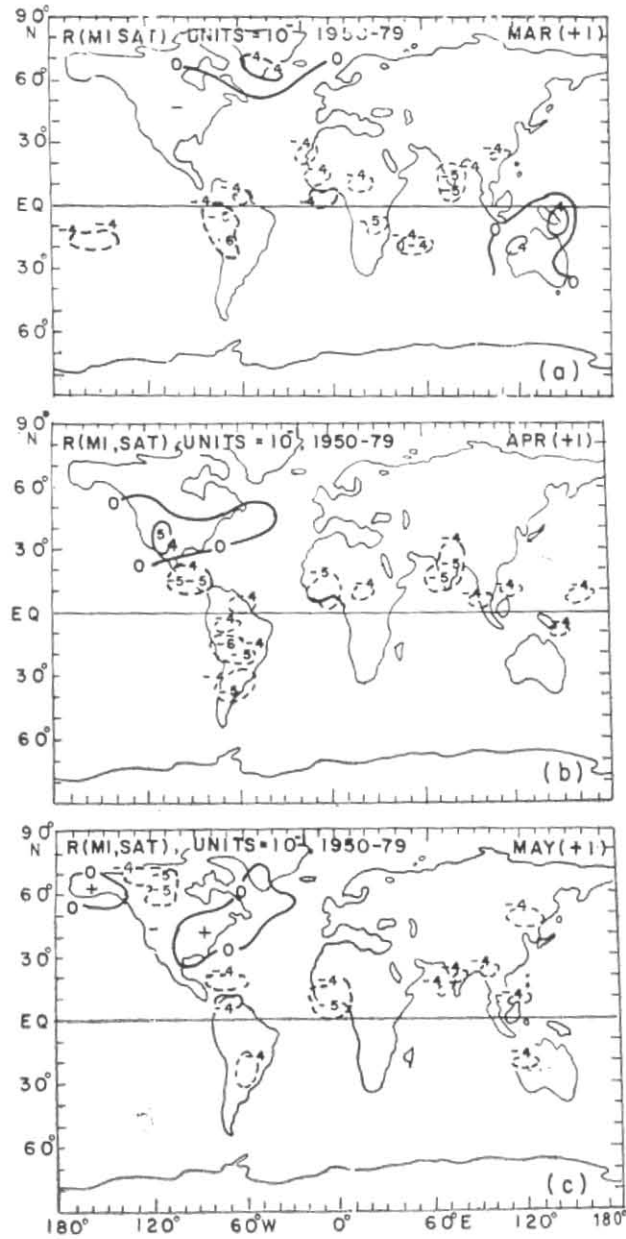
It is well known that the region of northwest India and adjoining Pakistan develops into an intense heat-low during the summer and plays a pivotal role in maintaining the monsoon circulation. This heat-low starts building-up during the pre-monsoon months of April and May. More is the intensity of this heat-low, greater is the pressure gradient across India and more vigorous is the monsoon circulation. Hence, the positive correlation of temperature anomaly over northwest India and adjoining Pakistan region during April-May is quite plausible. Its predictive value for long-range forecasting of monsoon precipitation is of practical importance.

3.2. Correlations with temperatures concurrent to monsoon

Figs. 4 (a-c) show the maps of correlation for the summer months of June, July and August—concurrent to monsoon. Confining our discussions to NH only, two regions appear to be more relevant—the Indian sub-continent and the west African region. The correlations are strong negative—implying that an above (below) average summer monsoon rainfall over India is associated with cooler (warmer) temperatures during the concurrent season over the Indian sub-continent and the west African region. These are the tropical regions of the NH encompassed by the summer monsoons (i.e., the southeast Asian and west African monsoons) and both are integral parts of the planetary scale Hadley circulation. Such a relationship is obvious since a more active monsoon will have greater cloudiness and the associated enhanced precipitation—both the factors cool the surface. The opposite will also hold.

3.3. Correlations with temperatures succeeding to monsoon

Figs. 5-7 show the maps of correlation of summer monsoon precipitation with the NH temperatures during the subsequent northern seasons of autumn (SON), winter (DJF) and spring (MAM). It is interesting to note that strong negative correlations more or less persist over Indian sub-continent through all the four seasons beginning summer monsoon season. This would emphasize that the temperature anomalies caused in association with a particular monsoon precipitation anomaly persist for almost throughout the year over the Asian monsoon region. Over west African region, the persistency is not that strong. It is quite possible that these long persisting correlations are the manifestation of the global scale

A negative temperature anomaly of large amplitude (i.e., much cooler than normal) during winter would tend to enhance the temperature gradient, strengthen the westerlies resulting in their shift towards the equator. The large temperature anomalies of winter generally tend to persist during the spring with lesser magnitude. The northern continents will experience less hot summer, weaker meridional temperature gradient and westerly wind anomaly. An apparent equatorward shift in the circulation patterns will weaken monsoon circulation. The opposite may occur when the temperature anomaly over 40° N - 70° N belt is large positive resulting in stronger than normal monsoon.

R. K. VERMA

Figs. 7(a-c). As Fig. 2 but for temperature anomalies for spring months, (a) Mar (+1), (b) Apr (+1) and (c) May (+1) subsequent to monsoon

anomalies caused by strong *ENSO* (*El-Nino Southern Oscillation*) episodes during the sample period since strong *ENSO* episodes persist for several months. This is supported by the studies of Pan and Oort (1983) and Jones and Kelly (1988) who showed high correlation between the temperature integrated over the entire northern hemisphere and the east equatorial Pacific SST demonstrating that the maximum positive correlation occurred when the NH temperatures lagged by six months. Also, it is established that *ENSO* events strongly influence the variability of monsoon precipitation on seasonal and interannual scales. In such a possibility, the relationship of monsoon with subsequent surface air temperature may hold better in association with an *ENSO* and may not hold during the periods when there is no *ENSO*. This hypothesis is supported implicitly in the strong negative correlations over the Peru coast and adjoining northwest region of Latin America, revealed in maps from Jun (0) through May (+1) (Figs. 4 to 7).

4. Conclusions and discussion

It is now recognised that the interannual variability of the global climate system is largely influenced by changes in lower boundary conditions of the earth's atmosphere. In the present study, the relationship of monsoon with NH surface air temperature anomalies are analysed for temperatures at different lags with respect to monsoon. The conclusions drawn may be summarised as follows :

(*i*) Three key regions are identified which reveal strong signals with their temperatures preceding to monsoon. Winter (JF) temperature anomalies in the higher latitudinal belt of about 40°N to 70°N over North America and Eurasia show significant positive correlations with the monsoon, *i.e.,* cooler winters over these regions are detrimental to the monsoon activity and *vice-versa*. Third region is located over northwest India and adjoining Pakistan which also reveals significant positive correlation, but during the pre-monsoon months of April and May. These relationships may suggest that global-scale influence on monsoon may initiate in winter, about two seasons in advance, mainly through the continentality of the northern hemisphere. Whereas the local forcing may be exercised during the pre-monsoon months. The relationships not only help to understand, at least partially, the mechanism of monsoon variability on interannual scale, but provide useful predictors for the long-range forecasting of seasonal rainfall activity of the Indian summer monsoon.

(*ii*) There are two regions in the northern tropics whose temperatures reveal strong concurrent relationship with the monsoon. These are monsoon regions of south Asia and west Africa. The correlations are negative, *i.e.,* wetter (drier) monsoon is associated with cooler (warmer) summer over most of the tropical land. The relationship is physically understandable as heavy precipitation and the associated greater cloudiness of the monsoon circulation will tend to cool the surface locally and *vice-versa*.

(*iii*) The more noteworthy point seems to be the persistence of temperature anomalies over land masses for several months after the summer monsoon. This tendency of temperature anomaly to sustain for 2-3 seasons, after the monsoon has withdrawn from the region, appears unlikely if temperature anomalies resulting from precipitation and cloudiness anomalies in association with the monsoon circulation alone are to be considered. Large temperature anomalies in sea surface are capable of persisting for 2-3 seasons. *ENSO* signal in continental temperature and precipitation records as revealed by Bradley *et al.,* (1987) are relevant. The large spatial and temporal scales of *ENSO* and because of the fact that interaction between ocean and atmosphere lie at the heart of *ENSO* phenomenon, one may hypothesize that a strong *ENSO* episode once triggered may cause temperature anomalies in NH and precipitation anomalies in monsoons with a possibility of feedback from monsoon to *ENSO* also. These chain of climatic anomalies probably get reflected in the correlations of monsoon with global temperatures (SST and surface air temperature), particularly the ones which are observed after the monsoon.

References

Bradley, R.S., Diaz, H.F., Kiladis, G.N., and Eischeid, J.K., 1987, "ENSO signal in continental temperature and precipitation records", *Nature*, **327**, 497-501.

Charney, J.G., and Shukla, J., 1981, Predictability of monsoons : 'Monsoon Dynamics,' Eds Sir James Lighthill and R.P. Pearce, Cambridge Univ. Press, 99-110.

Jones, P.D., Raper, S.C.B, Bradley, R.S., Diaz, H.F., Kelly, P.M; and Wigley, T.M.L., 1986, Northern hemisphere surface air temperatures : 1851-1984, " *J. Climate Appl. Meteor,* **25,** 161-179.

Jones, P.D., and Kelly, P.M., 1988, "Causes of international global temperature variations over the period since 1861," In, H. Wanner and U. Sigenthaler, Eds., *Long and short term variability of climate,* Lecture notes in Earth Sciences, **16,** Springer-Verlag, 18-34.

Mooley, D.A. and Parthasarathy, B., 1984, "Indian summer monsoon rainfall and the east equatorial Pacific sea surface temperatures", *Atmosphere-Ocean,* **22,** 23-25.

Oort, A.H. , 1983, "Global Atmospheric Circulation Statistics 1958-1973", NOAA Paper 14, US Government Printing Office, Washington, DC 20402, 180 pp +47 microfiches.

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," *Mon. Weath. Rev.* **111**, 1244-1258.

Sellers, W.D., 1965, The Climatology of the Hemispheres : 'Physical Climatology,' Chicago University Press, 4-10.

Shukla, J., 1986, Interannual variability of monsoons: 'Monsoons', Eds J.S. Fein and P.L. Stephens, Wiley and Sons, 523-547.

Verma, R.K., 1980, Importance of upper tropospheric thermal anomalies for long-range forecasting of Indian summer monsoon activity," *Mon. Weath. Rev.*, **108**, 1072-1075.

Verma, R.K., 1982, "Long-range prediction of monsoon activity : A synoptic-diagnostic study," *Mausam,* **33**, 1, pp. 35-44.

Verma, R.K., Subramian, 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," *Proc. Indian Acad. Sci. (Earth Planet. Sci.),* **94**, 187-198.

Verma, R. K., 1990, 'Recent monsoon variability in the global : climate perspective," *Mausam,* **41**, 4, pp. 315-320.