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Relationships between planetary-scale waves, Indian monsoon rainfall and ENSO

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सार – एल नीनो के साथ सहसंबंधित भूमध्यरेखीय पूर्वी प्रशांत में समुद्री सतह ताप कैसे भारत में लघुवृत मानसून वर्षा को उत्पन्न कर सकता है, जो कि पृथ्वी के दूर-दूर तक अलग भागों में है, का अन्वेषण करने के लिए भारतीय मानसून वर्षा (जून-सितम्बर) में एल नीनो परिघटना और भूमंडलीय मान तरंगों और अंतरावलय भिन्नताओं के मध्य संबंधों का विश्लेषण किया गया। प्रेक्षित संबंधों के अनुसार लघुकृत भारतीय मानसून वर्षा के साथ एल नीनो को जोड़ने के लिए एक सत्याभासी यंत्रावली पर विचार विमर्श किया गया है। ज्ञात किए गए संबंधों से पता चलता है कि एल नीनो के साथ संबंधित अधिक गर्म समुद्री सतह ताप विसंगतियां भूमंडलीय तरंगों को पूर्व की ओर विस्थापन के लिए प्रेरित करती है जिसके कारण भारतीय मानसूनी वर्षा कम होती है।

ABSTRACT. The relationships between the *El Nino* phenomenon and the planetary-scale waves, and the interannual variations in the Indian monsoon (June-September) rainfall have been analysed to investigate as to how SST in the equatorial eastern Pacific associated with the *El Nino* can produce reduced monsoon rainfall over India which are at widely separated parts of the globe. In terms of the observed relationships, a plausible mechanism for linking *El Nino* with the reduced Indian monsoon rainfall is discussed. The relationships noted suggest that large warm SST anomalies associated with *El Nino* induce eastward shift in the planetary waves which in turn reduce the Indian monsoon rainfall.

1. Introduction

The intercorrelation between SST in the equatorial eastern Pacific and central Pacific and the Indian monsoon rainfall is addressed by many researchers (Bhalme 1985, Elliott and Angell 1987). They reported the inverse relationship. A strong association between *El Nino* events over the equatorial eastern Pacific and deficient Indian monsoon rainfall was first suggested by Sikka (1980). This finding receives support from several other researchers who found significant associations between strong to moderate *El Nino* events and deficient Indian monsoon rainfall or droughts. However, these researchers have not addressed to the problem as to how SST in the equatorial eastern Pacific associated with *El Nino* can produce variations in the Indian monsoon rainfall which are at widely separated parts of the globe. In this paper we report on the possible coupling between *El Nino* event and planetary waves of 200 mb height field to produce interannual variations in the Indian monsoon rainfall. Potentiality for long-range prediction of droughts/floods during Indian monsoon from planetary waves of 200 mb height field is also highlighted.

2. Northern hemispheric contour field

The dominant circulation event in the northern hemisphere summer season is the establishment and evolution at upper tropospheric levels of the high pressure system and corresponding strong easterly jet over the low latitudes of tropics. This feature is strongly connected with the progress of the Asian and Indian summer monsoon.

A number of studies (Joseph 1978, Bhalme and Mooley 1980, Verma 1982), have drawn attention to the changes that take place in the upper tropospheric levels particularly at 200 mb in the month of May and performance of Indian monsoon. Many investigators (Kanamitsu and Krishnamurti 1978, Arkin 1982), showed that the global tropical motion field at 200 mb during 1972, the *El Nino* year, was quite anomalous on planetary scale.

The Indian monsoon rainfall is inversely related to SST in the eastern equatorial Pacific. In Rasmusson and Carpenter (1982) composite anomaly of SST at Puerto Chicama (7.7° S, 79.5° W), anomalous warmth appears abruptly in February (Fig. 1) of the year of *El Nino* occurrence and reaches a peak in May immediately preceding a monsoon season, suggesting a basis for seasonal forecast of Indian monsoon rainfall.

In the light of above, we have examined USSR northern hemisphere mean monthly synoptic maps of 200 mb for May from 1971 to 1975 to investigate the coupling between *El Nino* and planetary scale waves, and the Indian monsoon droughts/floods.

2.1. *Climatology*

Contour map of average (1950-69) height of the 200 mb pressure level in May over the northern hemisphere is shown in Fig. 2. The prominent features of 200 mb pressure level are three cellular high pressures systems in the tropics. The intense high over the Indian region is east-west oriented, extending between 70° E & 110° E longitudes with the centre around 15°N,

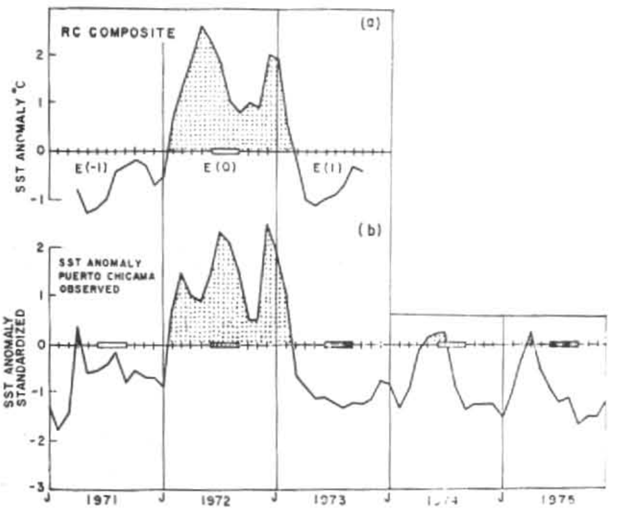

Fig. 1. (a) Composite *El Nino* SST anomaly at Puerto Chicama [*After* Rasmusson and Carpenter (RC)]. E(O) indicates year of occurrence of *El Nino*, E(—1) year prior to *El Nino* and E(+1) year following *El Nino*.

(b) Observed SST anomaly at Puerto Chicama for indicated years. The period of Indian monsoon is marked across zero, anomaly line by rectangles. Unshaded rectangle indicates normal Indian monsoon year, dotted rectangles are drought and shaded flood years over India.

TABLE 1

Percentage area of India with monsoon rainfall excess (> +20% of the normal) and deficient (< —20% of the normal) for the period 1971-75

Year	Excess	Deficien
1971	16.5	17.3
1972	0	60.3
1973	31.8	4.5
1974	8.1	39.1
1975	57.0	2.9

TABLE 2

Correlation coefficients among the Indian monsoon rainfall (IMR), 200 mb May ridge location (Long. E) and SST standardized anomaly at Puerto Chicama (SST)

	IMR	Long. (°E)	SST
IMR	1.00	—0.95***	—0.90*
Long. (°E)		1.00	0.93**
SST			1.00

***, ** & * indicate coefficient of correlation significant at 99, 98 and 96 per cent confidence level respectively.

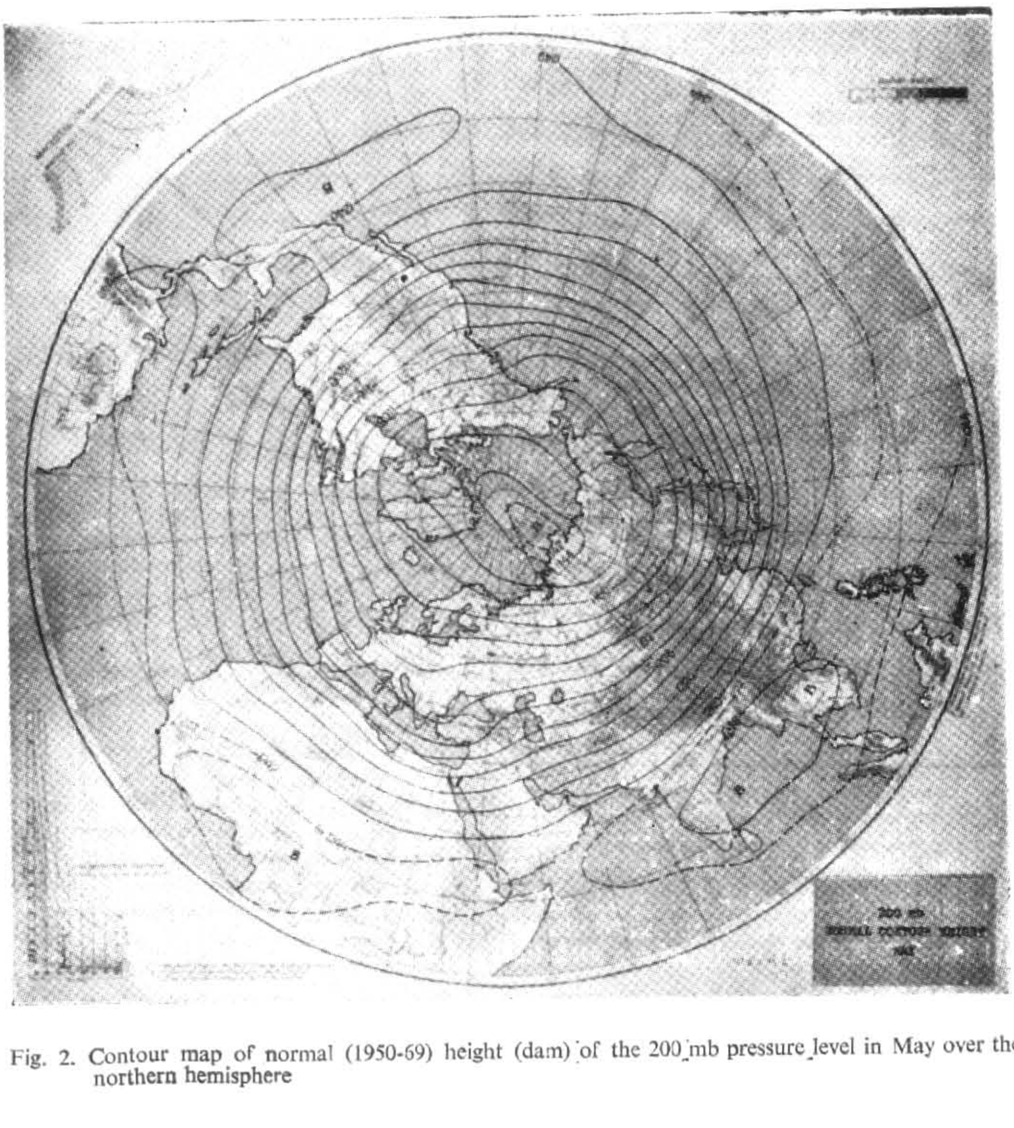

Fig. 2. Contour map of normal (1950-69) height (dam) of the 200 mb pressure level in May over the northern hemisphere

90° E. The other one over the eastern Pacific extends between 90° W & 130° W longitudes with its centre around 15° N, 105° W which is weaker in intensity than that over the Indian region. The third one is over Africa. Any persistent anomalies in the intensity and location in these large scale divergent high pressure systems are likely to affect organised convection and hence, monsoon rainfall over India.

2.2. *Year to year variations*

The five-year period 1971 to 1975 was characterized by a large year to year variations in the Indian monsoon. Fig. 3 presents maps of monsoon rainfall deficiencies and excesses for the various meteorological sub-divisions of India for these five years. Large scale failure of monsoon rainfall, *i.e.*, drought occurred over India during the years 1972 and 1974. In contrast, 1973 and 1975 were excess monsoon rainfall (flood) years, and 1971 a normal monsoon rainfall year for India (Table 1).

Contour maps of mean height of the 200 mb pressure level in May over the northern hemisphere for the 5-year period 1971-75 were examined. The noteworthy features are : (*i*) presence (absence) of marked cellular feature in the tropics for monsoon flood (drought) years and (*ii*) weaker intensity and eastward shift of quasi-permanent high over Indian region for monsoon drought years. An objective quantitative method for determining the shift in location of high is discussed in the following section.

3. Planetary scale quasi-stationary waves

The weather in the tropics is mainly seasonal which is controlled by quasi-stationary waves of different scales. In the lower troposphere, synoptic-scale waves appear dominant but in the upper troposphere, small-scale waves disappear and only planetary-scale waves are discernible. The principal mechanisms for forcing planetary-scale quasi-stationary waves involves orography and zonal variations in atmospheric heating. Seasonal and interannual variations in the amplitudes and phases of these waves, cause lagre-scale anomalies in the weather over the tropics as well as extra-tropics. It seems appropriate, therefore, to study planetary-scale waves for possible use in long-range forecasting of monsoon.

In order to determine the characteristics of planetary waves in geopotential height field of tropics, we used contour maps of mean height of the 200 mb pressure level in May over the northern hemisphere as presented in Fig. 2 and for the years 1971-75. The grid point values were picked at interval of 10-degree longitudes along a latitude circle of 15°N, the latitude of highest pressure of cellular high pressure systems. The picking out grid point values involves some subjectivity. We have carried out some experiments to ensure that the subjectivity in picking out the grid point values is not much. The 36 grid point values along 15° N latitude circle were subjected to harmonic analysis for 1 to 18 waves numbers. We have, however, presented wave numbers 1 to 10 in Fig. 5 because of negligible contribution to the variance of geopotential height by the wave numbers beyond 10.

A zonal harmonic analysis of geopotential height field along 15° N latitude circle reveals that wave numbers 1 to 3 are prominent and contribute a large proportion of variance in geopotential height field (Fig. 5). The integrated effect of the first 3 wave numbers were considered to determine locations of troughs and ridges (Fig. 4). The noteworthy features are :

(*i*) A prominent ridge is located along 100° E, *i.e.*, over the Indian region, while detectable ridge is along 80° W, *i.e.*, over the eastern Pacific, in the climatological normal geopotential height field of 200 mb level in May.

(*ii*) In the years of drought, decrease in amplitude and eastward shift by about 30°-36° longitudes of the ridge over the Indian region is remarkable. In a major drought of 1972 the ridge is located along 136° E and in a 1974 drought year the ridge is along 130° E.

However, the ridge over the eastern Pacific shows marked increase in amplitude and westward shift by about 10° longitudes in the case of severe drought year.

(*iii*) In the years of flood in 1973 and 1975 ridge is located along 94° E and 100° E respectively. The ridge over the eastern Pacific is, however, not detectable.

4. Relationships between SST in the equatorial eastern Pacific, 200 mb ridge and the Indian monsoon rainfall

In order to investigate as to how SST in the equatorial eastern Pacific associated with *El Nino* influences the Indian monsoon rainfall, we analysed the relationships between SST standardized anomaly in May at Puerto Chicama, longitude of ridge location in the integrated first 3 wave numbers along 15°N latitude circle and the Indian monsoon rainfall. As stated earlier, in the data of Rasmusson and Carpenter (1982) composite SST anomaly of SST at Puerto Chicama (Fig. 1), anomalous warmth appears abruptly in February of the year of occurrence of *El Nino* and reaches a peak in May. Therefore, May SST standardized anomaly data at Puerto Chicama for the years 1971-75 were used in the analysis. Data for the location of ridge used are those obtained by the method of integrated effect of the first 3 wave numbers along 15° N latitude circle in the geopotential height field of 200 mb pressure level in May which were identified in the previous section.

Table 2 gives correlation coefficients between the Indian monsoon rainfall and longitude of 200 mb ridge in May, and SST anomaly in May at Puerto Chicama.

(*i*) The longitude of the May ridge location is significantly (r=0.93, significant at 98% CL) related to the May SST anomaly at Puerto Chicama. This implies warmer (colder) SST anomalies are associated with eastward (westward) longitude of the ridge location.

(*ii*) The highest (—0.95) and statistically significant (at 99% CL) correlation is found between the Indian monsoon rainfall and the longitude of the ridge location in May over the Indian region. The variations in the ridge location appear to be highly inversely related to the Indian monsoon rainfall, with rainfall tending to be less

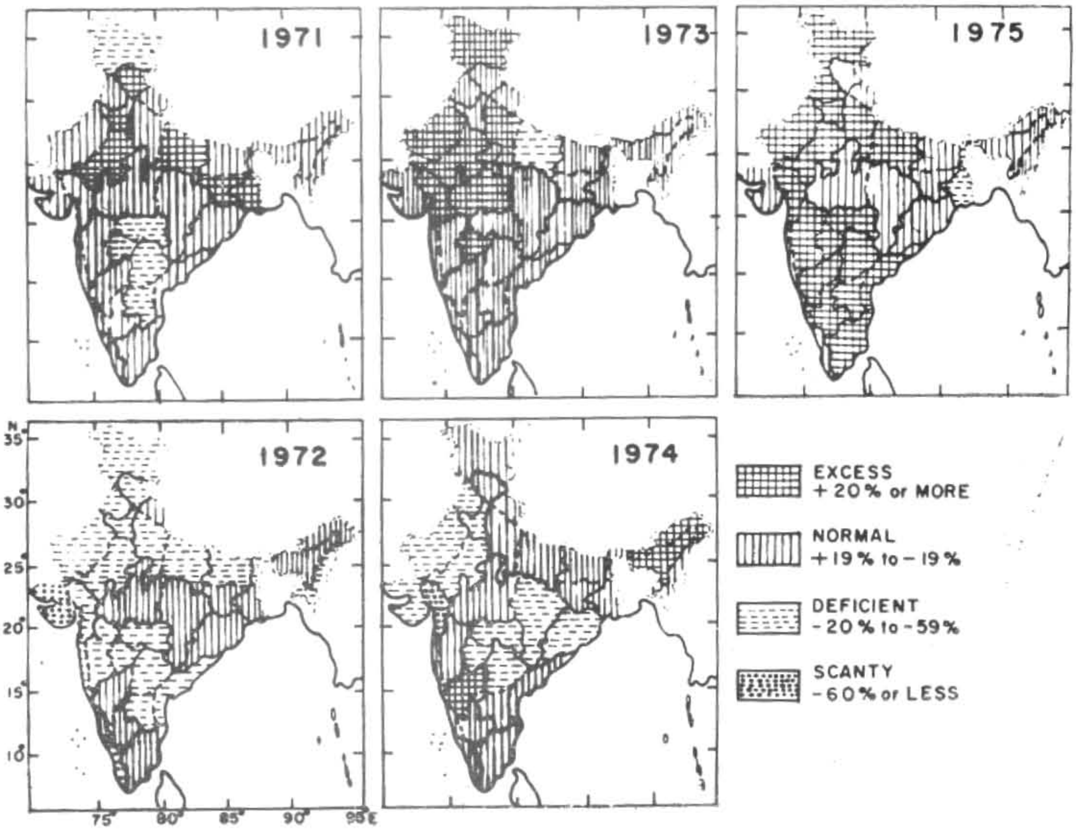

Fig. 3. Rainfall excess and deficiencies sub-divisionwise, compared to the normal for the period June through September

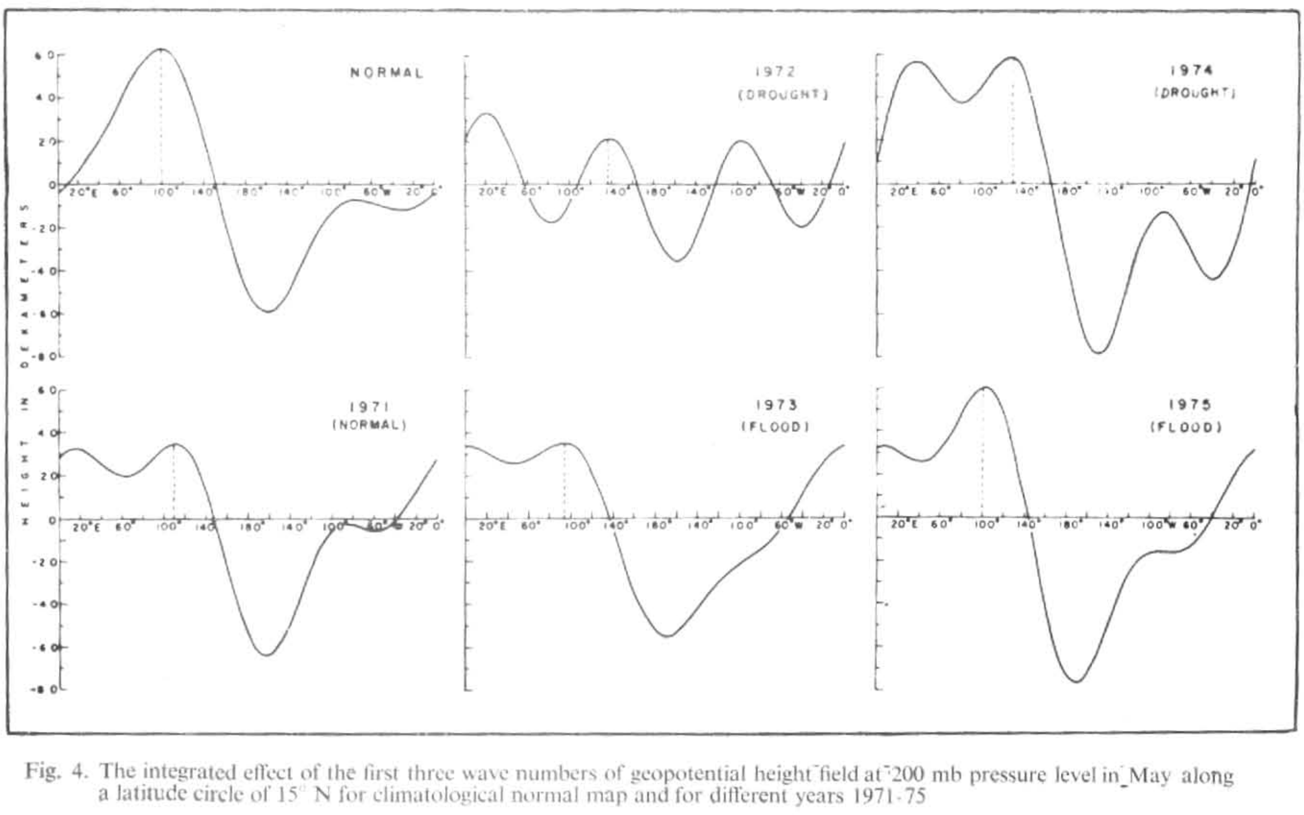

Fig. 4. The integrated effect of the first three wave numbers of geopotential height field at 200 mb pressure level in May along a latitude circle of 15° N for climatological normal map and for different years 1971-75

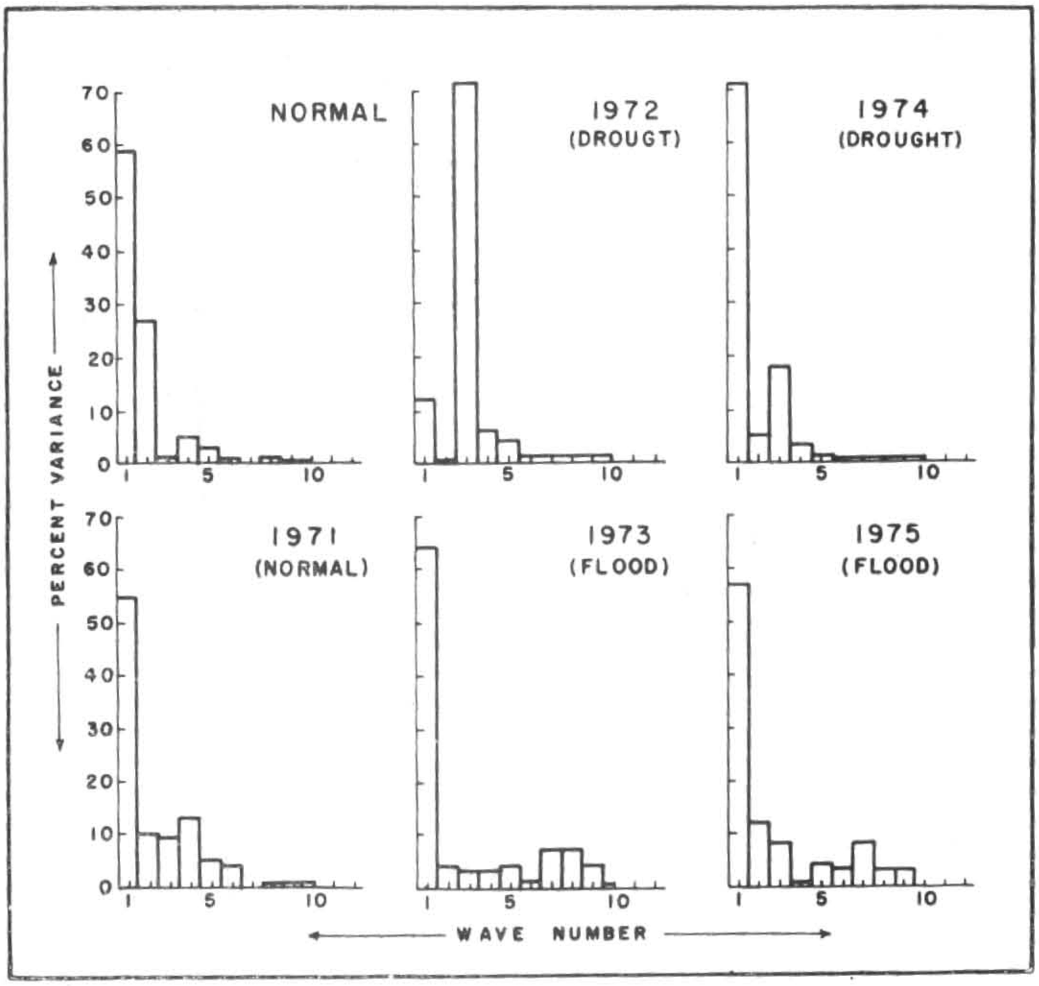

Fig. 5. Per cent variance as a function of zonal wave number of geopotential height field at 200 mb pressure level in May along a latitude circle of 15° N for climatological normal map and for different years 1971-75

(more) than normal during eastward (westward) longitude of the ridge location, suggesting some predictive value for the Indian monsoon rainfall.

(*iii*) The Indian monsoon rainfall and May SST anomaly at Puerto Chicama is inversely related ($r=-0.90$, significant at 96% CL). The close relationships between SST anomaly in May, longitude of the 200 mb ridge in May, and the Indian monsoon rainfall are clear in Fig. 6. It may be noted that the data sample is small. There is no guarantee that high correlations would be stable if we had a longer sample. However, the analyses suggest a strong physical link between the *El Nino* phenomenon and the planetary-scale waves, and the Indian monsoon rainfall activity. Although statistical analyses make no claim for cause and effect, the relationships noted suggest that May SST variations associated with *El Nino* induce shift in planetary waves which in turn effect the convective activity and Indian monsoon rainfall.

5. Summary and conclusions

The relationships between SST standarized anomaly in May at Puerto Chicama, longitude of ridge location over Indian region of the integrated planetary-scale waves (numbers 1-3) along 15° N latitude circle in geopotential height field of 200 mb pressure level in May and the Indian monsoon rainfall (June-September) have been analysed for the years 1971-75 for linking *El Nino* with reduced Indian monsoon rainfall activity.

The study suggests the following :

(1) The noteworthy features of contour maps of mean height of the 200 mb pressure level in May over the northern hemisphere are : (*i*) the presence (absence) of marked cellular features in the tropics for monsoon flood (drought) years and (*ii*) the weaker intensity of quasi-permanent high over the Indian region and its eastward shift for monsoon drought years.

(2) The longitude of ridge location over the Indian region of the integrated planetary waves (numbers 1-3) along 15° N latitude circle of 200 mb height field in May is significantly ($r=0.93$, significant at 98% CL) related to the May SST anomaly at Puerto Chicama. This implies that warmer (colder) SST anomalies are associated with eastward (westward) longitude of the ridge l ocation

(3) The variations of the ridge location in May appear to be highly inversely ($r=-0.95$, significant at 99% CL) related to the Indian monsoon rainfall, with rainfall tending to be less (more) than normal during eastward (westward) longitude of the ridge location, suggesting some predictive value for the Indian monsoon rainfall. The planetary-scale waves seem to play an important role on the variations of the Indian monsoon rainfall activity.

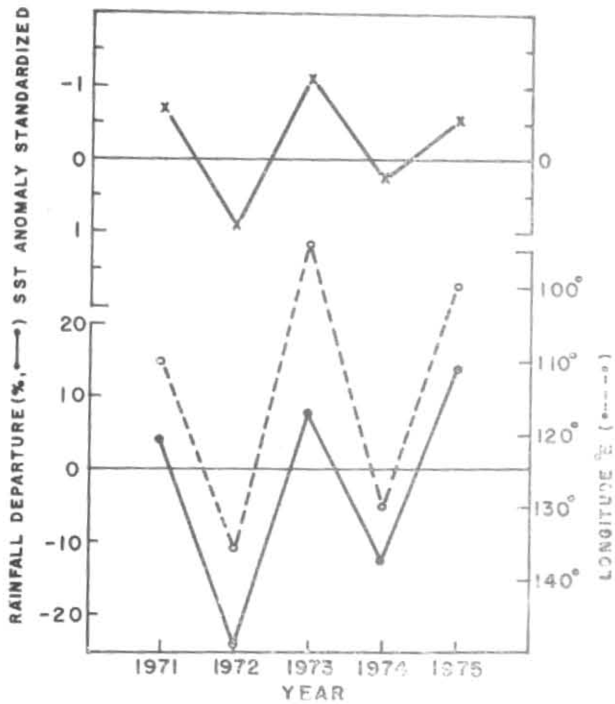

Fig. 6. The relationships among the Indian monsoon rainfall (% departure), ordinate (reversed) longitude (°E) of the ridge for integrated first 3-wave numbers along 15°N latitude circle in the height field of 200 mb pressure level for May and ordinate (reversed) SST standardized anomaly in May at Puerto Chicama

(4) The Indian monsoon rainfall and May SST anomaly at Puerto Chicama are inversely related ($r = -0.90$, significant at 96% CL).

(5) The enormous heat storage capacity of the oceans and obvious energy exchange which takes place between atmosphere and oceans make air-sea interaction a likely cause of climate variability. Sea surface temperature (SST) anomaly in the tropics is one of the most important decisive factors of the interannual variability of the tropical monsoon circulations. The influence of SST anomaly on tropical circulation is mostly determined by the changes in moisture and rainfall.

We have already presented the evidence for significant relationships between SST in the eastern equatorial Pacific 200 mb ridge location and the Indian monsoon rainfall. The fundamental question centres on the problem as to how SST in the equatorial eastern Pacific associated with *El Nino* can produce reduced monsoon rainfall over India which are at widely separated parts of the globe. In terms of the observed relationships the plausible mechanism for linking *El Nino* with the reduced Indian monsoon may be the following :

(*i*) A large warm SST anomaly in May associated with the *El Nino* in the equatorial eastern Pacific can increase the sensible heating, evaporation and moisture, giving rise to enhanced rainfall in the eastern Pacific.

(*ii*) As a consequence, the planetary-scale waves (integrated wave numbers 1-3) in the height of 200 mb pressure level in May alter the position and amplitude. The marked eastward shift in ridge location by 30° to 36° longitudes over the Indian region can lead to massive displacements of rainfall regions, bringing reduced monsoon rainfall (droughts) over India. This mechanism receives some supporting evidence from Keshavamurty's (1982) studies with GFDL model in which he found large warm SST anomaly over central and western Pacific induced an eastward shift of the Tibetan high and reduced rainfall.

(*iii*) On the contrary, when the SST in the equatorial Pacific is colder than the normal, 200 mb ridge comes towards its normal position over the Indian region, leading to enhanced monsoon rainfall over India.

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