

Relationship between Indian summer monsoon rainfall and position of Pacific Ocean warm pool

C K Gopinathan & J S Sastry

National Institute of Oceanography, Dona Paula, Goa 403 004, India

Received 3 October 1989; revised 16 July 1990

A new oceanic parameter linked to Indian summer monsoon rainfall (ISMR) has been identified. A large area of the Pacific Ocean having sea surface temperature $> 29^{\circ}\text{C}$ in satellite derived multi-channel sea surface temperature (SST) or blended SST, called Pacific Ocean warm pool (POWP) is the new parameter. Statistical relationship between monthly anomalies of the position of POWP and monthly ISMR anomalies has been investigated. A significant negative relationship is observed between the parameters. The linear correlation coefficient obtained between anomalies of the zonal positions of POWP and ISMR, for 22 pairs of observations between 1983 and 1988, is -0.79 and significant at 0.1% level. The non-linear correlation coefficient, corresponding to the second degree equation fitted to the data, is -0.80 . The high correlation is due to dependence of the atmospheric circulation pattern in the tropics, especially over India on the position of POWP. Probable sequence of related events is explained and ways of utilising the relationship for forecasting monthly rainfall over India are discussed.

Many attempts have been made to forecast seasonal mean summer monsoon rainfall over India, since the pioneering work of Blandford¹. Long range forecasting of rainfall anomalies is generally based on statistical techniques. During the last 100 y, several parameters which have significant relationship with Indian summer monsoon rainfall (ISMR) have been identified and multiple regression equations or models utilising some of them have been developed²⁻⁶ to forecast seasonal mean ISMR. However, attempts to forecast monthly mean ISMR have not been made because of its very large variability.

Low latitude rainfall variability is more predictable⁷ because of its dependence on boundary anomalies like sea surface temperature (SST). Relationships between SST at selected locations of oceans and seasonal mean ISMR have also been investigated by several workers. Varadachari *et al.*⁸ have recently reviewed the present status. Gadgil *et al.*⁹ have shown that SST above 28°C does not necessarily contribute to large scale clouding over the Indian Ocean area. However, Fu *et al.*¹⁰ have observed that migrations of heavy rainfall regions over the Pacific Ocean to the east during an El Nino southern oscillation (ENSO) episodes were associated with a corresponding migration of area of SST more than 28.5°C . A careful re-examination of the data from Bjerknes¹¹ indicates that very heavy rainfalls over Canton Island were asso-

ciated with SST more than 28.9°C . Gopinathan¹² has observed a shift/spread of waters warmer than 29°C in the equatorial Pacific Ocean to the east of Date line during the years of negative ISMR anomalies.

The objective of this study is to obtain a statistical relationship between monthly rainfall anomaly over India and position anomaly of areas of SST $> 29^{\circ}\text{C}$ (warm pool) in the Pacific Ocean and to give a physical explanation for this link.

Materials and Methods

Monthly SST charts supplied by Ocean Products Center, National Weather Service, USA were utilised for this study. These were basically satellite sensed multi channel SST data. Since 1985, SST charts were made by blending satellite derived SST with ship reported SST. The details of data processing in preparation of the charts were explained¹³. These charts cover all oceans. We have limited our study to SST variations in the tropical Pacific Ocean.

The anomalies in monthly position of Pacific ocean warm pool (POWP) were computed with reference to those obtained from climatological¹⁴ monthly mean values. The data analysed cover the summer monsoon months from 1982 to 1988. However, the data utilised for computation were 22 months from June 1983, because of some bias in the data for 1982 caused

by aerosol contamination¹⁵. The charts of summer seasonal SST and monthly and seasonal outgoing long wave radiation (OLR) were obtained from Climate Analysis Center, NOAA, USA.

The data on monthly rainfall of 35 sub-divisions over India are routinely reported¹⁶ since 1983. Data during summer monsoon months of 1982-88 as well as data on normal monthly rainfall were obtained from these reports during different years. The anomalies in monthly rainfall were computed and their relationship with POWP anomalies was investigated.

Results and Discussion

An examination of the yearly mean SST fields of world oceans¹⁴ shows that the region between 140° and 180°E is the warmest part of all oceans. The region with temperature exceeding 29°C in smoothened SST

field is the Pacific Ocean warm pool (POWP). The longitude at which the center of POWP is situated, computed from the SST field, has been termed as the position of POWP. Distribution of areas with SST > 29°C (warm pool) in the Indo Pacific oceanic regions during summer (June-August) is shown in Fig. 1. The areas of large scale convection and intense clouding, as indicated by low (< 220 W m⁻²) OLR values in the area during the same period are shown in Fig. 2. A gradual shift/spread of POWP to the east in the Pacific Ocean from 1984 to 1987 is observed. A corresponding shift or spread in the low OLR value areas is also noticed. During the ENSO (El Nino southern oscillation) year of 1987, when ISMR negative anomaly was maximum, POWP extended very much towards east of the International date line. A corresponding shift or spread of the OLR value areas is observed.

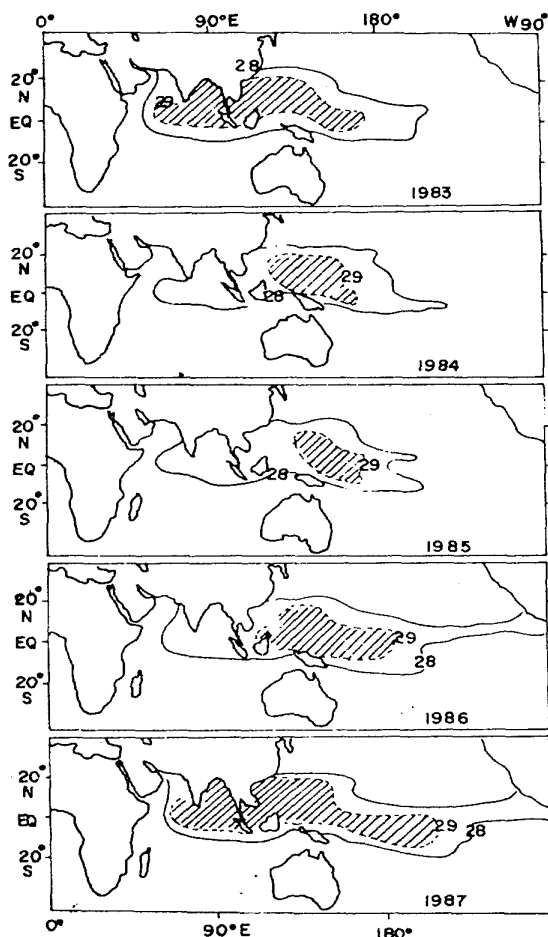


Fig. 1—Distribution of areas of sea surface temperature warmer than 29°C (hatched area) in the Indo-Pacific region during summer months (June to August) of 1983 to 1987

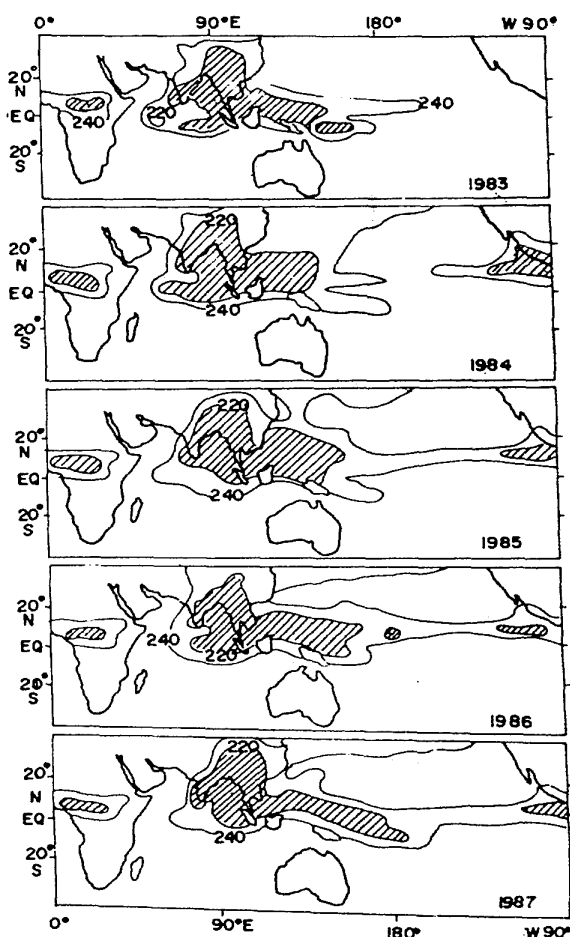


Fig. 2—Distribution of areas of satellite sensed low (< 220 W m⁻², hatched) outgoing long wave radiation (OLR) values over the region during summer months of 1983 to 1987

However, the shift of the center of OLR contours lags behind the center of POWP. At monthly time scales, both POWP and low OLR break down into smaller areas as they shift eastward (see POWP in Fig. 3), but POWP generally leads the low OLR areas as they shift.

The computed climatological monthly mean positions of POWP are 136°E, 144.6°, 147.3° and 149.4°E during June to September respectively. POWP is on the western side of the Pacific Ocean at the beginning of Indian Summer monsoon season and shifts its position to the east during the rest of the season. The clim-

atological monthly mean rainfall values used for the computation of the rainfall anomaly are 164.7, 300.3, 252.6, and 176.1 mm respectively in June-September. The monthly rainfall anomalies showed a range from +43% to -28% during 1983-1988.

Temporal variation of POWP during the period May to September of 1987 and 1988 is shown in Fig. 3. These years represent the period when extreme swing in the rainfall anomalies were observed. Variations in POWP anomalies and corresponding rainfall anomalies during 1982-1988 are shown in Fig. 4. As seen from the figure, neither of the anomalies of ISMR nor

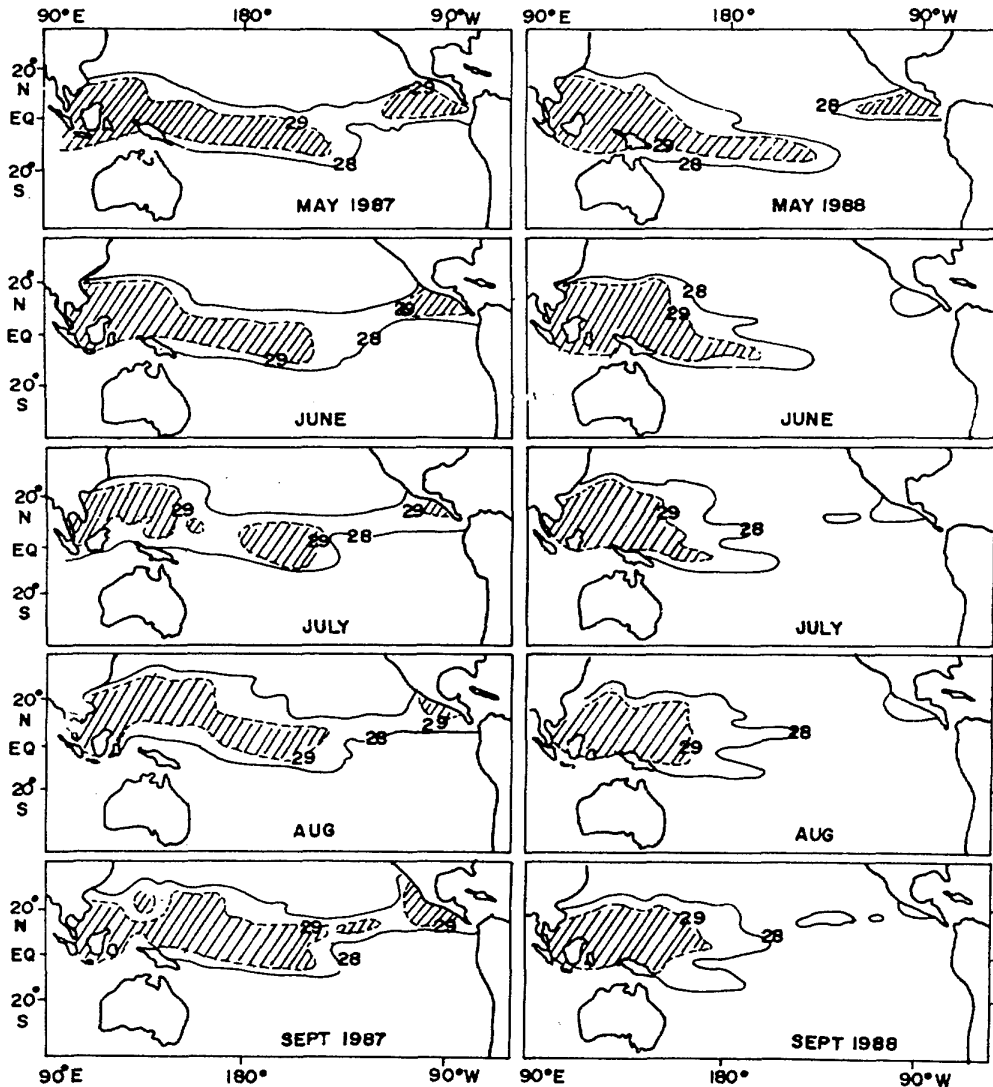


Fig. 3—Monthly mean (May to September) position of Pacific Ocean warm pool (POWP, hatched area) during 1987 and 1988

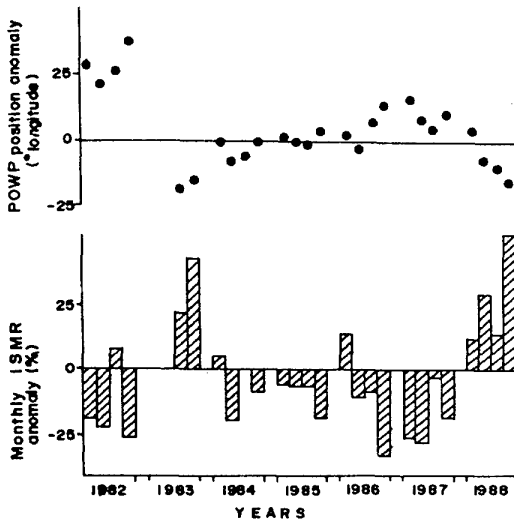


Fig. 4—Variations in anomalies of monthly summer monsoon rainfall and the Pacific Ocean warm pool position during 1982 to 1988

POWP show a persisting pattern in a season as the anomalies sometimes change their sign during the season.

The correlation coefficient worked out between the anomalies of monthly rainfall of a given month and zonal position of POWP during the previous month is -0.56 . The correlation is significant at 0.5% level. The values of monthly mean rainfall anomalies calculated from least square fitted straight line give the standard error of 17.7%.

The observed relationship between monthly rainfall and POWP position anomalies is shown in Fig. 5. The correlation coefficient between the two parameters is -0.79 . The correlation is significant at 0.1% level. The rainfall anomalies, computed from the least square fitted straight line $Y = -0.2897X + 0.7427$ give a standard error of 15.9% in the estimations. A second degree equation $Y = 0.041X^2 - 2.205X - 1.248$, where X is POWP anomaly, fitted by least square method, reduces the standard error in estimations to 13.5%. This may be compared with 25.2% standard deviation of the percentage departure from normal of monthly rainfalls on long term basis. The value of the non linear correlation coefficient is -0.8 . Other types of curves fitted to the data do not reduce the standard error in the estimations.

The first component of EOF analysis of the normalised seasonal mean rainfall over 80 y till 1980 explains only 31% of the observed variability¹⁷. The present short term study shows that the zonal position of POWP alone is able to explain as much as 64% of

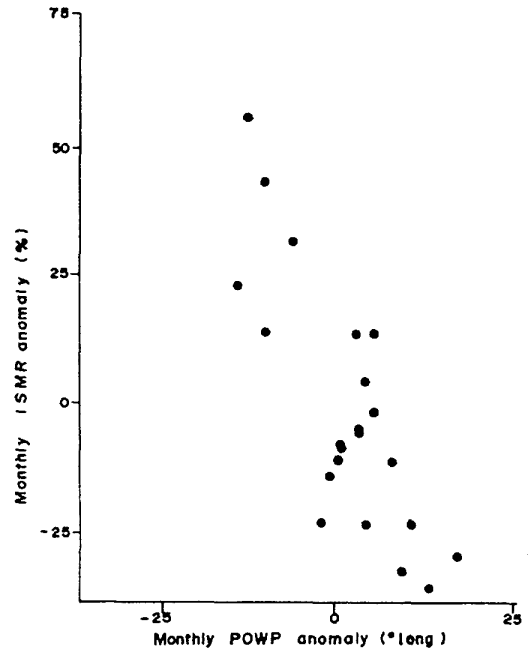


Fig. 5—Scatter diagram showing the relationship between monthly anomalies of Pacific Ocean warm pool and the Indian summer monsoon rainfall

monthly ISMR variability and so it may be used as an indicator of monthly rainfall over India.

It has been pointed out that ENSO cycles are the result of natural oscillation in the ocean atmospheric system centred around the Pacific Ocean¹⁸. The question arises how Indian summer monsoon rainfall is related to this. An explanation of the link can be given based on the changes in the east-west (Walker) circulation¹⁹ resulting from the shift of POWP. According to this concept, there are 3 major tropical east-west cells in the atmosphere which encircle the globe. The ascending branches of 2 of them are over the Pacific Ocean and the other one in the Atlantic Ocean. The Indian cell has its ascending branch over the western side of POWP while the Pacific Ocean cell has its ascending branch over the eastern side of POWP. The descending branches of the Atlantic and the Indian Ocean cells are over the tropical areas of Africa. The upper level easterly winds correspond to the easterly branch of the Indian Ocean cell and the lower level south west monsoon winds correspond to the westerly branch of this cell. An ENSO event is preceded by weakening of subtropical high pressure centers and associated weakening of equatorial trade winds over the Pacific Ocean. This results in an anomalous eastward shift of the center of POWP and the ascending branches of the Walker cells over the Pacific Ocean as was observed^{20,21} during the ENSO events of 1972

and 1982. This is associated with a shift of both the ascending and descending branches of the Walker cell over India. The southern oscillation follows and the sea level pressure over India becomes above normal and this causes below normal rainfall over India.

During an El Nino year, such as 1987, the center of POWP is on the eastern side of the International date line. Because of high vorticity transport associated with the mature phase of ENSO, sub-tropical high pressure centers become strong soon after the warm event and the resulting strong trade winds shift the warm pool to the western Pacific Ocean. The Walker circulation over India gets intensified and sea level pressure over India becomes low, resulting in higher than normal ISMR anomaly immediately following the El Nino year such as 1988. During other years, Indian rainfall anomaly becomes positive or negative depending upon POWP position anomaly.

Two ways of predicting monthly Indian rainfall anomaly emerge from this study. The position anomaly of the center of POWP during one month may directly be used to obtain a simple forecast of rainfall anomaly during the succeeding month. Alternately, the position of POWP during a month may be forecasted from the knowledge of the previous month's POWP position and dynamics of the ocean-atmosphere interaction in the tropical Pacific Ocean, by a method similar to that used by Barnett *et al.*²² The oceanic changes, being slow in nature, are more predictable than atmospheric changes. Once the position anomaly of POWP is known, the rainfall anomaly can be computed.

Results of the present study indicate that the position of the POWP is useful in predicting monthly ISMR. Further studies are needed to improve our understanding of the relationship between ISMR and POWP.

Acknowledgement

Thanks are due to Dr B N Desai, Director, for encouragement and Mr V Kesava Das and Dr V V R Varadachari for critical evaluation of the manuscript.

References

- 1 Blanford H F, *Mem India Met Dept*, 3 (1886) 658.
- 2 Walker G T, *Mem India Met Dept*, 24 (1923) 75.
- 3 Banerjee A K, Sen P N & Raman C V R, *Indian J Met Hydro Geophy*, 29 (1978) 425.
- 4 Kung E C & Sharif T A, *J Met Soc Japan*, 60 (1980) 672.
- 5 Shukla J & Mooley D A, *Mon Weath Rev*, 115 (1987) 695.
- 6 Hastenrath S, *J Climate*, 1 (1988) 298.
- 7 Charney J G & Shukla J, in *Monsoon dynamics*, edited by J Lighthill and R P Pearce (Cambridge University Press, London) 1981, 99.
- 8 Varadachari V V R, Kesava Das V & Sengupta D, in *Contributions in marine sciences*, edited by T S S Rao, R Natarajan, B N Desai, G Narayana Swamy & S R Bhat (Dr S Z Qasim Sastya-badapurti Felicitation Volume, National Institute of Oceanography, Goa, India) 1987, 141.
- 9 Gadgil S, Joseph P V & Joshi M V, *Nature Lond*, 312 (1984) 141.
- 10 Fu C, Diaz H F & Fletcher J O, *Mon Weath Rev*, 114 (1986) 1716.
- 11 Bjerknes J, *Mon Weath Rev*, 97 (1969) 163.
- 12 Gopinathan C K, *Curr Sci*, 57 (1988) 1163.
- 13 Reynolds R W, *J Clim* 1 (1988) 75.
- 14 Halpert M S & Ropelewski C F, *Atlas of tropical sea surface temperature and surface winds*, NOAA Atlas No. 8, (Department of Commerce, USA) 1989, 13.
- 15 Strong A Z, *Ocean-air Interactions*, 1 (1986) 11.
- 16 Anonymous, *Mausam*, 34 (1983) 343.
- 17 Shukla J, in *Monsoons*, edited by T S Fein & P L Stephen, (John Wiley and Sons, New York) 1987, 116.
- 18 Graham N E & White W B, *Science Wash*, 240 (1988) 1293.
- 19 Krishnamurti T N, in *Meteorology of the tropical oceans*, edited by D B Shaw, (Royal Meteorological Society, Berkshire, U K) 1978, 36.
- 20 Krueger A F & Winston J, *Mon Weath Rev*, 97 (1975) 465.
- 21 Tourre Y M, *Trop Ocean-Atmos Newslett*, 40 (1987) 1.
- 22 Barnett T P, Graham N, Cane M, Zebiak S, Dolan S, O'Brein J & Leger D, *Science Wash*, 241 (1988) 192.