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Rainfall over Oman and its Teleconnection with El Nino Southern Oscillation

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Abstract: The Sultanate of Oman is located in the south-eastern part of the Arabian Peninsula and covers the larger part of the southern coasts of the Arabian Peninsula in both arid and semi arid environments except for the southern part which is swept by the monsoon affecting the Arabian Sea during the period from June to September. The summer rainfall over the Oman shows year to year variability and this is caused by oceanic and atmospheric influences. The present study aims to explore the influence of El Nino on the summer rainfall over Oman using different data sets. The EOF technique employed to the zonal wind at 850 hPa for the 30 year period and showed that second and third modes of EOF revealed high variability over the Oman regions. The corresponding PCs were subjected to FFT analysis and it showed a peak abut 5-6 years. In addition to this the zonal wind over the Oman regions was correlated with the global zonal wind and found a significant correlation (1% significant level). It has already been proved that the wind and rainfall during summer monsoon is in phase and therefore, it can be concluded that the El Nino in the Pacific favors summer rainfall over the Oman region.

Key words: EL Nino · Rainfall · Teleconnection · EOF Analysis

INTRODUCTION

The Sultanate of Oman have limited resources of freshwater, in combination with extremely high summer temperatures and high evaporation rates. The amount of rainfall received over Southern Oman during the four months from June-September (Summer monsoon) plays vital role in the GDP of the country. In recent decades the country developed in socio-economic zones and therefore the stress of the water is increasing in the present days [1]. The limited water amount from the seasonal rainfall showing interannual variability [2] and therefore, it is necessary to determine the current rainfall variability based on the atmospheric and oceanic circulations which form the main external forcings to govern this mode of variability. From annual to decadal time scale monsoon variability is influenced by changes such as internal boundary conditions, tropical sea surface temperatures in the Indian Ocean [3], variation in Eurasian snow cover [4] and linkages with El Nino Southern Oscillation (ENSO) in the Pacific Ocean [5].

Geographically Oman having different characteristics and therefore, different parts of Oman exhibit different types of rainfall variability. Southern Oman is mainly dependent on the Indian summer monsoon for precipitation, where more than 80% of total annual precipitation falls during this period summer monsoon period. During the southwest monsoon season, the amount of rainfall increases with altitude, varying from 150 mm at the coastal plain to 500 mm in the Dhofar Mountains [6, 7]. ENSO is one of the main sources of inter-annual variability in weather and climate around the world [8]. The rainfall variability over the Sultanate of Oman and its global teleconnection to ENSO and the Indian Ocean Dipole had been analyzed by Charabi [9]. The author described that IOD and ENSO have complementary effect on the summer monsoon rainfall. In the present paper, an attempt to understand the variabilities of rainfall over the Sultanate of Oman and its influence by El Nino is the aim.

Data and Methodology: Monthly rainfall data derived from the daily rainfall data of 12 stations for the period from 1977 to 2007 over Oman region have been published by the General Directorate of Civil Aviation and Meteorology (GDCAM). The selection of stations for constructing the

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rainfall pattern over Oman has been made using two criteria: 1) The stations should have long and continuous daily rainfall records and 2) The stations should be spread throughout the country, giving good spatial representation.

Based on the above criteria the 12 stations cover more than 30 years of data set to study the interannual variability. In addition to the station data, the NCEP-NCAR reanalysis data of zonal wind at 850 hPa level, on a spatial resolution of 2.5 X 2.5 latitude–longitude grid for a period from 1960 to 2007 were used [10].

To understand the major mode of variabilities, the zonal wind anomaly at 850 hPa employing Empirical Orthogonal Function (EOF) analysis was studied. A brief description of EOFs is given below. The anomaly data matrix *X'* is determined and then its covariance matrix is defined by:

$$\sum = \frac{1}{n-1} X'^T X'$$

which contains the covariance between any pair of grid points. The aim of EOF/PCA is to find the linear combination of all the variables, i.e. grid points, that explains maximum variance. That is to find a direction $a = (a_1, a_2, ... a_p)^T$ such that $X'a$) has maximum variability [11]. Now the variance of the (centered) time series $X'a$ is:

$$\mathrm{var}(X'a) = \frac{1}{n-1}\|X'a\|^2 = \frac{1}{n-1}(X'a)^T(X'a) = a^T \sum a$$

To make the problem bounded, the vector to be unitary is normally required. Hence the problem readily yields:

$\max(a^T \Sigma a)$ such that $a^T\ a = 1$

The solution of this problem is a simple eigenvalue problem (EVP): $\Sigma a = \lambda a$

By definition the covariance matrix Σ is symmetrical and therefore diagonalizable. The kth EOF is simply the kth eigenvector ak of Σ after the eigenvalues and the corresponding eigenvectors have been sorted in decreasing order. The covariance matrix is also semi definite, hence all its eigenvalues are positive. The eigenvalue λ_k corresponding to the kth EOF gives a measure of the explained variance by ak, k = 1, p. It is usual to write the explained variance in percentage as:

$$\frac{100\lambda_k}{\sum_{k=1}^{p}\lambda_k}\%$$

The projection of the anomaly field *X'* onto the k[th] EOF ak, i.e. ck = *X'* ak is the k[th] principal component (PC)

$$c_k(t) = \sum_{s=1}^{p} x'(t,s)a_k(s).$$

RESULTS AND DISCUSSION

The interannual variability of Oman rainfall anomaly is given in Figure 1. It clearly showed that the rainfall was sometimes above and below normal epochs. Mostly a 4 year clustering of rainfall could be noticed in these epochs. Recently the below normal epoch was persisting for a about a decade. In addition to this epochal variability, Oman rainfall shows year to year variability also. The magnitude of these variabilities could be linked with the externally/internally forced mechanisms. The ENSO was one of the mechanisms which influenced the rainfall around the world [5, 8]. The El Nino, as an oceanic phenomena that cyclically visits the central/eatern parts of pacific by warming the ocean surface that with a periodicity of 2 to 7 years. The recent El Nino years are tabulated in Table 1.

According to the available data of rainfall, an increase of rainfall during El-Nino years; 1976, 1977, 1982, 1991, 1994 and 1997 was observed. However in the 2002 El-Nino case the situation was entirely different from the previous El-Nino years and Oman persisted dry condition (Figure 1). Based on this analysis only, it was clear how much the Oman rainfall associated with the ENSO tele-connection. Therefore, the EOF analysis of zonal wind anomaly at 850 hPa over the Middle East region was employed to identify the major mode of variabilities and association of the different types of variabilities with the global tele-connection.

EOF technique aims at finding a new set of variables that capture most of the observed variance from the data through a linear combination of the original variables. EOFs have been introduced in atmospheric science since the early 1950's [11]. The EOF terminology is first used by Lorenz [11]. A review of PCA/EOFs can be found in [12]. The current used this technique to link the major mode of variability over the Middle East regions to the climatic variabilities to the rest of the world such as El Nino/La Nina.

In this study, it was found that rainfall had a random variability in interannual time scale in most part of the Oman but these variabilities could not be attributed to any specific atmospheric/oceanic variabilities. The EOF analysis of zonal wind anomaly during summer months for

Table 1: Recent El Nino Years

Weak	Moderate	Strong
1969	1951	1957
1976	1963	1965
1977	1968	1972
2004	1986	1982
2006	1987	1997
	1991	
	1994	
	2002	
	2009	

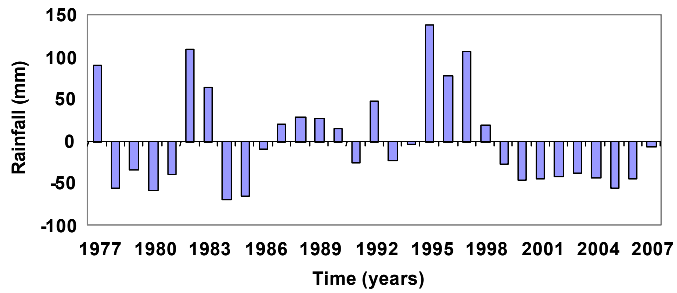

Fig. 1: The interannual variability of rainfall anomaly over Oman for period 1977-2007

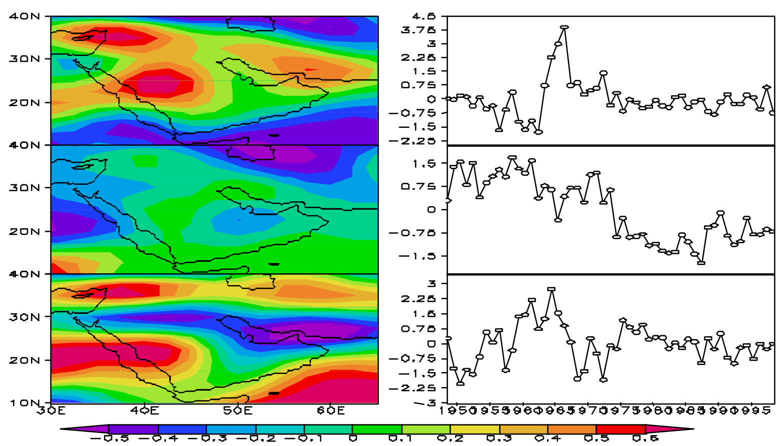

Fig. 2: Three modes of EOF and their PCs. In the spatial plot the first one is for EOF1 and middle one is for EOF2 and the bottom one is for EOF3. Similarly first, second and third are respectively for PC1, PC2 and PC3

51 years 1948-1998 represented the major mode of variabilities (Figure 2). Here, three EOFs were presenting namely; EOF1, EOF2 and EOF3 and these three EOFs represented 60% of the total variability. EOF1 corresponded to 30% of the total annual variability and EOF2 showed 19% of the total variability and EOF3 represented 13 % of the total variability of summer monsoon season in interannual time scale. The time evolution of the corresponding EOFs is also given in the right panels of Figure 2 as PCs.

From the figure EOF1 showed high variance in the middle part of the Middle East. Over the Oman area the variance of the first mode was found to be negligible. In EOF2, it was noticed that the amplitude of the variability was considerably high over Oman region and therefore, it could be concluded that this mode was mainly influencing the variability of Oman climatology. The EOF3 had also high variability in the northern part of Oman. Now it could be understood that the EOF1 was mainly playing its role in the middle part of the Middle East and it seemed that there was no influential role in regulating the Oman climatology. However, the second and third EOFs were contributing about 32% of the total variance of the interannual variability during summer monsoon period over Oman region. However, it is difficult to confidently say that this variability had any connection with any other kind of known variabilities such as El Nina/La Nina.

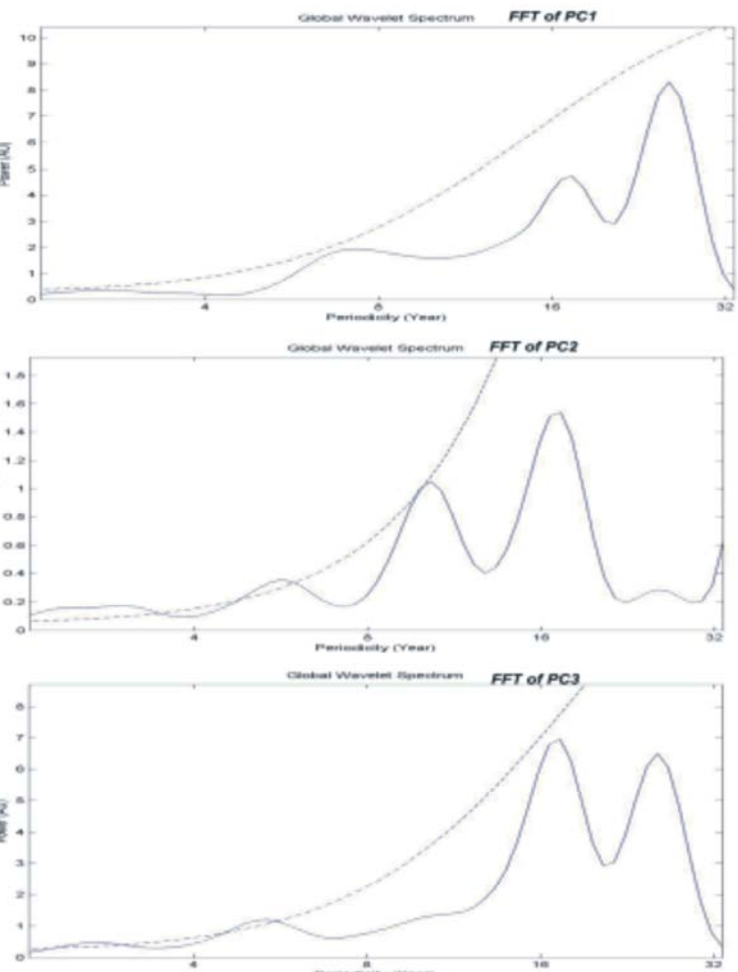

Fig. 3: FFT analysis of PC1, PC2 and PC3. The dotted line indicates the 95% confidence level

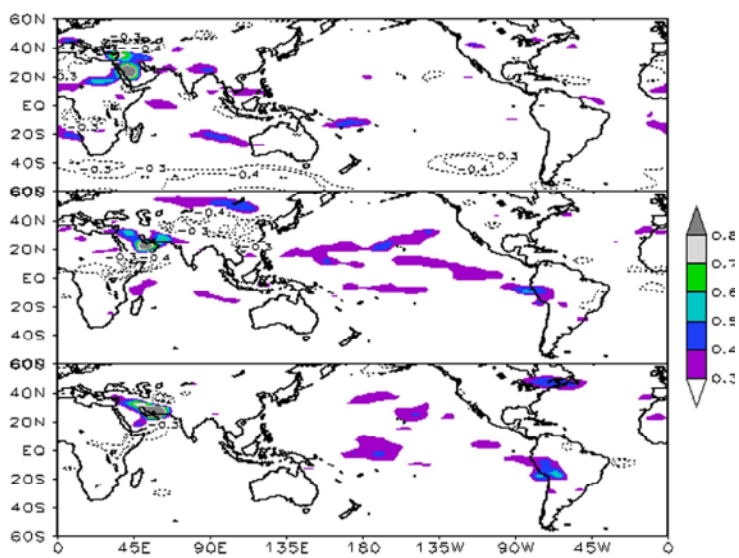

Fig. 4: Correlation of zonal wind anomaly at 850 hPa with the same parameter over the each grid point in the entire altitude between 60° S to 60°N

To understand the periodicity of the variability, Fast Furrier Transformation (FFT) analysis was first employed for the corresponding PCs of the EOFs. Figure 3 show the FFTs of PC1, PC2 and PC3. The dotted line indicated the 95% confidence level. From the FFT analysis, it was found that PC1 showed some mode of variability but it was below 95% confidence level. The FFT of PC2 showed a peak at about 5-6 years with a confidence level of more than 95%. Another peak was observed at about 10 year periodicity but this one had a confidence level of less than 95%. FFT analysis of PC3 showed a high peak at about 6 years very similar to that was found in the FFT of PC2. The second peak in the FFT of PC3 was observed at about 16 years (less than 95% confidence level). Therefore, from the PC2 and PC3, a significant periodicity at about 5-6 years had been observed almost similar to the periodicity of the ENSO.

It was important to identify the linkage of these variabilities to the global circulation. Therefore, the spatial correlation of zonal wind anomaly at 850 hPa during summer period of 51 years was computed and given in Figure 4. From EOF1, it could be observed that the high amount of variability was contributing in the middle part of the Middle East region. Consequently, a box average zonal wind anomaly at 850 hPa over the area 37.5° E-40° E and 20° N-27.5° N was made and correlated with every grid point between 60°S to 60°N for the entire latitude (upper panel of the Figure 4). The spatial correlation did not influence much with other regions in the global scale. High correlation value (more than 0.7) was noticed just east of the Mediterranean Sea and an area of negative correlation was observed just above the area of positive correlation.

The second and bottom panels of the Figure 4 are showing the same as that of the upper panel but the box area had been changed. In the case of second panel of the figure, the box average was over the area 47.5°E-55°E and 20°N-25°N and for the bottom figure was over the area 50°E-62.5°E and 22.5°N-30°N. In the EOF2 and EOF3, it was observed that Oman region (Central region in the case of EOF2 and Northern region in the case of EOF3) shown high amount of variance in the zonal wind anomaly at 850 hPa level. From the correlation analysis, it was found that high values of correlation coefficient (more that 0.4) in the regions of east equatorial Pacific Ocean (Nino4 region). This correlation value indicated a positive phase in the zonal wind anomaly over the Oman region. It was described earlier that the zonal wind at 850 hPa as a good agreement with the summer rainfall in the central part of Oman. Therefore, it could be concluded that the zonal wind anomaly over the east equatorial Pacific had a good correlation with the zonal wind anomaly itself over the Oman region and this wind has a good agreement with the rainfall over the same region and therefore the zonal wind anomaly over east equatorial Pacific Ocean had a positive correlation with the rainfall over the Oman region. From the FFT analysis, it was observed that the periodicity was about 4-7 years and hence it could be concluded that the El Nino had a positive correlation with the rainfall over the Oman region. Therefore, during El Nino year, Oman region was getting good amount of rainfall. In the time series of annual rainfall, it was observed that in most of the El Nino years Oman received above normal rainfall.

SUMMARY AND CONCLUSIONS

The present paper dealt with the teleconnective relation of Oman summer monsoon rainfall with the El Nino in the Pacific. This study revealed that El Nino governs the rainfall variability as the second mode. This sort of conclusion drawn based on the EOF analysis of zonal wind at 850 hPa for the three decade period. It has been observed that the zonal wind is in coherence with the rainfall over the region. The rainfall data and EOF analysis together says that during El Nino years Oman regions gets above normal rainfall. From the EOF study of zonal wind, the first, second and third EOFs corresponds to 30%, 19% and 13% of the total variability respectively in interannual time scale. The EOF2 and EOF3 have noticed that the amplitude of the variability is considerably high over the Oman region and therefore it can be concluded that this mode is mainly influencing the Oman climatology. The second and third EOFs were contributing about 32% of the total variance of the interannual variability during summer monsoon period over Oman region. However, EOF1 is showing variability at middle parts of the Middle East and it seems that there was no influential role in regulating the Oman climatology. From the FFT analysis for the corresponding PCs, we noticed that a 5-6 year periodicity with a confidence level of more than 95% for PC2. More over, the correlation analysis shows that high values of correlation coefficient (more that 0.4) in the regions of east equatorial Pacific Ocean (Nino 4 region). Therefore, during El Nino year, Oman region is getting good amount of rainfall. In the time series of annual rainfall, it was observed that in most of the El Nino years Oman received above normal rainfall.

REFERENCES

1. Alpert, P., 2004. The water crisis in the E. Mediterranean-and relation to global warming?, Water in the Middle-East and N. Africa (Eds. F. Zereini and W. Jaeschke), Springer, pp: 55-61.
2. Hilal, 2011. Climatological regems and their govering mechanisms over Sultanate of Oman, Thesis sumitted to University of Malaya.
3. Burns, S.J., D. Fleitmann, M. Mudelsee, U. Neff, A. Matter and A. Mangini, 2002. A 780-year annually resolved record of Indian Ocean monsoon precipitation from a speleothem from south Oman. Journal of Geophysical Research, 107: 4434.
4. Barnett, T.P., L. Dumenil, U. Schlese, E. Roekler and M. Latif, 1988. The effect of Eurasian snow cover on regional and global climate variations. Journal Atmospheric Science, 46: 661-685.
5. Webster, P.J., V.O. Magana, T.N. Palmer, J. Shukla, R.A. Tomas, M. Yanai and T. Yasunari, 1998. Monsoons: processes, predictability and the prospects for prediction. Journal of Geophysical Research, 103: 14451-14510.
6. Dominik Fleitmann, Stephen J. Burns, Ulrich Neff, Manfred Mudelsee, Jan Kramers, Augusto Mangini and Albert Matter, 2003. Holocene Forcing of the Indian Monsoon Recorded in a Stalagmite from Southern Oman, Science, pp: 300.
7. Kwarteng, A.Y., A.S. Dorvlo and G.T.V. Kumar, 2009. Analysis of a 27-year rainfall data (1977-2003) in the Sultanate of Oman, International Journal of Climatology, 29: 605-617.
8. Kiladis, G.N. and H.F. Diaz, 1989. Global climatic anomalies associated with extremes in the Southern Oscillation. J. Clim., 2: 1069-1090.
9. Charabi, Y., 2009. Arabian summer monsoon variability: Teleconexion to ENSO and IOD, Atmospheric Research, 91: 105-117.
10. Kalnay, E., *et al*., 1996. The NCEP/NCAR 40-Year Reanalysis Project. Bull. Amer. Meteor. Soc., 77: 437-471.
11. Lorenz, E.N., 1956. Empirical orthogonal functions and statistical weather prediction. Sci. Rep. No. 1, Statistical Forecasting Project, M.I.T., Cambridge, MA, pp: 48.
12. Kutzbach, J.E., 1967. Empirical eigenvectors of sea-level pressure, surface pressure and precipitation complexes. J. Appl. Meteor., 6: 791-802.