Technical Note

Spatial and Temporal Variability of Sea Surface Temperature of the Arabian Sea over the Past 142 Years

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Abstract

The main emphasis of this study is to understand the variability of sea surface temperature over the Arabian Sea and its relationship with local and global climatic parameters. Monthly sea surface temperature (SST) data of Met Office Hadley Centre having resolution of 1° x 1° for the period from 1870 to 2011 is used. Principal component analysis (EOF) technique has been used to reveal the teleconnection of the regional sea surface temporal and spatial variability. The first four EOF modes cumulatively account for more than 90% of the total variance. Only first EOF mode explains 64% of the total variability and this mode is taken as a leading mode. Further analysis is carried out by comparing first temporal mode (PC1) of SST with local climatic indicators (Temperature & Precipitation) and global climatic indicators (ENSO & PDO).This investigation shows that SST (PC1) variation has a negative relation to both precipitation and temperature of Pakistan. A significant negative correlation is observed between SST (PC1) and Multivariate ENSO index (MEI) and no relationship is found between SST (PC1) and Pacific Decadal Oscillation (PDO).

Keywords: Sea surface temperature, ENSO, PDO, Temperature, Precipitation

Introduction

The Ocean plays an important role in Earth's climate system due to its capacity of large heat storage. The energy stored in 3.5m deep water column of the ocean is approximately equal to that of entire atmosphere of the globe. There is always an exchange of energy taking place between the atmosphere and the ocean by different mechanisms. It implies that sea surface temperatures plays a significant role in regulating climate and its variability. The Indian Ocean is the third largest ocean and is considered as the warmest ocean in the world. Hence the Arabian Sea being northwestern wing of the Indian Ocean has substantial heating. Major sea routes connecting Asia with Europe and America are passing through Arabian Sea. So to study the climatology of sea surface temperature (SST) in the Arabian Sea and its relationship with other climatic parameters is very important.

There have been many studies in the past on the SST variations in Arabian Sea. Shukla et al., (1977) correlated mean monthly SST over Arabian to the summer monsoon rainfall and significant correlation was observed. Latent heat flux intensity is large in the Arabian Sea and Bay of Bengal because of high surface temperatures which result in more evaporation. Water vapor plays an important role in transfer of radiation and latent heat in atmosphere and its fluctuations are closely related to sea surface temperatures (Stephens, 1990). A negative correlation was observed between local SST and winter precipitation over mainland of India (Shouraseni, 2006). Silva et al., (2006) investigated the influence of SST of different regions around the globe on the air temperature in north east Brazil. They presented a prediction model to reconstruct air temperature time series in North East Brazil. McCabe et al., (2007) analyzed the

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relationship of decadal to multi decadal (D2M) variability in global sea surface temperature with (D2M) variability in the river flow. The results suggest that SSTs in all of the oceans have some relation with upper Colorado River flow. Many researchers found that there is a relationship between North Atlantic SSTs and temperature and precipitation. When North Atlantic SSTs are warmer than average then precipitation remains below average and temperature generally remains above average on most parts of United States results an increase in drought (Enfield et al., 2001; Hidalgo. 2004; McCabe et al., 2004; Sutton and Hodson, 2005).

Data and Methods

Data

In the present study, monthly data of HadISST1 SST data set of 142 years for the period from 1870 to 2011 is used. This data set has a resolution of 1o Latitude-longitude and is archived by Met Office Hadley Centre.HadISST1 temperatures are reconstructed by using a two stage reduced optimal interpolation technique. In order to restore local details quality improved gridded observations are superimposed onto the reconstruction. Comparison of this data set with the others shows that it captures well most of the trends in the data with better month-to-month and time variance (Rayner et al., 2003). Global and regional climate is related to spatial and temporal variability of SST in the Arabian Sea. El Nino-Southern Oscillation (ENSO) is responsible for the inter annual variability of the global climate (Webster et al., 1998).

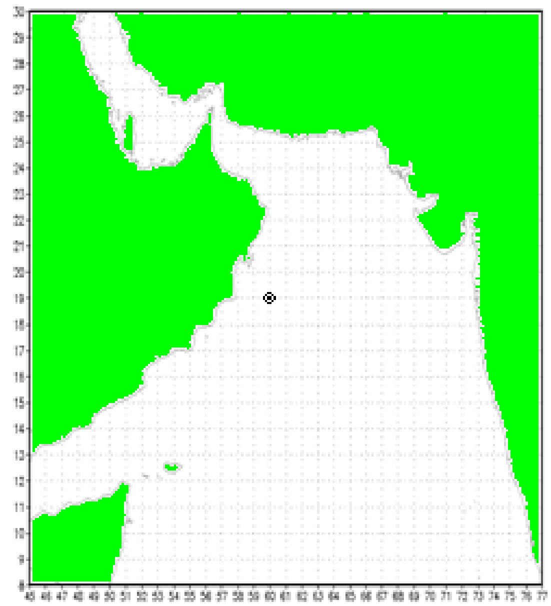

Figure 1: Location of grid points over Arabian Sea for which data is extracted for this study. Data point (60 °E, 19 °N) at the middle of the domain indicated by a bold circle is used as a reference point for SST.

Variability of SST in the Arabian Sea region is investigated by comparing it with the regional and global climate. Pacific Decadal Oscillation (PDO) and multivariate ENSO index (MEI) are used to represent global climate. The PDO index used in this study is derived as leading principal component of monthly SST in the North Pacific Ocean. (Zhang et al., 1997).MEI ENSO index is the first unrotated principal component (PC1) of six observed variables combined over tropical pacific. These variables include sea level pressure, sea surface temperature, air temperature, zonal and meridional components of surface wind and total cloudiness fraction of the sky.

Data Analysis Methods

The monthly SST data over Arabian Sea for the last 142 years contains both spatial and temporal variability. The temporal variability is mainly influenced by seasonal signal. Grid point at (19°N & 60°E) is taken as a reference point to show variations in SST data over Arabian Sea. Data is further analyzed at this specific location to show seasonal and annual variations. Seasonal component of SST data shows increasing trend with 0.37°C rise in winter season (Dec-Mar), 0.45°C rise in (Apr-May), 0.65°C rise in summer season (June-Sep) and 0.58°C rise in (Oct-Nov) in the last 142 years. The increasing trend up to 0.51 °C has also been observed in annual mean component of data.

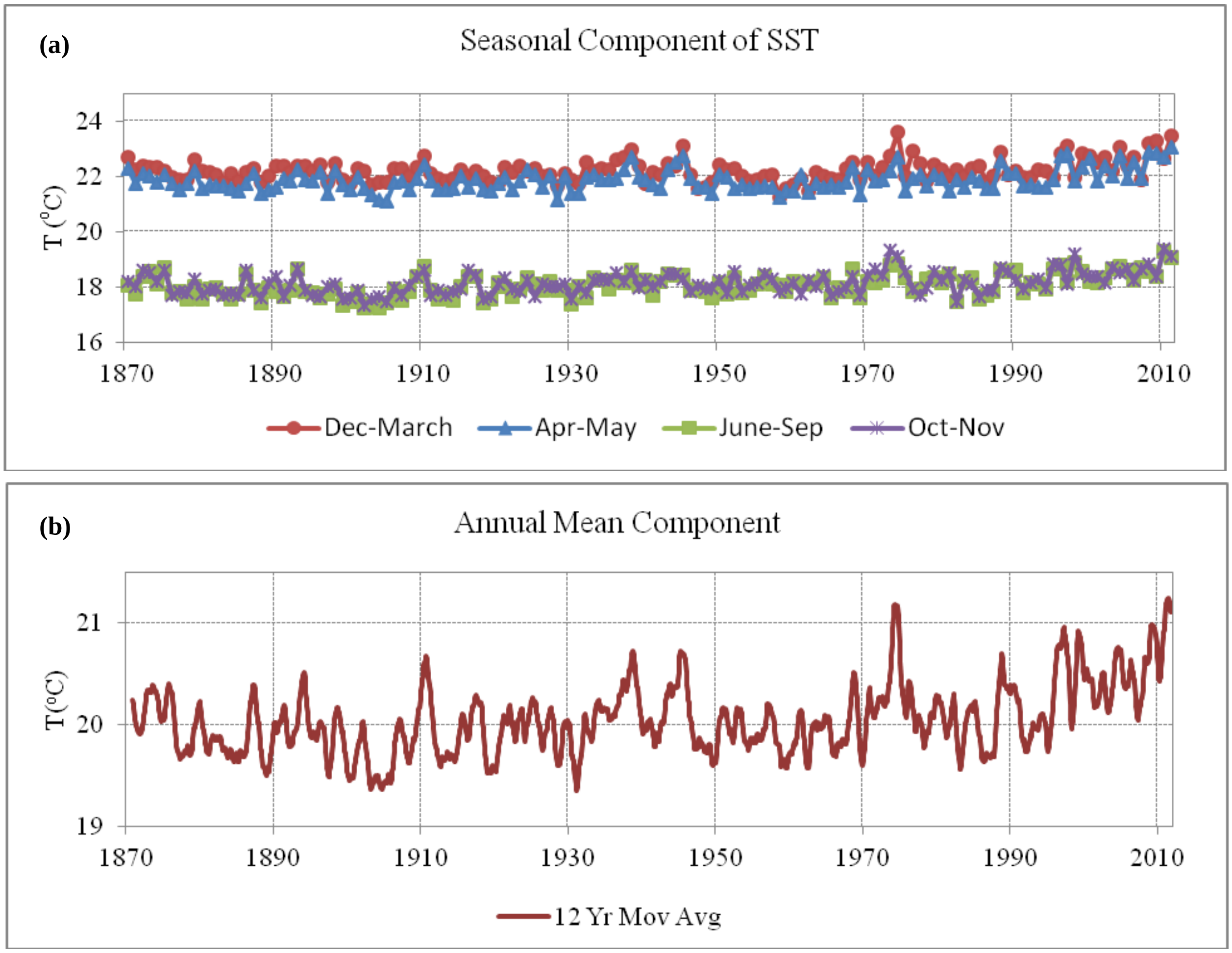

Figure 2: Partition of SST into Seasonal and Annual mean component. **(a)** Seasonal SST at a specific location (60 °E, 19 °N) as indicated in Figure 1 as a bold circle. **(b)** Annual mean component shown by 12 years moving average

In order to analyze long term variability, seasonal signal has been truncated from the original data so that to focus the low frequency variability i.e. inter annual to decadal scales and long term trend. Firstly, solution of a covariance matrix of the standardized data for eigen value problem is considered. For every eigen value ,there is an associated eigen vector .These eigen values are arranged in such a way that highest eigen value and the related eigen vector is on the top and the rest of have been sorted in decreasing order. This first eigen vector is called EOF1.Each of these eigen vectors can then be regarded as a spatial map. Similarly, the eigen vector corresponding to second biggest eigen value is EOF2.Each of these eigen values measure a fraction of the total variance explained by that mode. When an EOF is plotted on a map, it represents a standing oscillation. The time evolution of these stationary oscillations is represented by principal components (PC's) and for each calculated EOF, there exists a principal component.

Results

SST data extracted from HadISST1 covering Arabian Sea for last 142 years for the period from 1870 to 2010 over a 1° x 1° grid is further analyzed on seasonal and annual scales. The data analyzed are monthly mean SST values. It is observed that the variance explained by first four modes is around 64%, 14%, 9% and 3% respectively. The first four EOF modes cumulatively account for more than 90% of the total variance. The spatial patterns corresponding to these four modes are presented in Figure 3.

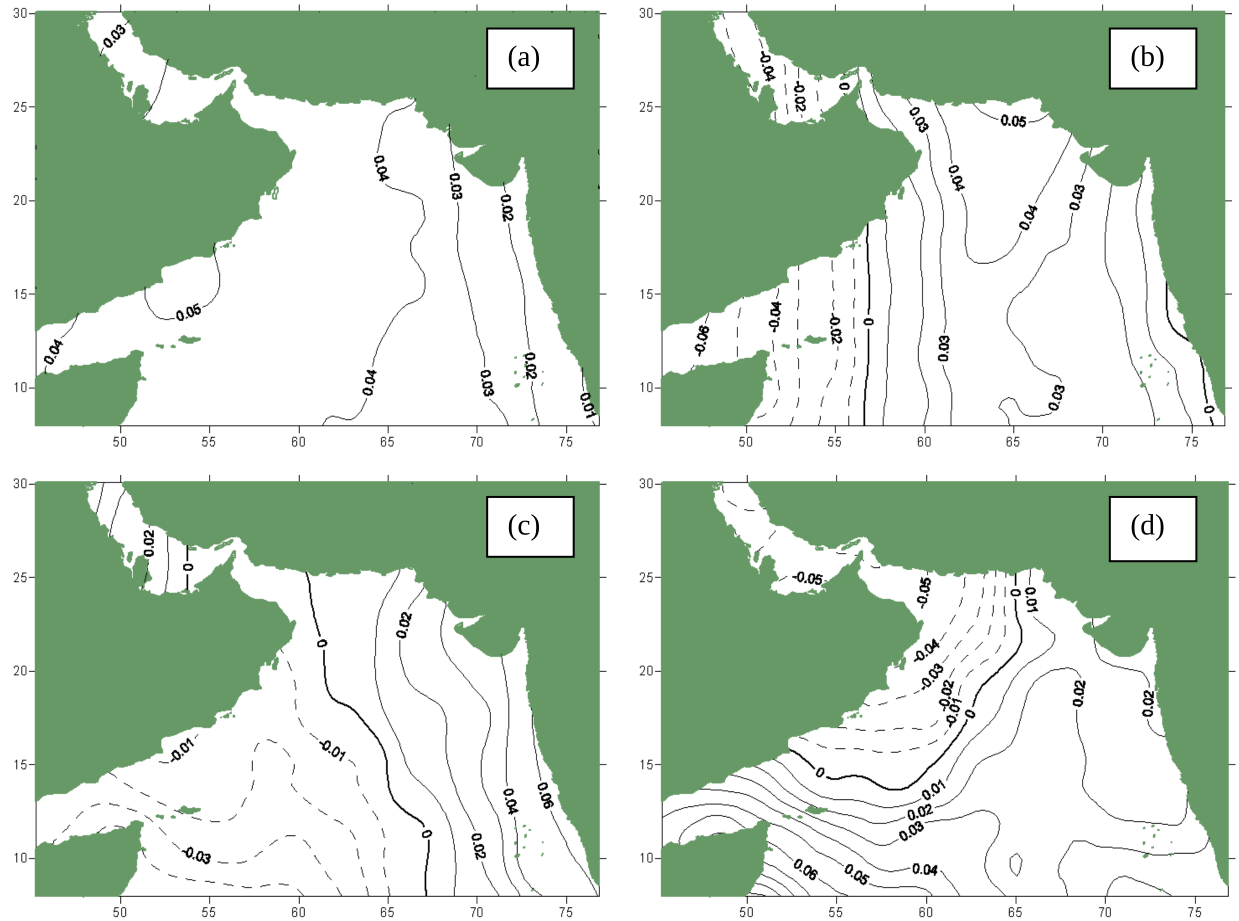

Figure 3: (a) First spatial mode EOF1, **(b)** Second spatial mode EOF2, **(c)** Third spatial mode EOF3, **(d)** Fourth spatial mode EOF4

The first leading pattern EOF1 indicate positive loadings over the entire Arabian Sea with higher values in western and central parts and lower values in the Eastern Arabian Sea. The corresponding time evolution of these first four EOF modes in terms of principal components is shown in Figure 4. The first principal component PC1 represents eight major peaks during 1938,1945,1974,1996,2002,2004,2009 and 2011.Interestingly, an increasing trend is dominant in principal component loadings after 1995.This analysis tells us that there is a rising trend in SST over entire Arabian Sea mainly from last fifteen years. The second EOF mode is showing a dipole structure present in Arabian Sea, where positive loadings are on northern, central and Eastern side while negative loadings are on western and south western Arabian Sea. The 12 year moving average of PC2 (in Figure 4b) is showing SST's behavior; more warmer in northern, central and Eastern Arabian Sea while colder on western and south western side. The third EOF mode is very similar to EOF2 showing dipole structure in the Arabian Sea but negative loadings extend more towards East. The fourth spatial mode (EOF4) explaining 3% variability in the data is showing north-south dipole structure. The northern part of Arabian Sea displays colder SST's while Southern Arabian Sea is showing warming. The temporal component PC4 associated with this spatial mode is showing decreasing trend in last few years.

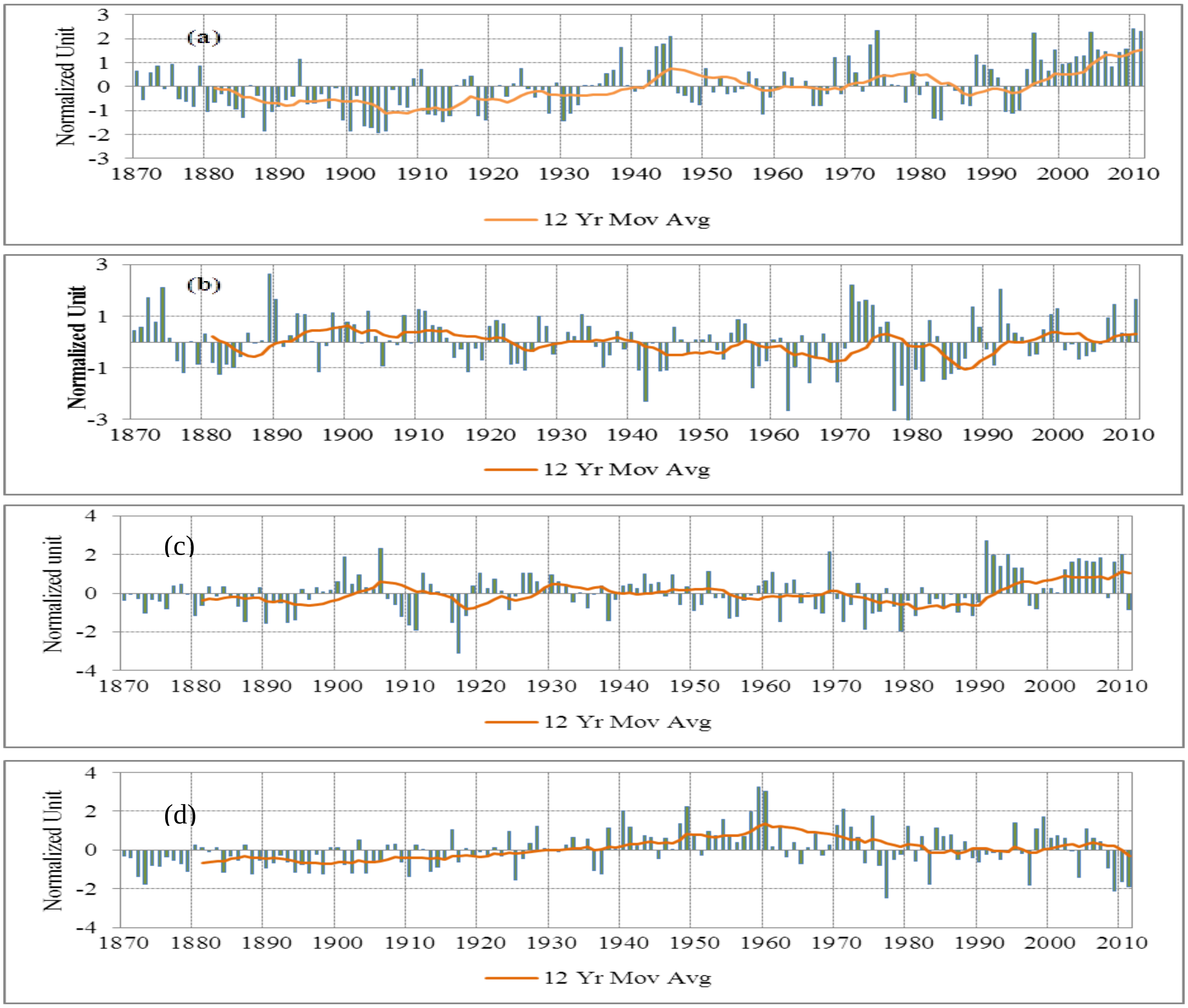

Figure 4: (a) First temporal mode (PC1) of SST, **(b)** Second temporal mode (PC2) of SST, **(c)** Third temporal mode (PC3) of SST, **(d)** Fourth temporal mode (PC4) of SST

Since first mode explaining 64% of the total variability in the data, so it is considered as the leading pattern of SST variation in the study area. Further analysis would be performed by considering this dominant mode of SST (PC1). The point wise correlations between SST (PC1) and local meteorological parameters (precipitation, temperature) and global climatic indices (MEI, PDO) are calculated.

In order to understand the relationship between SST (PC1) and observed monthly mean precipitation over Pakistan, a parametric test was applied to know the significance of results. This analysis shows that there is a significant negative correlation between the two variables at the 95% level of significance as shown in the Table.1.

Similarly, a negative correlation with a correlation coefficient of -0.663 was observed between SST (PC1) and mean monthly temperatures observed over Pakistan. At the level of significance Alpha=0.050 the decision is to reject the null hypothesis of absence of correlation. Hence the correlation is significant.

Table 1: Correlations between Local and Global Climatic Parameters with Arabian SST

	Arabian SST v/s Local Parameters		Arabian SST v/s Global Parameters	
	SST(PC1) v/s Precipitation	SST(PC1) v/s Mean Temperature	SST(PC1) v/s MEI	SST(PC1) v/s PDO Index
Observed Value	-0.184	-0.663	-0.103	0.034
Two-tailed p-value	0.0001	0.0001	0.005	0.215
Alpha	0.05	0.05	0.05	0.05

Next, we correlate climatic indicators (ENSO, PDO) with SST (PC1).The first result shows that there is a negative correlation between multivariate MEI and SST (PC1). Although correlation coefficient is very low but still correlation is significant at 95% confidence level.

There was observed no direct relationship between SST (PC1) and Pacific Decadal Oscillations (PDO) over the study period. As shown in the Table.1, at the level of significance Alpha=0.050 the decision is to not reject the null hypothesis of absence of correlation. In other words, the correlation is not significant.

Conclusions

It is evident from the multivariate analysis of SST over the selected domain of Arabian Sea that there are four spatial and temporal patterns which are dominant over the Arabian Sea and these modes account more than 90% of the total variability. Since first leading spatial mode (EOF1) and its associated temporal mode (PC1) accounts 64% variability in the data, therefore it is considered as the main dominant mode which is showing warming over the Arabian Sea mainly in the last fifteen years. Variability of SST was further analyzed by investigating its relationship with regional and global climate indicators.

The amount of precipitation over Pakistan showed a negative but significant correlation with the dominant Pattern of SST over the selected domain of the Arabian Sea. Similarly, a strong negative correlation was observed between mean monthly temperature over Pakistan and leading mode of SST. This relationship shows that warmer SSTs over Arabian Sea cause a weak precipitation and lower temperatures over Pakistan.

It is evident from the analysis that the first temporal mode of SST is negatively related to MEI. Even though the correlation coefficient is very week but is significant at 95% confidence level. This study shows that there is no relationship between Arabian Sea SST (PC1) and Pacific Decadal Oscillation.

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