Spatio-Temporal Trend Analysis of Sea Surface Temperature (SST) Over Exclusive Economic Zone (EEZ) of Pakistan

Shaikh Abdullah, Akhtar Ali Memon, Mehwish Shafi Khan, Matee ul Haq, Muhammad Mansha

***Abstract*—Ocean – Atmosphere interactions have been increasingly acknowledged to play an important role in climate change. It is necessary to understand ocean behavior, including the Sea Surface Temperature (SST) that is a basis for initiating atmospheric model and climate change studies [1]. The study presents analysis of monthly average SST from 2001 to 2015 using MODIS (onboard Terra) data with spatial resolution of 4 km along Extended Economic Zone (EEZ) of Pakistan (i.e. 19.15° N – 25.15° N and 61.30° E – 68.00° E). The results show negligible increasing trend of mean SST during study period that is consistent with recent global findings. Further, the nature of temporal trend of SST leads us to build a statistical model by applying Fourier fit of order 4. For the purpose, MODIS SST data from 2001 to 2011 is used for calibration and rest is used for validation. The results reveal significant accuracy with Squared Pearson Correlation coefficient of 0.89 and root mean squared error of 0.59 °C. All the results have been obtained with 95% confidence level.**

***Index Terms*—Sea Surface Temperature (SST), Monthly Mean Temperature, Oceanographic parameters, Pakistan EEZ, MODIS, Atmospheric Model.**

I. Introduction

Sea Surface Temperature (SST) is one of the important geophysical parameters, providing the boundary conditions used in the estimation of heat flux at the air-sea interface. In order to monitor climate properly, it is necessary to obtain accurate SST data over the global oceans [2]. Satellite Remote Sensing provides frequent observations related to oceans and coasts such as coastline dynamics, freshwater aquifers, Sea Surface Salinity, Chlorophyll concentration etc. Remote sensing along with Geographic Information System provides an opportunity to acquire spatial information from various satellite sensors and to map them. Due to importance of Sea Surface Temperature to study climate; we need regular observations. In fact, the Satellite Remote Sensing methods provide frequent observations of SST with different spatial and temporal resolution and can be derived from several Remote Sensing platforms to monitor SST daily, monthly or yearly. Regular monitoring of SST may help us to understand the ocean- atmosphere interaction. Recent studies show that Global mean surface warming has stalled since the end of the twentieth century [3], [4]. It is considered that additional heat of our warming planet due to natural and anthropogenic activities is being absorbed by oceans and it is reported that a significant portion of heat missing from atmosphere near Pacific is expected to be stored in the Pacific Ocean. On the other hand, in-situ record shows that Pacific Ocean heat content has been decreasing and the model suggested that increased heat transport from the Pacific Ocean to the Indian Ocean [5], [6]. If the condition is true then temperature of Indian Ocean should be increasing. Therefore a study has been conducted over Exclusive Economic Zone (EEZ) of Pakistan; a part of Indian Ocean. MODIS (or Moderate Resolution Imaging Spectroradiometer) is an instrument installed in NASA's Terra and Aqua satellites. Terra MODIS and Aqua MODIS has temporal resolution of 1 to 2 days, acquiring data in 36 spectral bands. Terra MODIS and Aqua MODIS can be acquired from NASA's online service "Giovanni". The NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) provides interface to utilize archived Earth Observing System (EOS) data for regional or global studies. They provide access to a user through World Wide Web interface to acquire online data through interactive data analysis application which is called the GES DISC Interactive Online Visualization and Analysis Infrastructure called Giovanni. The availability of Giovanni with high-quality ocean color data supports investigators to gather important oceanic phenomena, such as coastal erosion, Identification of Potential Fishing Zone, estimation of Chlorophyll concentration and ocean acidification. In this study monthly average SST from 2001 to 2015 using MODIS (onboard Terra) data with spatial resolution of 4 km was

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analyzed which shows negligible increasing trend of mean SST in study area over study period. We compared our results with other latest findings about the waters of the Western Pacific and the Indian Ocean warmed significantly from 2003 to 2012 that the warming did not occur at the surface; It showed up below 10 meters (32 feet) in depth, and mostly between 100 to 300 meters (300 to 1,000 feet) below the sea surface [7], which supports finding of this study.

II. Methodology

A. Data and Processing

Giovanni Ocean Color Radiometry online Visualization and Analysis system [8] was used to acquire MODIS-Terra 4km Monthly SST product. ASCII data was downloaded and converted into CSV format using Microsoft Excel® and imported gridded point data in mapping software ArcGIS®. Geographic latitude / longitude projection and World Geodetic System (WGS-84) datum were selected and entries of "No Data" were excluded through "selection by attributes" from shape file of dataset. Linear Kriging method of semivariogram model was applied to generate and estimate surface from a scattered set of points. Due to statistical spatial homogeneity in the data throughout the surface; interpolation by linear kriging method of semivariogram model was carried out. Kriging follows regionalized variable theory assumes that the given data is spatially homogeneous. After kriging application, subset was extracted using shape file of EEZ of Pakistan. Average pictures of each month from 2001 to 2015 were then extracted for further statistical analysis.

B. Study Area

The study area is Exclusive Economic Zone (EEZ) of Pakistan; a region of Arabian Sea extends within 19.15°N – 25.15°N and 61.30°E – 68.00°E. (see Fig. 1).

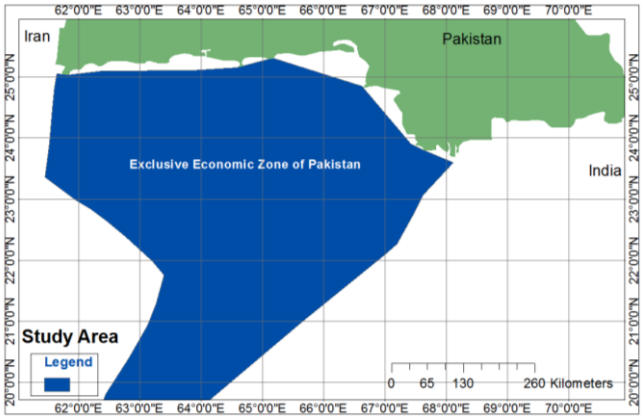

Fig. 1: Geographical location of Exclusive Economic Zone of Pakistan

III. Results and Discussion

A. Trend of SST

SST over EEZ of Pakistan was analyzed from 2001 to 2015 considering monthly averages. Seasonal high is recorded in the month of June which is 29.7 °C while seasonal low is recorded in the month of Jan which is 20.6 °C. Seasonal variation in temperature is obvious throughout the year and is depicted in Fig. 2 i.e. increasing temperature trend is first observed during March to June (prominent highest in the month of June in our case) and second highest during September and October (prominent highest in the month of October in our case). Similarly decrease in temperature trend observed from November to February (prominent lowest in the month of February in our case) and second lowest trend observed during June to August (prominent lowest in the month of August in our case).

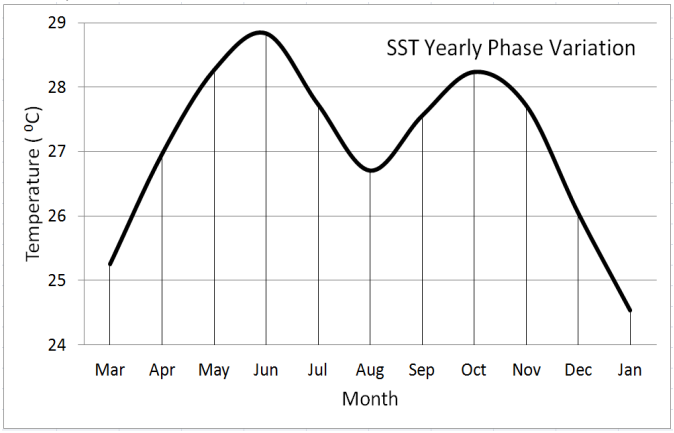

Fig.2: SST Yearly Phase Variation

Fig. 3 showed that warm region is shifted toward landward during June to Sept (at around 25°N latitude) and prominent warm region is observed in the month of August toward Northern part of Arabian Sea while cooler region is shifted toward deep ocean (at 20°N latitude). While in other months (except the month of Sep) cooler region is shifted toward landward (at around 25°N latitude) and warmer region is shifted toward deep ocean (at around 20°N latitude). In Sep two cooler regions observed i.e. near land or at Deep Sea. During study period negligible increase in monthly mean temperatures is observed.

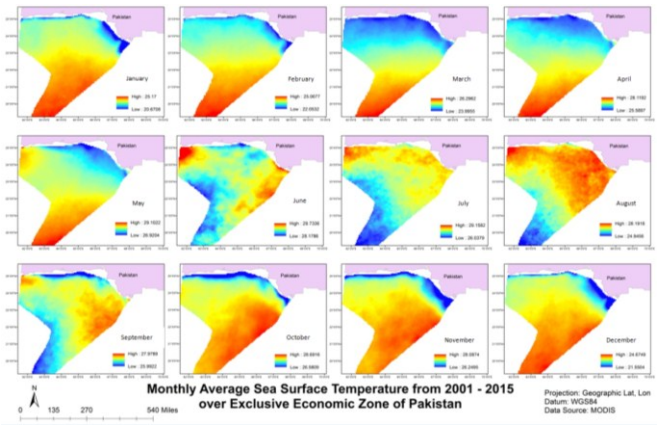

Fig. 3: Monthly Averages of Sea Surface Temperature from 2001 – 2015 over EEZ of Pakistan

B. *Statistical Model*

Statistical model was developed to observe nature of temporal trend of SST. For the purpose an average value of a month is considered as a single value and applied Fourier Fit of order 4 to 11 years' data, i.e. from 2001 to 2011. MODIS SST data from 2001 to 2011 is used for calibration and data from 2012 to 2015 was used for validation. Model Equation is shown below:

$$SST = a_0 + a_1 \times \cos(x \times w) + b_1 \times \sin(x \times w) + a_2 \times \cos(2 \times x \times w) + b_2 \times \sin(2 \times x \times w) + a_3 \times \cos(3 \times x \times w) + b_3 \times \sin(3 \times x \times w) + a_4 \times \cos(4 \times x \times w) + b_4 \times \sin(4 \times x \times w) \quad (1)$$

Model Coefficients in (1) are a_0=26.83, a_1=-1.065, b_1=-1.221, a_2=0.6377, b_2=-1.137, a_3=-0.2226, b_3=-0.09172, a4=0.08848, b_4=0.1257, w=0.5242. "x" indication number of months such as "x=1" indicates "Jan 2001" and so on. "w" also a measure of period and period is found to be 12.0023 showing the pattern repeat itself annually.

Modeled equation (1) was applied to whole data points of 15 years (from 2001 to 2015; 15 x 12 points), a modeled result graph was generated as shown in Fig. 4. Model validation graph as shown in Fig. 5 was obtained by applying (1) to the data of 4 years (2012 to 2015). Actual and Modeled SST graph is shown in Fig. 6.

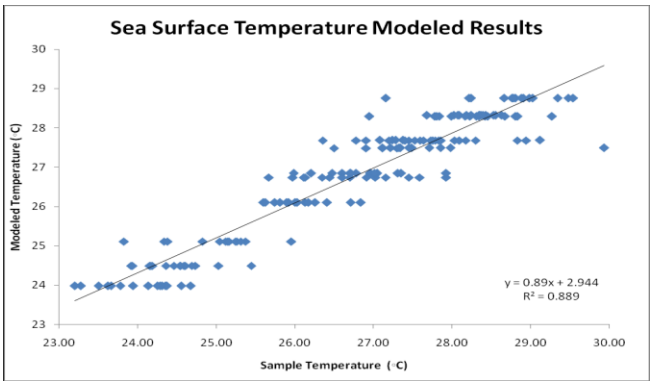

Fig. 4: Sea Surface Temperature Modeled result with correlation coefficient of 0.889

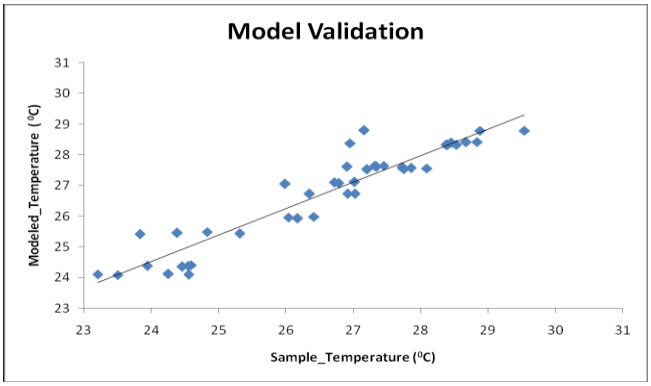

Fig. 5: Sea Surface Temperature Modeled result with correlation coefficient of 0.889

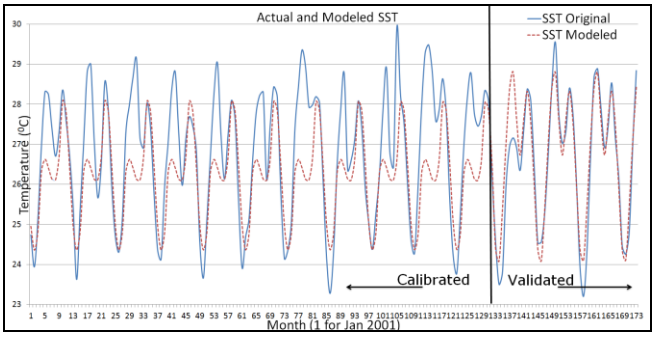

Fig. 6: Actual and Modeled SST

The results reveal significant accuracy with squared Pearson correlation coefficient of 0.885 (R^2=0.885) and root mean squared error of 0.59 °C. All the results have been obtained with 95% confidence level.

Time series of SST during study period is generated by averaging the raster over whole spatial domain of study area is shown in Fig. 7 and in Fig. 8 for monthly minimum and maximum temperature respectively. Trend of time series reveals insignificant increase or decrease in minimum and maximum temperature over period of time. It is observed that that variation of SST occurs during transition from one month to another but trend for the entire period shows negligible change.

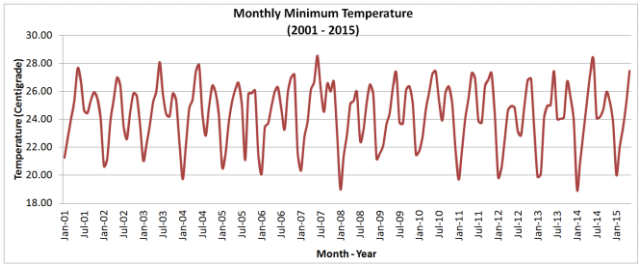

Fig. 7: Monthly Minimum Temperature from 2001 – 2015 with Trend line close to the horizontal axis

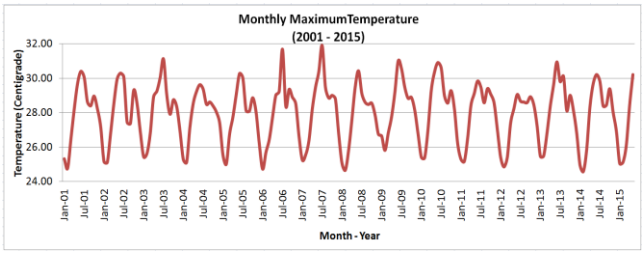

Fig. 8: Monthly Maximum Temperature from 2001 – 2015 with Trend line close to the horizontal axis

IV. CONCLUSIONS

SST over EEZ of Pakistan was analyzed from 2001 to 2015 considering monthly averages. Statistical model was developed to observe nature of temporal trend of SST. The results show negligible increasing trend of mean SST during study period which supports finding of this study. Global

mean surface warming has stalled since the end of the twentieth century [3], [4]. More likely the heat is being absorbed by oceans. It was suggested that heat near Pacific is expected to be stored in the Pacific Ocean. On the other hand, in-situ record shows that Pacific Ocean heat content has been decreasing and the model suggested that increased heat transport from the Pacific Ocean to the Indian Ocean [5]. Other latest findings about the waters of the Western Pacific and the Indian Ocean warmed significantly from 2003 to 2012 that the warming did not occur at the surface [7]. Our latest findings provide similar results that at-least temperature at the surface of the EEZ of Pakistan; a part of Indian Ocean is not significantly increasing. MODIS monthly average product of SST was analyzed from 2001 to 2015 and observed seasonal variation round a year. No significant change is observed in the trend SST using the mentioned datasets.

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REFERENCES

[1] Muhammad, S. et al., "Seasonal and Spatial patterns of SST in the Northern Arabian Sea during 2001 – 2012", in Egypt. J. Remote Sensing Space Sci., 2016 [submitted for publication].

[2] Reynolds, R.W., Rayner, N.A. et al., "An improved in situ and satellite SST analysis for climate", in J. Climate. 15(13), 2002, pp. 1609–1625.

[3] Loeb, N. G. et al., "Observed changes in top-of-the-atmosphere radiation and upper-ocean heating consistent within uncertainty", in Nature Geosci. 5, 2012, pp. 110_113.

[4] Allan, R. P. et al., "Changes in global net radiative imbalance 1985_2012" in Geophys. Res. Lett. 41, 2014, pp. 5588_5597.

[5] Lee, S.-K. et al,. "Pacific origin of the abrupt increase in Indian Ocean heat content during the warming hiatus", in Nature Geosci., 8, 2015, pp. 445-449.

[6] Levitus, S. et al., "Global Ocean heat content 1955–2008 in light of recently revealed instrumentation problems", in Geophys. Res. Lett. 36, L07608, 2009.

[7] Veronica, N. et al., "Recent hiatus caused by decadal shift in Indo-Pacific heating", in Science ,Vol. 349, Issue 6247, 2015, pp. 532-535.

[8] http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=ocean_month, August, 1992.