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RESEARCH PAPER

Seasonal and spatial patterns of SST in the northern Arabian Sea during 2001–2012

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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 models and climate change studies. In this paper, we analyze the spatial and temporal patterns of SST using monthly MODIS data of 2001–2012 from north Arabian Sea (11.9–25.68 °N, 56.7–75.03 °E). Seasonally, four phases of SST have been observed namely warming, cooling, warming and again cooling. Further, an empirical statistical model was fitted to the observed data that describes the annual SST pattern with significant accuracy.

1. Introduction

Sea surface temperature (SST) data are measured through satellite remote sensing using microwave (infrared) wavelength (DICCE-G, 2012). Remote sensing measurements of SST actually measure the "skin temperature", the temperature at the top 0.1 mm of the water column, which is more strongly influenced by solar irradiance, and therefore differ somewhat from sea surface temperature (Giovanni-3, 2012). SST is essential to understand the global climate (Idham, 2009). SST is an important indicator of the state of the earth's climate system. Thus, appropriate assessment of SST is essential for climate monitoring, research, and prediction (Reynolds et al., 2002).

SST variations control meteorological and oceanographic processes such as change in current speed or the frequency of events like El Nino (DICCE-G, 2012), monsoon depressions and subsequent floods, large-scale sea level fluctuations and formation of tropical cyclones (Tariq Masood et al., 2008). The expected rise in SST of about 0.2–2.5 °C (Mitchell et al., 1990), may also cause sea level rise and other natural disasters such as an increase in storm frequency and intensity and sea water encroachment into agricultural land (Singh et al., 1999; Khan et al., 2002).

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The rise of SST increases the saturation of vapor pressure which triggers water vapors and latent heat, causing the intensification of cyclones. Evan and Camargo (2011) and Emanuel (1987) explained the significance of SST in the increasing cyclonic intensity in addition to floods and other natural disasters. Observations indicate the existence of a temperature threshold necessary for the development of major hurricanes rather than a continuous positive relationship between maximum storm intensity and SST (Michaels et al., 2006). Therefore, careful monitoring of SST is required to assess its impacts on regional weather and climate system that in turn affects the socio-economic system. This study analyzes the spatial and seasonal trend of SST and building a statistical model using satellite derived data since January 2001 till July 2012 aiming to take a step further to initiate a ground for regional climate and hazards monitoring.

2. Study area

The study area is a region of Arabian Sea bounded on the east by India, on the north by Pakistan and on the west by Arabian Peninsula, ranging from 11.90–25.68 °N in latitude and 56.87–75.03 °E in longitude (see Fig. 1).

3. Methodology

The data for the study is obtained from Giovanni[1] online data system. The data are available in ASCII format with average gridded points having temporal resolution of one month and spatial resolution of 1 km. The data were imported to ArcGIS 9.3 and applied the projection as geographic latitude/longitude and datum as World Geodetic System (WGS-84). Due to statistical spatial homogeneity in the data throughout the surface, interpolation by linear kriging method of semivariogram model has been carried out. Kriging follows regionalized variable theory that assumes data spatially homogeneous to deal with (El-Hattab, 2014). Kriging results in a conversion of vector into a raster format. Using model builder tool in ERDAS Imagine 9.2, we have averaged out the raster data for each month during 2001–2012. The resulting images have been extracted for further analysis using statistics and GIS tools.

4. Results and discussions

4.1. Spatial and temporal trend of SST

Spatial and temporal analysis of monthly average sea surface temperature (SST) between 2001 and 2012 has been carried out. Seasonally, the highest values of SST were recorded in May and the lowest in February. On average, SST was the highest in 2010 and the lowest in 2008. No long term trend was observed, but strong seasonal patterns emerged, shown in Fig. 2. On the time scale the analysis revealed the four phases of SST variation namely warming-cooling-warming-cooling starting from the month of March. Warming elapses from March to May, cooling from June to August, warming from September to October and cooling from November to February as shown in Fig. 2. First seasonal warming of SST between March and May is caused by the increasing intensity of solar radiation. Although the solar irradiation continues to increase, strong winds and cloud cover cause a decrease in SST from June to August. Low wind speed in September allows the SST to increase again until November, despite of now modest solar radiation, although the peak is lower than that in May. From November to February, SST decreases again due to very low solar radiation. This bimodal seasonal cycle repeats itself every year (Fig. 3). The low standard deviations of monthly values over more than a decade of observation (Table 1) reveal the persistence of the seasonal cycle of SST.

Analysis of spatial and temporal data during the months between January and March show that SST increases from north-west to south-east. From November to April, the SST increases from north-west to south-east; this pattern starts to change slowly in May, June is especially unstable spatially, and a different gradient, namely increase in SST from west to east, develops during the months July–September. In October, the spatial pattern changes again, into north-west to south-east gradient that prevails from November to April. Furthermore, south-east portion of the study area has almost been observed to be relatively hot round the year (see Fig. 4).

SST on the Pakistan Margin shows a clear seasonal signal with a high SST in summer (~28.5 °C) and low SST (~23.5 °C) in winter (Levitus and Boyer, 1994). Khan et al. (2004) observed an increasing trend in SST in the northern Arabian Sea from Oman to Karachi and Mumbai, whereas, an increase in winter SST was insignificant. Rana et al. (2014) concludes that SST near the coastal zone shows more warming tendency as compared to the deep sea region during the last three decades. The historic rapid temperature changes could be due to the variation in the monsoon-induced upwelling. During the last glacial the SW monsoon, and therefore upwelling, was not entirely terminated (Saher et al., 2007). An increase in temperature of the upwelled water, due to a different (possibly shallower) provenance, or a somehow enhanced incorporation of warm ambient surface water in the upwelling cells could also have caused temperature shifts (Saher et al., 2007). Furthermore, records of SST during last 3 thousand years were linked to deglaciation after the last glacial maximum (Böll et al., 2015). In comparison with the Bay of Bengal, there have been only a few observational studies of SST anomalies associated with monsoon active and break phases over the Arabian Sea. Vialard et al. (2012) suggests that wind-stress intra-seasonal variations are much more important in driving SST response to the monsoon active and break phases over the Arabian Sea than over the Bay of Bengal. Our results suggest highest sea surface temperature trend during 2010 and was the warmest year during the study period. During this year a record flood event occurred that originated mostly because of the rainfall followed by three more continuous years flooding triggering economical, infrastructure and life losses (Haq et al., 2012; Memon et al., 2015). In 2011 and 2012 although flooding occurred but the SST trend was not much significant suggesting that SST is not the only determining and causing factor of intensifying monsoon rainfall.

4.2. Development of statistical model

A regular and repeated trend of SST since 2001–2012 leads us to develop a statistical model that could predict a value of

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

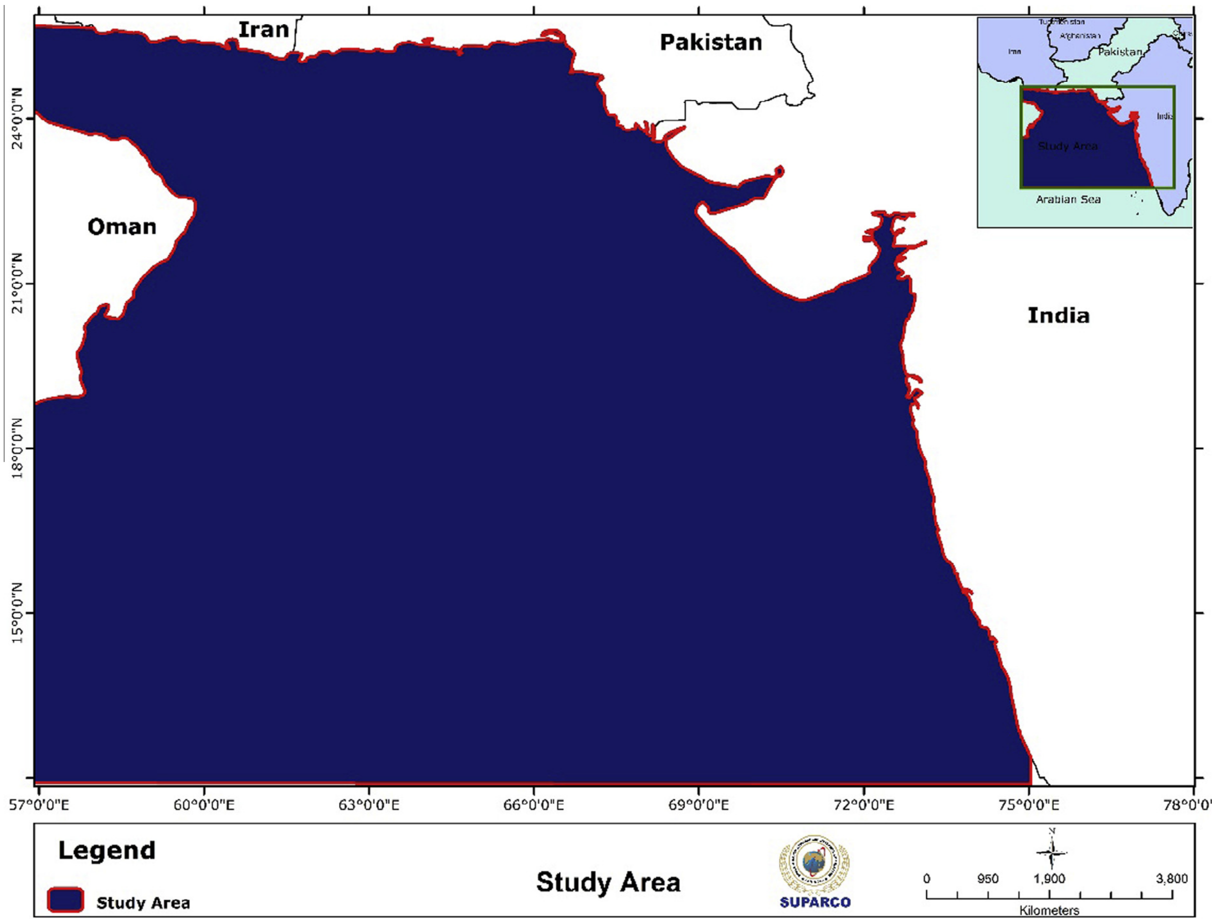

Figure 1 Location and extent of study area.

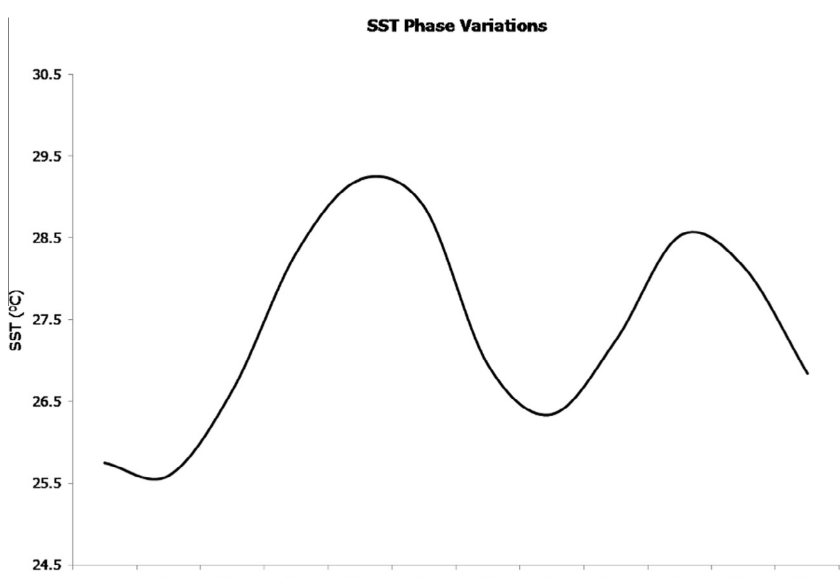

Figure 2 Monthly SST trend averaged out for 2001–2012. Turning points show the phase variations while the gradients show an increase or a decrease in SST.

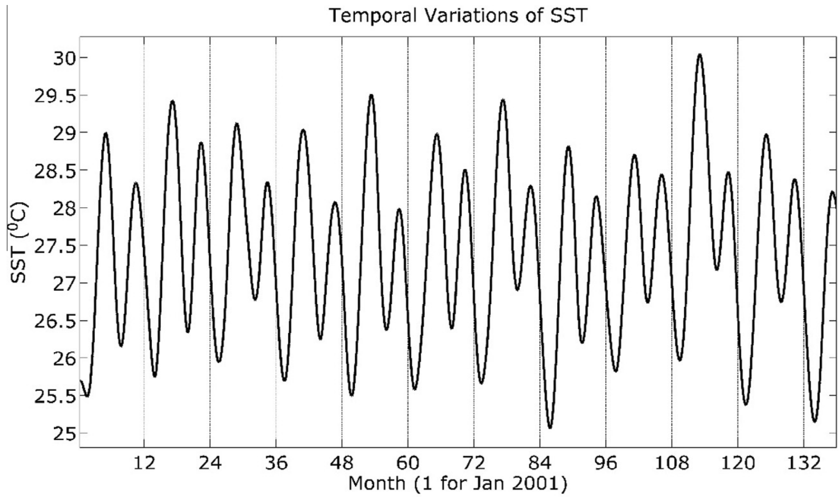

Figure 3 Monthly pattern of SST.

Table 1 Monthly standard deviation (SD) during study period.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SD (°C)	0.34	0.4	0.47	0.50	0.44	0.55	0.57	0.38	0.30	0.32	0.21	0.34

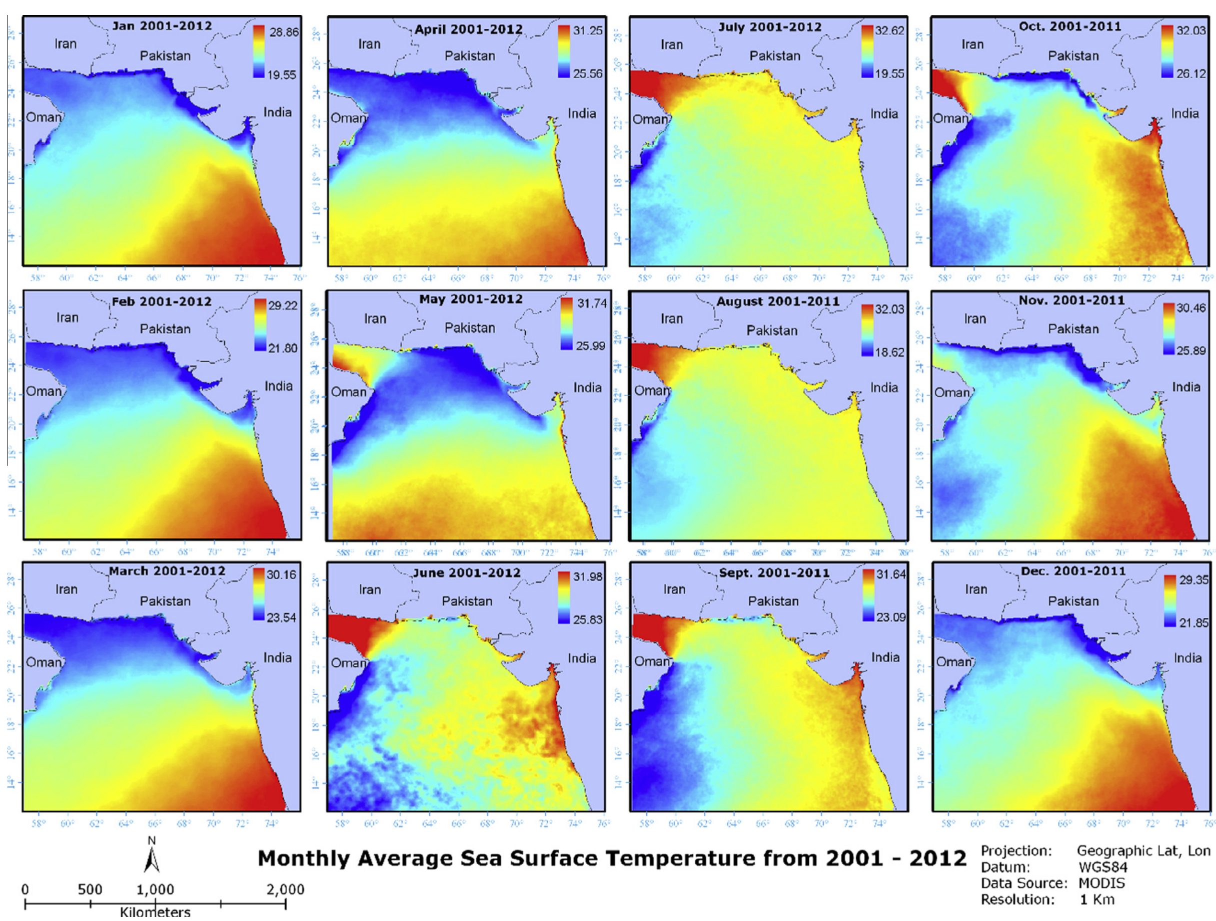

Figure 4 Average spatial trend of SST for every month from 2001 to 2012.

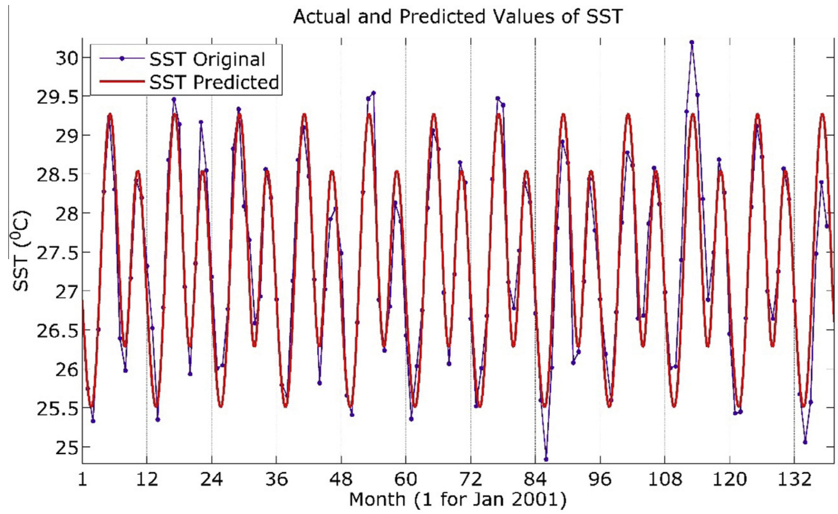

Figure 5 Observed (from MODIS sensor) values and predicted (from model) values.

monthly SST with significant accuracy. In this regard, the authors have applied Fourier fit of order 4 on the time series. Eq. (1) shows the model equation;

$$\begin{aligned} SST = & a0 + a1 * \cos(x * w) + b1 * \sin(x * w) \\ & + a2 * \cos(2 * x * w) + b2 * \sin(2 * x * w) \\ & + a3 * \cos(3 * x * w) + b3 * \sin(3 * x * w) \\ & + a4 * \cos(4 * x * w) + b4 * \sin(4 * x * w) \end{aligned} \quad (1)$$

where $a0 = 27.37$, $a1 = -0.6904$, $a2 = 0.3941$, $a3 = -0.2094$, $a4 = 0.01472$, $b1 = -0.2504$, $b2 = -1.372$, $b3 = 0.07949$, $b4 = 0.04928$, $w = 0.5235$ and x shows the number of month starting from 1 for Jan 2001. In addition, w term is also a measure of period. $2*\pi/w$ converts to the period in months and it is found to be 12.0023 presenting the pattern repeats itself yearly. Fig. 5 shows the graph between observed values and predicted values of SST. The squared Pearson Correlation coefficient is found to be of 0.8937 (i.e. $R^2 = 0.8937$) with root mean squared error of 0.4157 °C. All the results have been obtained with 95% confidence level.

5. Conclusion

Spatial and temporal variability along northern Arabian Sea using MODIS archived data of SST have been determined. In this regard monthly average point data of SST between January 2001 and July 2012 in ASCII format have been analyzed using remote sensing and GIS techniques. It has been found that the SST had different phases of variations spatially and temporally in a particular year but these patterns repeat themselves annually. Temporally, SST followed four phases of variations round the year that are classified according to the increasing or decreasing gradient of SST. Spatially, there were also four different trends starting from January in which SST first increased toward south-east till March then toward south during April and May then toward north-east up-to August and then again toward south-east up-to December.

Conflict of interest

There is no conflict of interest.

Acknowledgments

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References

Böll, A., Schulz, H., Munz, P., Rixen, T., Gaye, B., Emeis, K.-C., 2015. Contrasting sea surface temperature of summer and winter monsoon variability in the northern Arabian Sea over the last 25 ka. Palaeogeogr. Palaeoclimatol. Palaeoecol. 426, 10–21.

Data Enhanced Investigations for Climate Change Education (DICCE) Giovanni Help Page, Last updated: Jul 26, 2012 02:57 PM ET. <http://disc.sci.gsfc.nasa.gov/giovanni/additional/users-manual/DICCE_Help#SST>.

El-Hattab, A.I., 2014. Single beam bathymetric data modelling techniques for accurate maintenance dredging. Egypt. J. Remote Sensing Space Sci. 17 (2), 189–195.

Emanuel, K.A., 1987. The dependence of hurricane intensity. Nature 326 (6112), 483–485.

Evan, A.T., Camargo, S.T., 2011. A climatology of Arabian Sea cyclonic storms. J. Clim. 24 (1), 140–158. http://dx.doi.org/10.1175/2010JCLI3611.1.

Giovanni-3 Online Users Manuals: Data Parameters Appendix, Last updated: Jul 26, 2012 03:01PM ET. <http://disc.sci.gsfc.nasa.gov/giovanni/additional/users-manual/G3_manual_parameter_appendix.shtml#SST>.

Haq, M., Akhtar, M., Muhammad, S., Paras, S., Rahmatullah, J., 2012. Techniques of Remote Sensing and GIS for flood monitoring and damage assessment: a case study of Sindh province, Pakistan. Egypt. J. Remote Sensing Space Sci. 15 (2), 135–141.

Idham, B.K., 2009. Seasonal and Spatial Variability of Sea Surface Temperature using MODIS Data in East Kalimantan Waters, Indonesia. International Institute for Geo-Information Science and Earth Observation, Enschede, 62 p.

Khan, T.M.A., Razzaq, D.A., et al, 2002. Sea level variations and geomorphological changes in the coastal belt of Pakistan. Mar. Geodesy 25 (1–2), 159–174.

Khan, T.M.A., Quadir, D.A., Murty, T., Sarker, M.A., 2004. Seasonal and interannual sea surface temperature variability in the coastal cities of Arabian Sea and Bay of Bengal. Nat. Hazards 31 (2), 549–560.

Levitus, S., Boyer, T., 1994. World ocean atlas, vol. 4. Temperature. NOAA Atlas NESDIS, U.S. Department of Commerce, Washington, D.C.

Memon, A.A., Muhammad, S., Rahman, S., Haq, M., 2015. Flood monitoring and damage assessment using water indices: a case study of Pakistan flood-2012. Egypt. J. Remote Sensing Space Sci. 18 (1), 99–106.

Michaels, P.J., Knappenberger, P.C., Davis, R.E., 2006. Sea-surface temperatures and tropical cyclones in the Atlantic basin. Geophys. Res. Lett. 33 (9), L09708.

Mitchell, J., Manabe, S., et al, 1990. Equilibrium Climate Change and its Implications for the Future. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 131–164.

Rana, A.S., Zaman, Q., Afzal, M., Haroon, M.A., 2014. Characteristics of sea surface temperature of the Arabian Sea Coast of Pakistan and impact of tropical cyclones on SST. Pak. J. Meteorol. 11 (21), 61–70.

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

Saher, M.H., Jung, S.J.A., Elderfield, H., Greaves, M.J., Kroon, D., 2007. Sea surface temperatures of the western Arabian Sea during the last deglaciation. Paleoceanography 22.

Singh, O.P., Khan, T.M.A., Rahman, M.S., 1999. Changes in the frequencies of cyclonic storms over the North Indian Ocean. Meteorol. Atmos. Phys. 75 (1), 11–20.

Vialard, J., Jayakumar, A., Gnanaseelan, C., Lengaigne, M., Sengupta, D., Goswami, B., 2012. Processes of intraseasonal sea surface temperature variability in the Northern Indian Ocean during boreal summer. Clim. Dyn. 38 (9), 1901–1916.