Chapter 4

Climatological study of the Variability of Wind speed over Arabian Sea

④ CLIMATOLOGICAL STUDY OF THE VARIABILITY OF WIND SPEED OVER ARABIAN SEA

4.1 INTRODUCTION

In climate change and related studies, the investigations on increasing temperature, precipitation, rising sea-level, increasing frequency, severity of cyclones, etc. have taken precedence over other factors. Perhaps because these variables have a much catastrophic effect on marine ecosystems as well the coastal human settlements, hence they have been the center stage for climate change effect and impacts investigations (*Parmesan., 2006).* However, there are other physical variables like humidity, pressure, cloud cover and wind that contribute to the climate of a region and have ecological implications. In terms of physical oceanography, wind plays a significant role in regulating the mechanism of air-sea interactions *(Babanin et al., 2009)*. They control the exchange of energy between the atmosphere and the oceans (*Donelan et al., 1997)*. The geomorphology of the earth and its diverse landforms result in a complex pattern of wind. Blowing from one direction to the other, they help in the transport of the atmospheric heat across the globe. The winds, when blowing above the sea surface not only cools the heated surface water, but also push against the top oceanic layers and lead to the formation of currents. These oceanic currents help in the transfer the heat absorbed by the oceans. Hence, in terms of oceans being the heat sinks, the role of wind cannot be overlooked.

In the oceans strong bio-physical coupling occurs. The physical and biological parameters affect and influence each other. Hence, in addition to sunlight and temperature, wind also influences the phytoplankton in the oceans (*Denman, 1973).* The growth of the phytoplankton is dependent on the availability of nutrients like Nitrogen, Phosphorous, Silicon and Iron *(Chisholm and Morel, 1991)*. As the wind blow, they cool the surface layer of oceanic waters by evaporation, making them cooler and denser. This thermal stratification of the water column in the sea results in processes like advection, upwelling, downwelling and changes the mixed layer depth which make the surface layer of the sea rich in nutrients favoring the growth of phytoplankton *(Schott and McCreary, 2001; Murtugudde et al., 2004)*. If the wind speed increases, it further deepens the mixed layer and entrains additional nutrients into the upper ocean *(Kahru et al., 2010)* thereby increasing the productivity.

In terms of the Arabian Sea, the importance of winds becomes more evident as it exhibits wind driven ocean circulation *(Wyrtki, 1973)*. The basin comes under the influence of strong monsoonal winds which undergo seasonal change in their directions owing to the differential heating of land and ocean. The wind direction over the Arabian Sea is southwesterly (toward the northeast) during the southwest monsoon season from June to September; and northeasterly (toward the southwest) during the northeast monsoon from December-March. Numerous studies have reported the fact that in the Arabian Sea basin, the air-sea interaction regulates the fluctuations and intensity of the monsoonal winds *(Saha and Bavadekar, 1973).*

Additionally, Arabian Sea, being regarded as one of the world's most productive oceanic zones, attributes its biological significance from numerous physical processes that are caused by the strong monsoonal winds *(Qasim, 1982; Banse, 1987)*. The northeasterly trade winds during the winter monsoon result in the cooling of the surface water due to evaporation. The denser cooler water being heavier results in the overturning of the entire water column causing convective mixing. This mixing circulates the nutrients from the bottom to the surface layer. As the supply of nutrient increases, it results in higher growth of the phytoplankton, which results in higher biological productivity *(Banse and McClain, 1986; Madhupratap et al., 1996; Prasanna et al., 2000)*. Similarly during the southwest monsoon season the southwesterly winds promote evaporative sea surface cooling resulting in vertical mixing of oceanic waters. This brings the nutrient in the upper oceanic waters and results in higher productivity *(McCreary et al., 1993).* Strong correlation between the winter bloom of phytoplankton and the northeasterly trade wind in the Northern Arabian Sea was reported by *Dwivedi et al. (2006)* using satellite data.

In the context of climate change, numerous investigations using different climate models have reported that in the last 30 years, the wind speed across the globe has decreased by 5–15% *(Vautard et al., 2010, McVicar et al., 2012)*. On the contrary *Zieger et al. (2009)* and *Young et al. (2011)* reported an increase in global wind speed. Several other studies based on different wind data sets viz. the ship buoy data, altimeter data; reanalyzed model data etc. have also shown that there has been an increase in the global wind speed *(Wentz et al. 2007, Thomas et al., 2008, Tokinaga & Xie, 2011)*. The variation in these results mainly comes from the fact the studies pertained to different time periods and also different methodologies used for the studies. Besides, as noted by *Young et al. (2011)* differences in the averaging processes may also affect the magnitude of the trend analysis. They also concluded that for a detailed investigation of the effect of wind speed, instead of global approach, a regional and basin wide investigation are more appropriate.

Looking at the importance of wind as a crucial physical factor, which not only supports the primary productivity, but is also being influenced by the changing climatic conditions across the globe, a climatological study of the variability of wind speed over the Arabian Sea basin was carried out to know its trend over the basin.

4.2 DATA USED

Fig. 4.1 shows the details of wind data used in the present study.

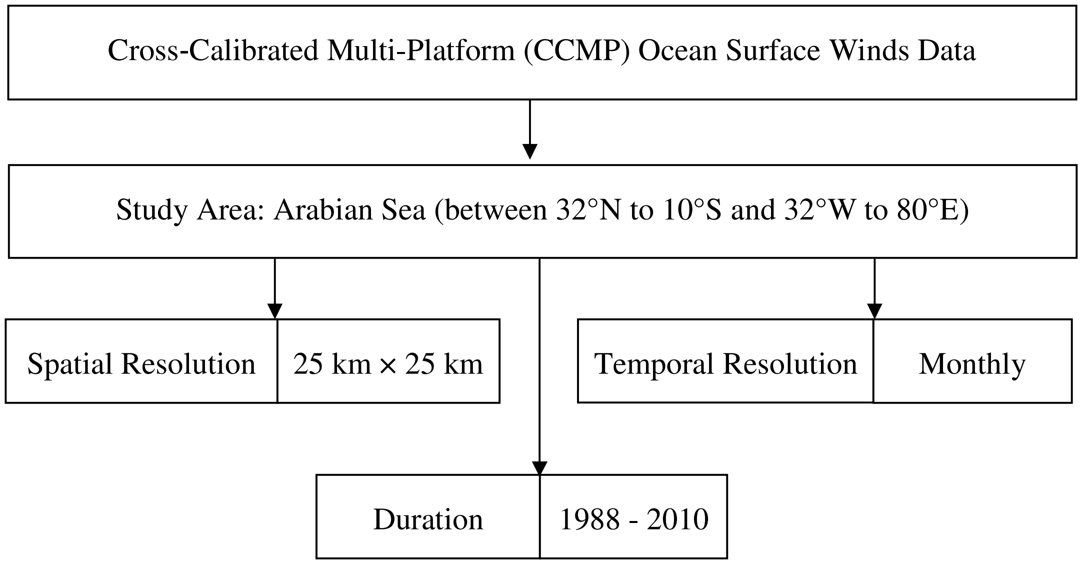

Fig. 4.1: Details of the Wind Data

In the present study, Cross-Calibrated Multi-Platform (CCMP) ocean surface winds data provided by the NASA PO.DAAC *(http://podaac.jpl.nasa.gov/DATA /ccmpinfo*) was used. The CCMP data product is derived through cross-calibration and assimilation of ocean surface wind data from SSM/I, TMI, AMSR-E, SeaWinds on QuikSCAT, and SeaWinds on ADEOS-II. These data sets are combined with conventional observations and a starting estimate of the wind field using a Variational Analysis Method (VAM) (*Ardizzone et al., 2009; Atlas et al., 2008, 2011*) The CCMP data is a near-global, high spatial and temporal resolution gridded dataset of surface wind vectors spanning 1987-present. The input data are a combination of inter-calibrated satellite data from numerous radiometers and scatterometers and in-situ data from moored buoys. An algorithm with the best-fit solution to all of the available observations was applied for cross calibration. As its temporal record is relatively stable, the CCMP data is recommended for studies of daily to interannual variability *(Ricciardulli & Lucrezia, 2017).*

In the present study, the monthly (level 3.5) gridded CCMP ocean surface wind speed of 25 km spatial resolution, for the period 1988 to 2010 was analyzed.

4.3 METHODOLOGY

The CCMP data sets (available as netCDF format) were analyzed using the software like MS Excel, Surfer and ERDAS 9.0. The monthly wind speed data pertaining to the Arabian Sea (between 32°N to 10°S and 32°W to 80°E) was extracted from the global data set for the duration 1988 to 2010. As the objective of the present study was to analyze the wind speed pattern and trend over the Arabian Sea, the land areas were masked.

The monthly, seasonal and annual variability in the wind speed over Arabian Sea was assessed by computing the normalized anomalies. For each of the months from January to December, the average wind speed over the entire basin was computed for the years from 1988 to 2010. The monthly, seasonal and annual climatological means for 23 years (1988-2010) were calculated. The inter annual variability for each month was analyzed using the monthly anomalies computed by subtracting the climatological mean from the monthly mean, which was then normalized to the standard deviation for that month.

For each month of the year from 1988 to 2010 for each grid point, a monthly average (My(i)) was calculated from monthly data. The climatological mean (CM_{23}) of 23 years (1988–2010) for each month was calculated by averaging the monthly mean ($M(i)$). The interannual variability was analyzed using the monthly normalized anomalies, computed by subtracting the monthly Climatological Mean (CM_{23}) from the monthly mean ($M(i)$) of each year, and normalized to the standard deviation for that month (SD_{23}) and given as:

$$\text{Normalized Anomaly} = (My(i) - CM_{23}) / SD_{23} \quad \text{(Equation 6)}$$

The spatial variability of wind speed over Arabian Sea was then analyzed by mapping the climatologically mean wind speed as well as the standard deviation of wind speed for the study period, using Surfer, ERDAS 9.0 and ENVI 4.0 software.

4.4 RESULTS AND DISCUSSION

4.4.1 Intraannual Variability of Wind Speed over Arabian Sea

Fig 4.2 shows that the wind over Arabian Sea follows a bimodal pattern across the months of a year with maximum speed during the southwest monsoon season (in the range of 7-8 m/sec) and a second but a smaller peak during the north east monsoon season (in the range of 4-6m/sec).

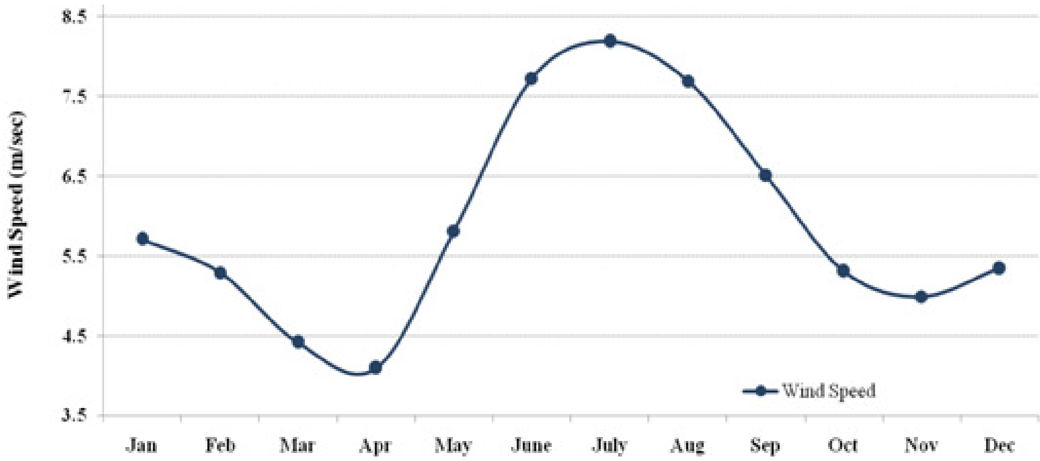

Fig 4.2: Climatological Mean Wind Speed over Arabian Sea

It blows at a comparatively lesser speed during the two intermonsoon seasons (i.e summer and autumn intermonsoon). The monthly averaged wind speed of the basin varied between 3.5-8.6 m/sec. The climatological averaged wind speed of the Arabian Sea from 1988 to 2010 was found to be 5.93 m/sec, with July showing the maximum speed of 8.2 m/sec while April being the month with the lowest wind speed of 4.2 m/sec.

4.4.2 Spatial Variability of Wind Speed over Arabian Sea

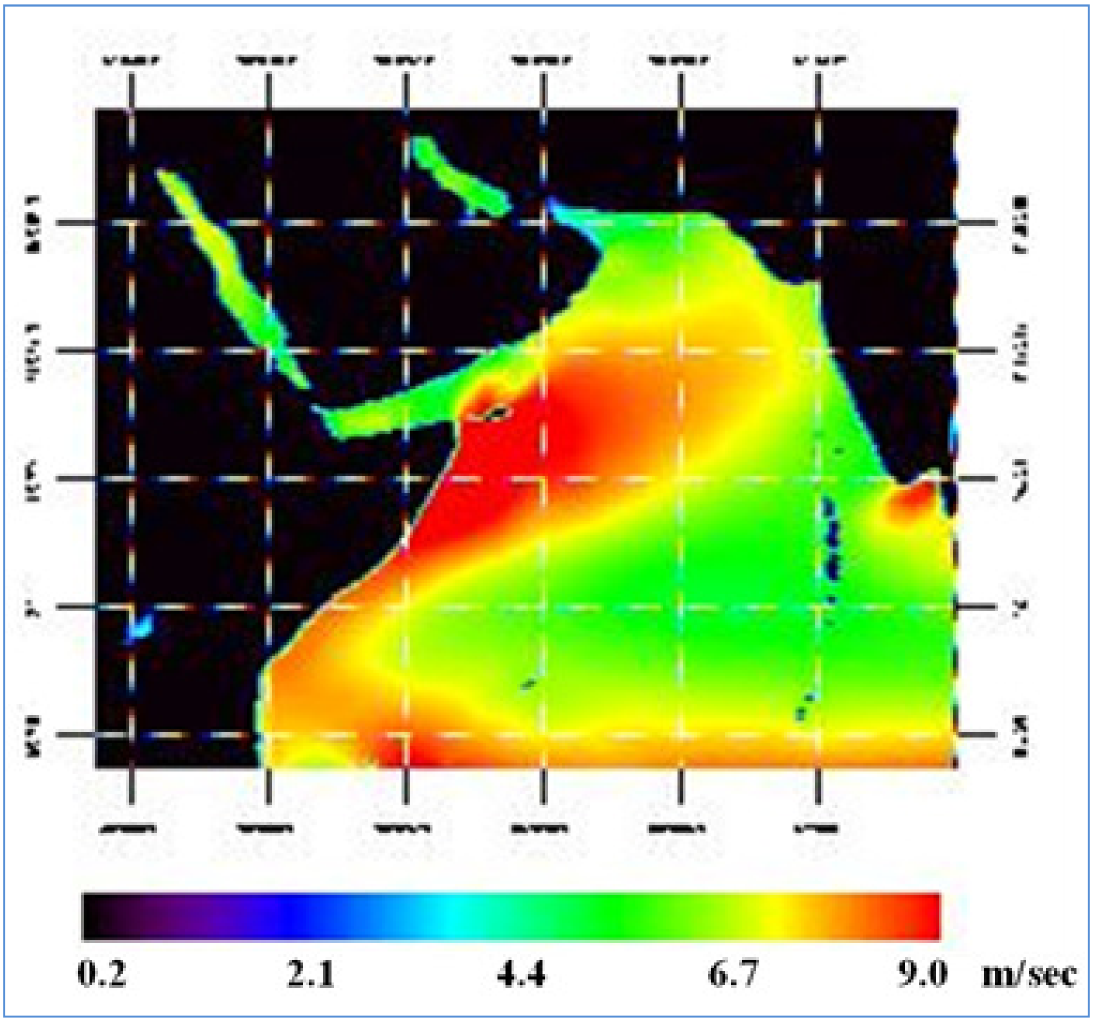

Fig. 4.3: Spatial Variability of Average Wind Speed over Arabian Sea from 1988 -2010 using CCMP data

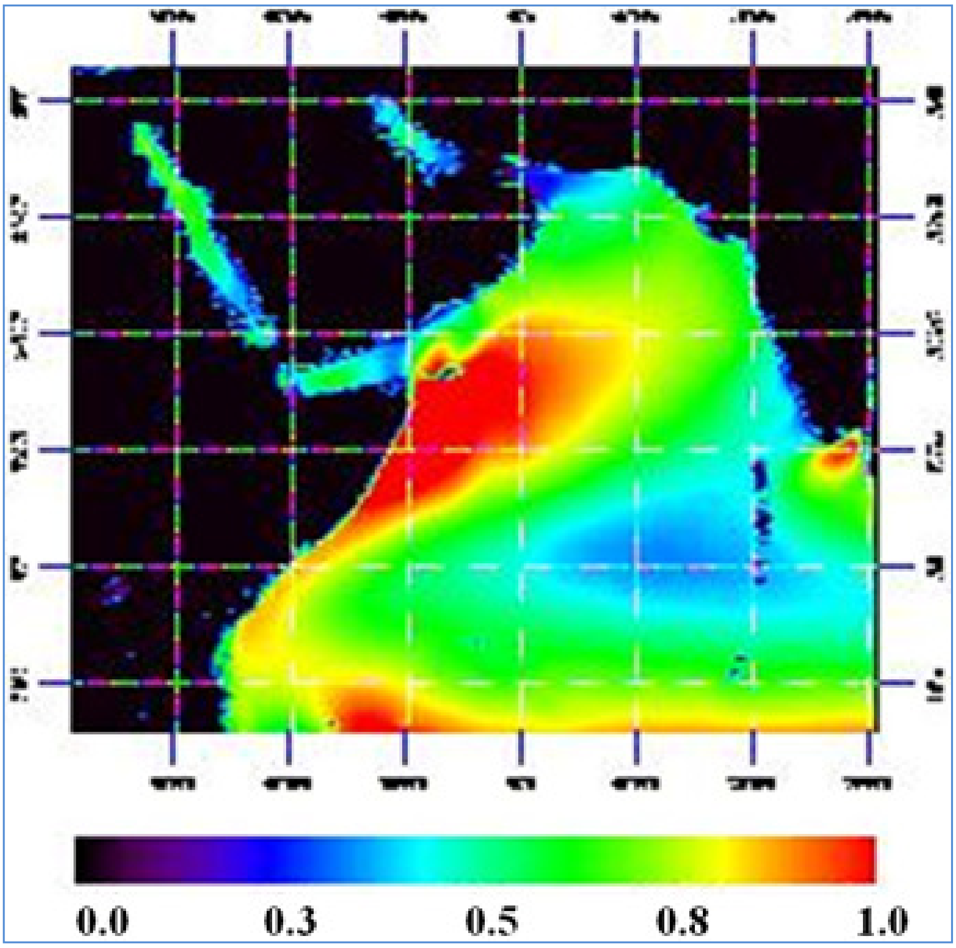

Fig. 4.4: Standard Deviation of Average Wind Speed over Arabian Sea from 1988 -2010 using CCMP data

As shown in Fig. 4.3 and 4.4, the wind speed over the Arabian Sea is not uniform; rather, it gives clear demarcation between its domains. While the average wind speed of the basin ranges from 4-6 m/sec, it is the northwestern part, specifically off the coast of Somalia, in which the maximum wind speed of the range 9-12 m/sec was observed. The interannual variability of wind speed was also the highest in the northwestern part with the standard deviation reaching up to 1 and more. This is the zone for upwelling and the effect of wind over this region of the Arabian Sea is clearly evident from the climatological wind speed map of the basin.

4.4.3 Temporal Variability of Wind Speed over Arabian Sea in different months

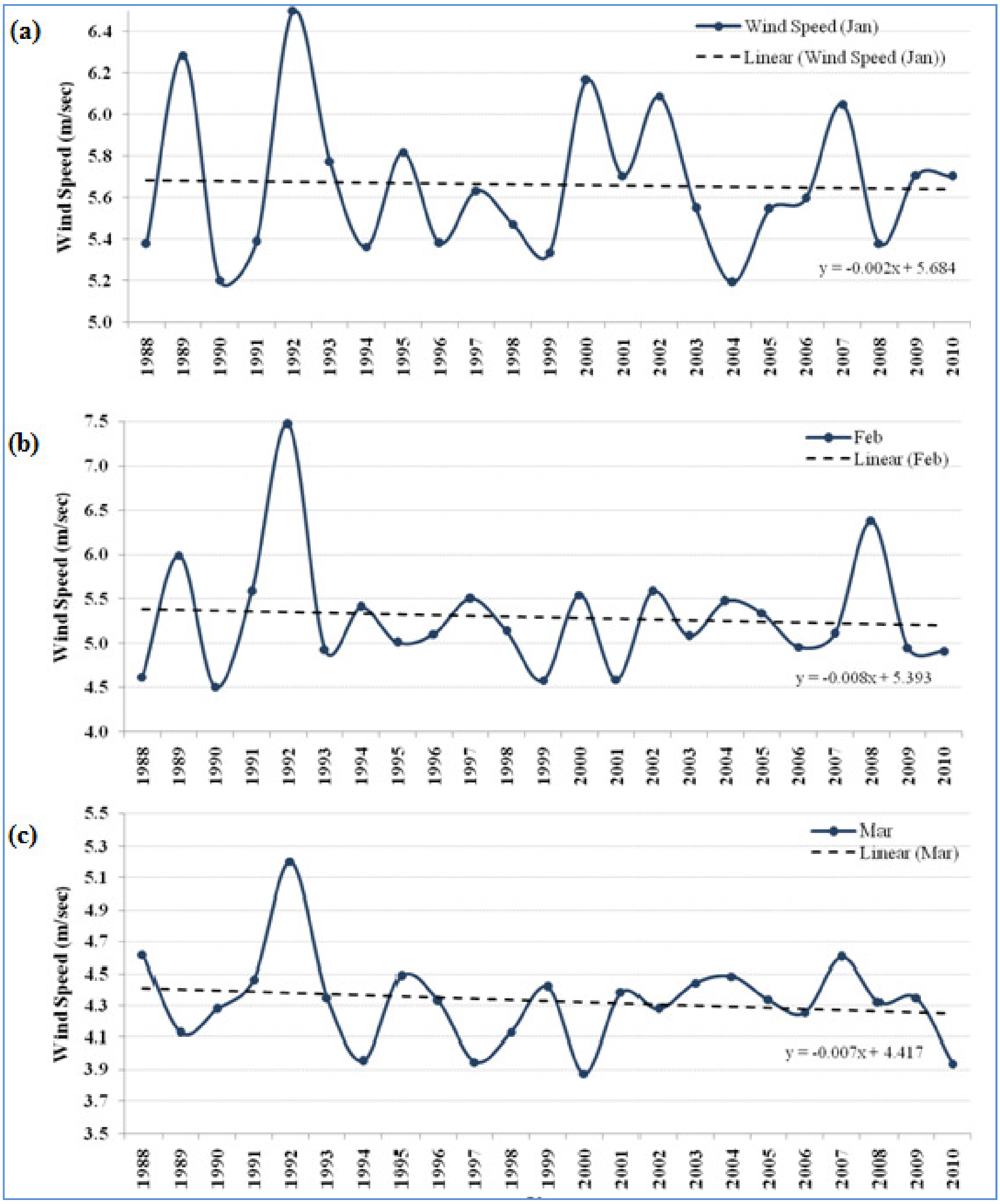

Fig. 4.5 (a-c): Monthly Wind Speed over Arabian Sea from 1988 to 2010 for (a) January; (b) February; (c) March

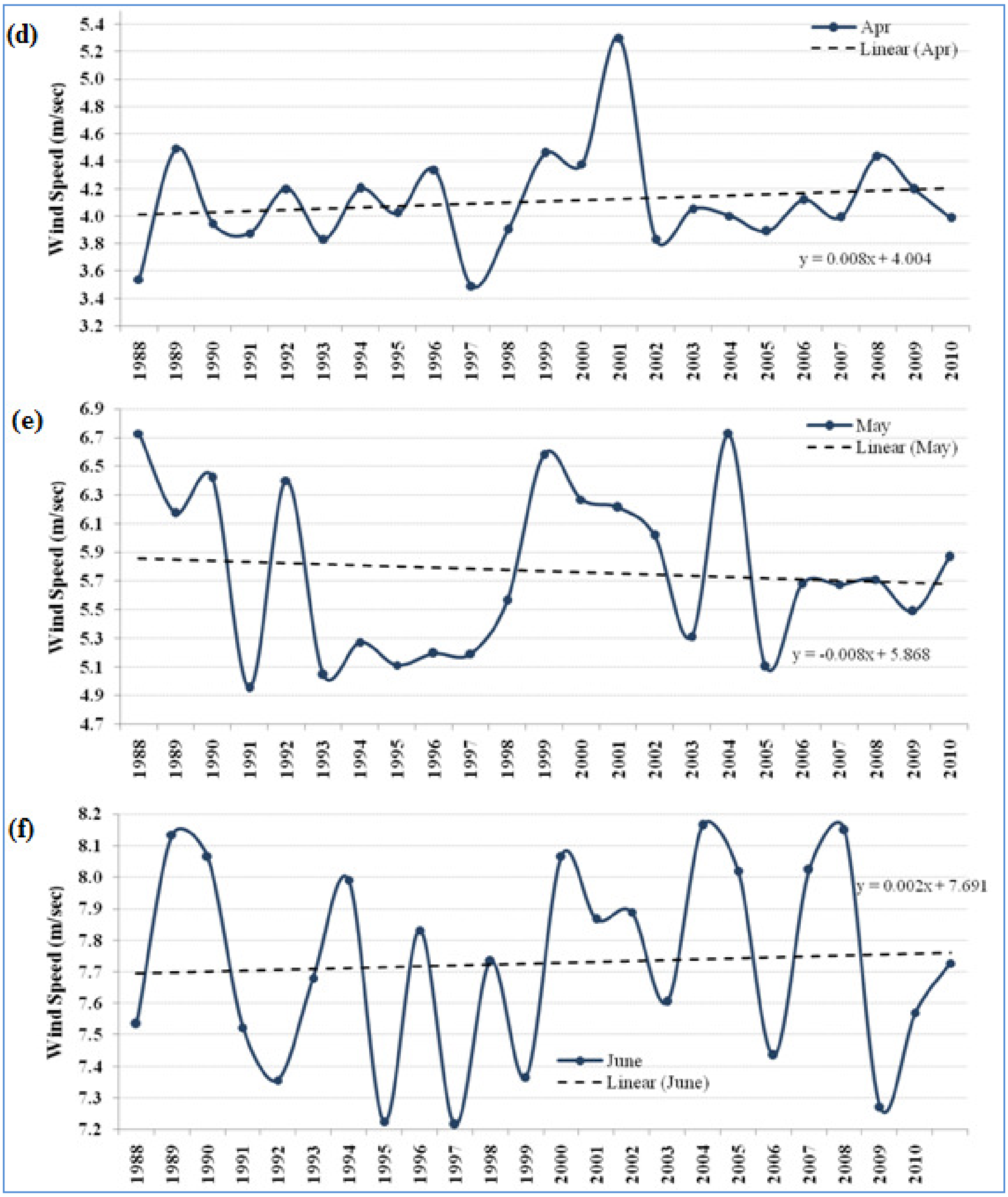

Fig. 4.5 (d-f): Monthly Wind Speed over Arabian Sea from 1988 to 2010 for (d) April; (e) May; (f) June

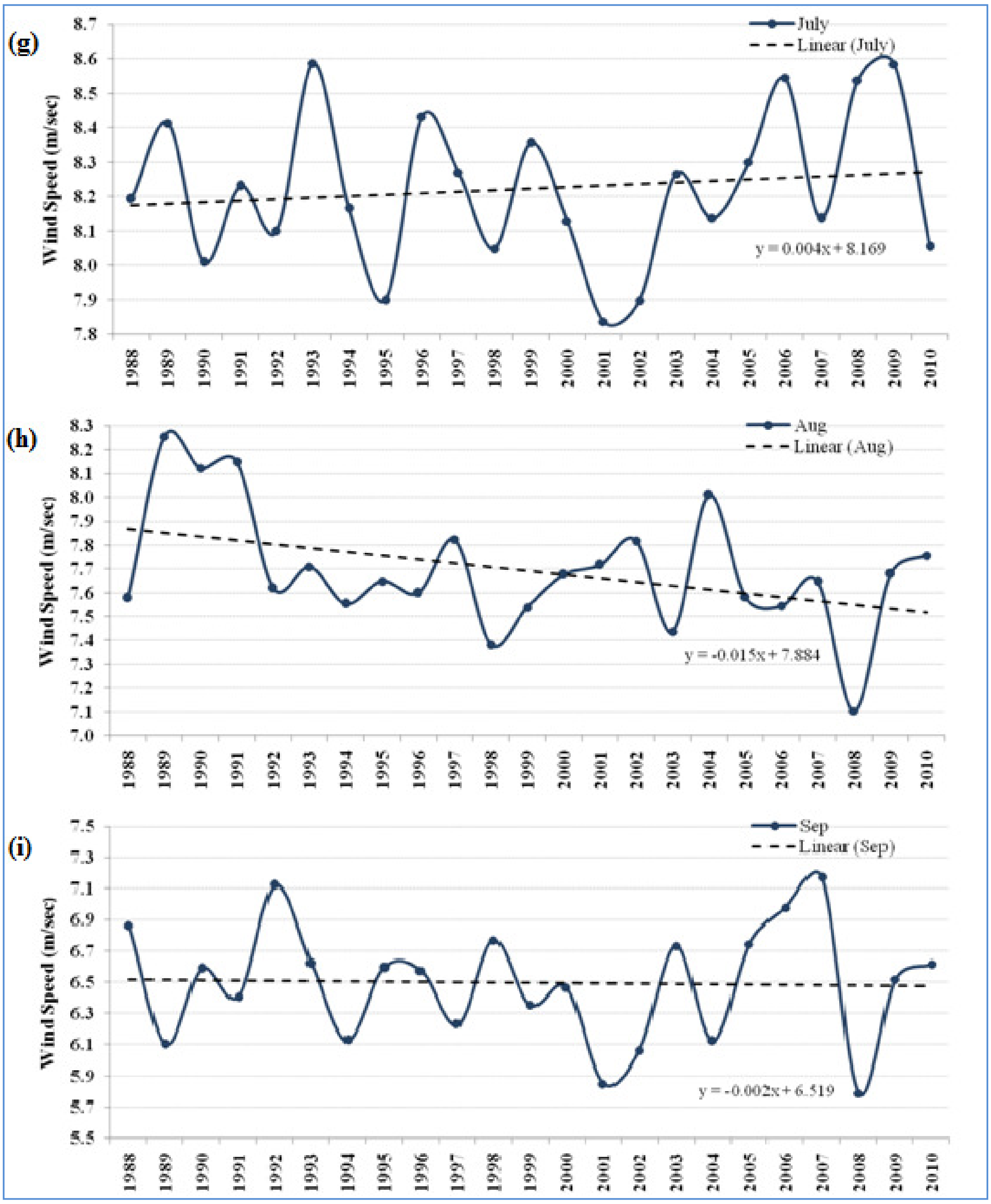

Fig. 4.5 (g-i): Monthly Wind Speed over Arabian Sea from 1988 to 2010 for (g) July; (h) August; (i) September

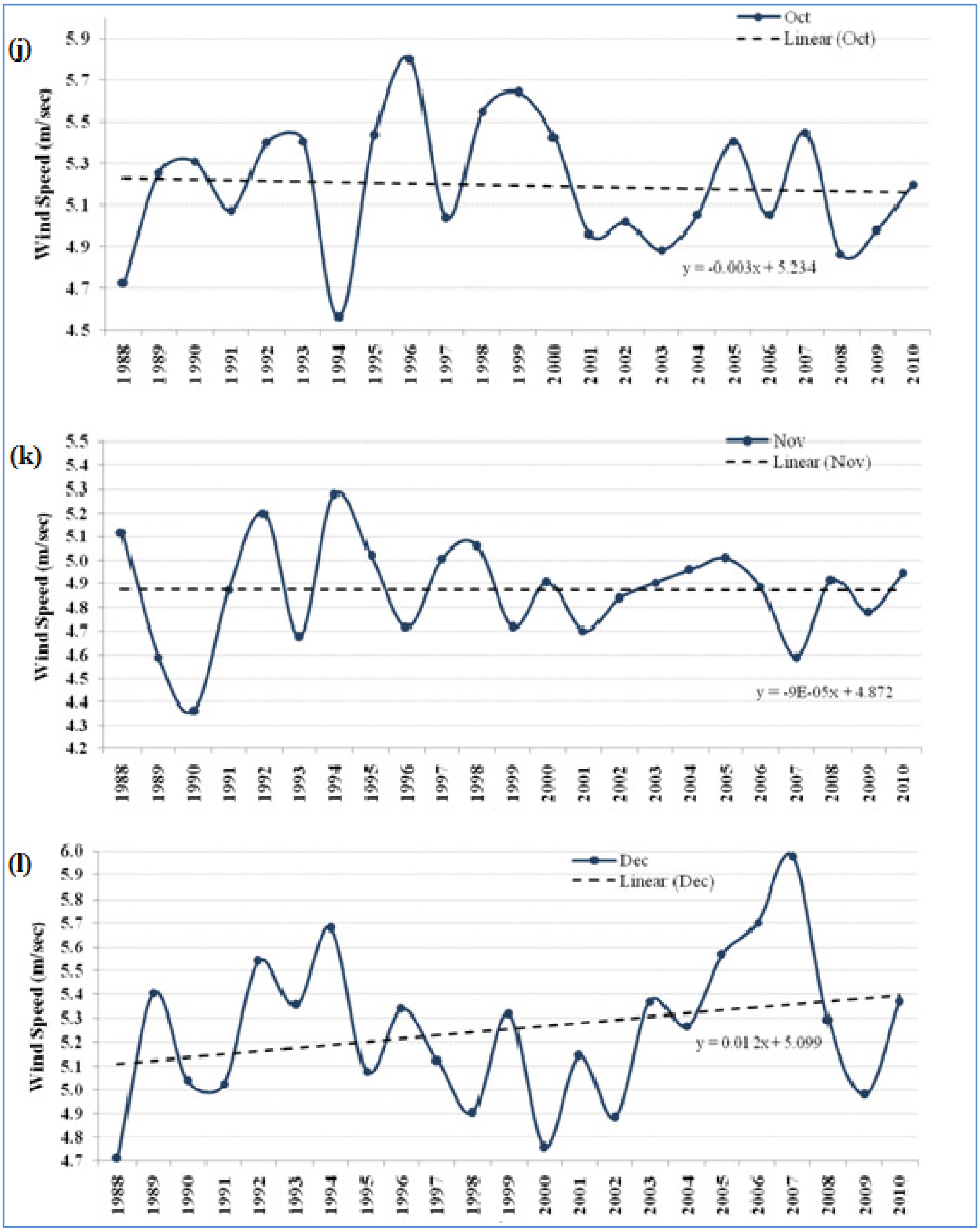

Fig. 4.5 (j - l): Monthly Wind Speed over Arabian Sea from 1988 to 2010 for (j) October; (k) November; (l) December

The monthly interannual variability of the wind speed over the Arabian Sea was analysed for the period 1988 to 2010. As seen from Fig 4.5 (a-l), the wind speed has decreased for all the months except April, June, July and December. This decrease is consistent with the findings of several other reports on decreaseing trend of the wind speed over Arabian Sea *(Kumar & Sajiv, 2010; Jiang et al., 2010; Shanas & Kumar, 2014).* Though this decrease is not substantial, yet if it continues, especially in the months corresponding to the biologically productive seasons i.e the southwest monsoon season and the northeast monsoon season, it is likely to affect the mixing of the oceanic waters and the resultant upwelling of the nutrients. In such scenario, the growth of the phytoplankton may get affected due to the limitation of nutrients.

In the present work, it was observed that the average wind speed decreased for most of the months of the year during the study period. The maximum decrease in the wind speed was found for the month of August, which was -1.5cm/sec/year. The wind speed decreased at the rate of -0.8cm/sec/year during for February and May, while for March the decrease was -0.7cm/sec/year. The result of decrease in the wind speed specially during the premonsoon months of May and the post monsoon month in August –September, may be corelated with the reports on decreasing trend of annual cyclonic frequencies in the Arabian Sea *(Singh et al., 2001).*

It was also observed that the wind speed increased during the months of April, July and December. While the increase during April and July were observed to be 0.8 cm/sec/year, 0.4 cm/sec/year respectively, it was December, in which a substantial increase of 1.2 cm/sec/year was found.

4.4.4 Interannual Variability of Wind Speed over Arabian Sea

The annual wind speed over the Arabian Sea basin was analyzed by computing the normalized wind speed anomaly across the years from 1988 to 2010 as shown in Fig 4.6.

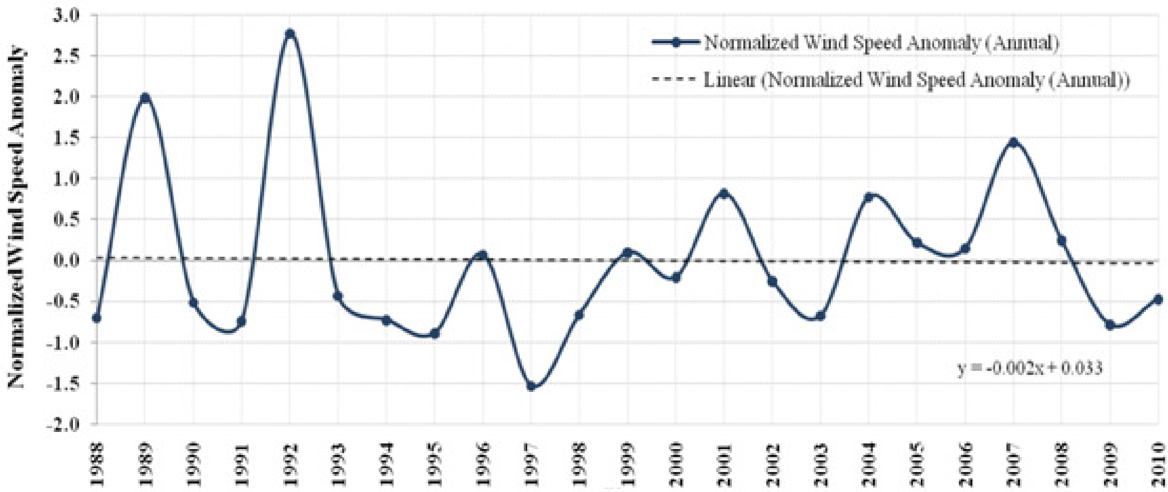

Fig. 4.6: Annual Normalized Wind Speed Anomaly from 1988 to 2010

The annual climatological mean wind speed was found to be 5.8 m/sec. Similar to the monthly pattern of wind speed, on annual scale also a decrease in the wind speed anomaly was observed. However, it was not statistically significant. It was noticed that of the 23 years, only in the years 1989, 1992, 2001, 2004 and 2007 the wind speed showed considerable positive deviation from the climatological mean. The normalized anomalies in these years were found to be +1.98 (1989), +2.76 (1992), +0.817 (2001), +0.772 (2004) and +1.44 (2007). These positive anomalies, though episodic events, disrupted the declining trend of the wind speed. Besides, it was also observed that in few years the increase in cyclonic events resulted in the positive anomalies for that particular month. For instance, in 1992, 2004 and 2007, there was more number of cyclonic events, which may have resulted in a higher speed of wind causing positive deviation from the climatological mean.

4.4.5 Man-Kendall Test Statistics for Wind Speed Trend over Arabian Sea

The statistical trend analysis for the wind speed over Arabian Sea during the period 1988 to 2010 was done using the non-parametric Man-Kendall Test. Table 4.1 gives the Z value which depicts whether the trend is decreasing or significantly decreasing or increasing or significantly increasing or there is no trend. Looking at the Z values, it can be inferred that for most of the months the trend is decreasing although not statistically significant at 95% confidence level.

Table 4.1: Man-Kendall Test Statistics for Monthly Mean Wind speed over Arabian Sea

Months	Z Value	Trend
January	- 0.21	Decreasing Trend
February	-0.26	Decreasing Trend
March	-0.60	Decreasing Trend
April	+0.63	Increasing Trend
May	-0.985	Decreasing Trend
June	0.00	No Trend
July	+0.475	Increasing Trend
August	-1.109	Decreasing Trend
September	-0.106	Decreasing Trend
October	-0.238	Decreasing Trend
November	-0.158	Decreasing Trend
December	+1.056	Increasing Trend
Annual	-0.898	Decreasing Trend

4.5 CONCLUSIONS

The study of wind pattern over the oceans is important for climate change related studies. It is well known fact that the increase in global temperatures will disrupt the thermal stratification adversely affecting the air circulation, which will have implications on the wind speed as well. Wind is a crucial physical factor, as it helps in surface cooling of the oceanic waters, which brings about the vertical mixing with the deeper layers and hence helps in bringing nutrients from the deeper layers to the surface which thereby promotes the phytoplankton growth and productivity. Hence, an overview of the changing pattern of wind speed is required for the assessment of the biological productivity of the oceans. From the present work, on the climatological study of the variability of wind speed over the Arabian Sea basin it can be concluded that:

1. In the last 23 years from 1988 to 2010, there has been a gradual decrease in annual speed of the wind over the Arabian Sea basin with its normalized anomaly decreasing at the rate of -0.02/decade.
2. The monthly analysis of the wind speed also showed a decreasing trend for all the months except April, July and December.
3. The rate of decrease of wind speed was highest during August, which was -1.5 cm/sec/year, followed by those of May, with -0.8cm/sec/year
4. The wind speed during the months of April, July and December followed an upward trend with the rate of increase being +0.8 cm/sec/year in April and,+ 0.4 cm/sec/year in July. December was the month with in which a substantial increase of wind speed at the rate of +1.2 cm/sec/year occurred.