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Impact of seasonal monsoon on coastal weather condition: a case study at Vengurla, west coast of India

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Study on coastal weather at Vengurla, west coast of India showed considerable seasonal climate variation. Diurnal variation of wind speed along with deviation of coastal breezes is gentle during pre- and post-monsoon periods. Coastal wind during summer monsoon period is dominated by remotely generated monsoon wind. Duration between setup and setdown of sea breeze event gradually extends from post-monsoon to pre-monsoon along with increasing trend in duration as well as strength of solar radiation and air temperature. During diurnal variation in pre- and post-monsoons, a reversal event occurs between relative humidity and coexisting air temperature. There was no considerable relation during summer monsoon seasons. The dramatic variation in the diurnal and seasonal atmospheric condition reveals the essential of annual time series data for local weather prediction.

[Keywords: solar radiation, atmospheric pressure, air temperature, relative humidity, wind]

Introduction

Information on weather and climate is not only important for scientific aspect but also needful for social activities[1-7]. Along Indian coast, occurrence of dramatic atmospheric condition across the consecutive monsoons in a complete annual cycle is usual phenomena. The summer (southwest) monsoon, that covers tentetively from June to September, dominates the west coast of India, whereas the winter (northeast) monsoon, that covers tentetively from October to December, and it has a considerable role along east coast of India. Remaining period belongs to calm weather condition which has been taken as pre-monsoon period. Monsoon periods are tentative as the occurrence of monsoon in advance or delay in withdrawal of monsoon varies among the different years[8,9]. These two monsoons affect the local weather and climate along Indian coastal belt. A strong seasonal variation in atmospheric condition can be observed along west coast of India compared to the variation occurs along east coast. Along with variation of weather and climate, the variation of the coastal processes such as wave characteristics, sediment transport and beach dynamics has been observed at open coast[10-13]. It shows impact of climate change in the coastal phenomena. So, disturbance in the local phenomena by these monsoons has unique role in imbalancing the regional economy in consideration of fishing community and tourism. Thus, interpretation of local weather and climate along Indian shoreline by covering a complete annual cycle is not only useful for the coastal dwellers but also important for planning any type of coastal development strategy. Information based on in situ data apart from prediction is highly considerable. In this study, in response to the coastal management project, the weather and climate conditions was examined at Vengurla, west coast of India (Figure 1). Vengurla is located at the south end of Maharastra and close to north boarder of Goa, and the location is bounded by the Arabian Sea at west and by the Weastern Ghat at east. Vengurla coast is at a tilt of 24° towards west from the true north. Jayappa and Narayan[14] reported that the coast between Vengurla and Rathnagiri is narrow, and many pocket beaches and long sandy beaches are present in this region. High weather condition during the summer monsoon might be hazardous to these narrow sandy beaches. Further, variation of weather condition in diurnal scale along shoreline is usual. The formation of

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coastal breezes along with variation of air pressure created by the different heat capacity of land and sea is a continuous process, and there is no acception in variation of temperature and humidity. In this study, diurnal and seasonal behavior of the major parameters namely solar radiation, precipitation, atmosperic pressure, air temperature, relative humidity and wind (speed and direction) were analyzed at Vengurla coast. This can be used for understanding the coastal problems associated with local weather and climate. These parameters are useful to provide the standard information during model setup for prediction of associated coastal physical, chemical, and biological processes.

Materials and Methods

Automatic Weather Station (AWS), composed of several sensors that manufactured by Virtual Electronics Company, was installed on shore at 15°49'25.17" N, 73°38'18.63" E on Vengurla coast (Figure 1) to record the behavior and pattern of weather and climate. The instrument was ~8 m elevation from mean sea level. Weather and climate data were collected for an annual cycle from 20th September 2014 to 28th August 2015 followed by half an hour recording interval. In this instrument, the pyranometer measures the solar radiation of wavelength from 305 to 2800 nm and it has the measuring capacity up to 2000 W/m^2 at an accuracy of ±5%. Tipping bucket rain gauge with magnet/Reed switch measures with a resolution of 0.2 mm. Precepitation accuracy is 2% up to 50 mm/h, however it measures up to 100 mm/h. Piezo-resistive silicon membrane pressure sensor measures the atmospheric pressure from 150 to 1150 mbar with a resolution of 0.1 mbar. Accuracy of pressure reading is ±1%. Instrument measures the temperature and relative humidity by the internal digital sensor. Sensor measures temperature from -40°C to 123.8°C with a resolution of 0.01°C. Accuracy in temperature reading is ±0.1°C from 5°C to 40°C. Simultaneously, it measures the relative humidity from 20 to 80% with an accuracy of ±2% while the resolution is 0.5%. Three-cup anemometer along with magnet/Reed switch measures the wind speed from 5 to 200 kph, and the accuracy of the sensor is 0.5 m/s. Magnetic Hall Effect sensor measures the wind at all direction from 0 to 360° in a resolution of 0.025° and the accuracy of sensor is ±0.3 to ±0.5% of signal range. All the five major parameters were depicted through time series plot, normal distribution plot and rose diagram plot for visualization of weather and climate condition. For better understanding of coastal phenomena, the scale for time series data is provided as per the Indian Standard Time (IST) which is five and half an hours (5.5 h) ahead than the Coordinated Universal Time (UTC). The normal (Gaussian) distribution plot is presented by histogram and probability density function for all the parameters. Histogram exhibits the relative frequency to the selected band for each

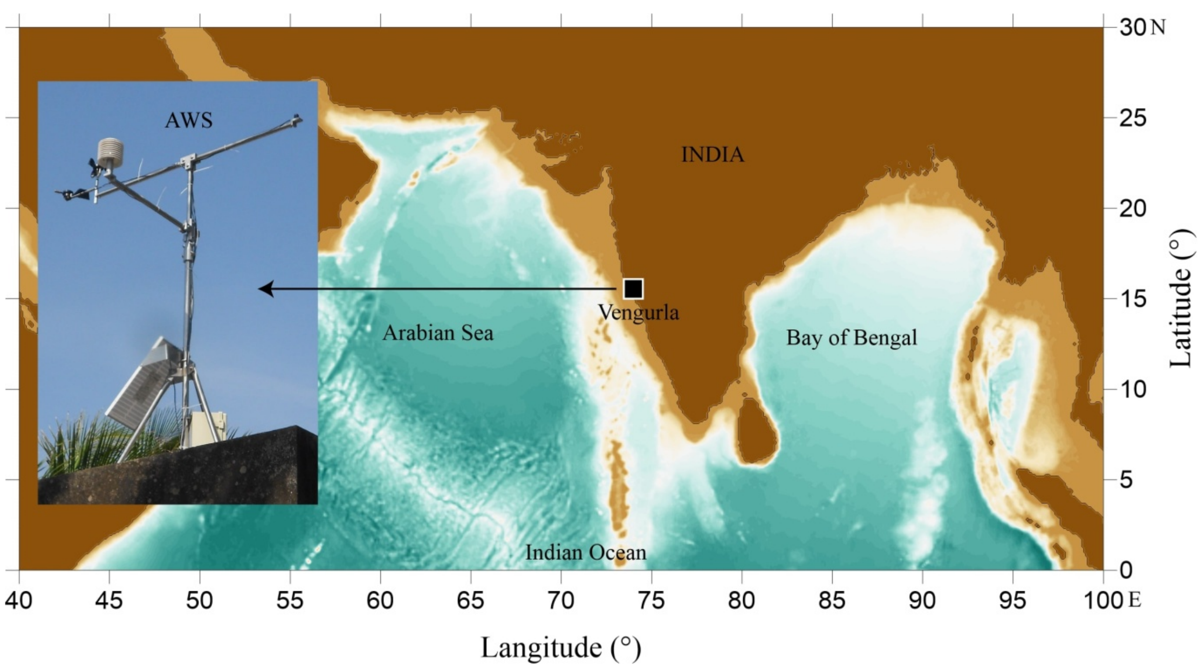

Fig. 1 — Geographic position of study area and Automatic Weather Station (AWS) location at Vengurla, west coast of India.

parameter. The relative frequency represents frequency of data for a specific band to total number of data set. Bin size in the histogram for the solar radiation was 200 W/m2, and that was 1 mm for precipitation, 2 mbar for atmospheric pressure, 4 °C for air temperature, 10% for relative humidity, 2 m/s for wind speed, and 30° for wind direction, which is same for wind rose diagram. For all parameter, there was no specific criterion for the selection of bandwidth in histogram. In wind rose diagram, wind speed was classified based on the Beauford wind scale[15], and presented with respect to wind direction. Meteorological convention was considered for presenting wind direction (the wind from 0° for north, 90° for east, 180° for south, and 270° for west).

Results and Discussion

During the annual cycle, solar radiation was up to 1116 W/m^2. Diuranal variation of solar radiation represents duration of day and night, whereas the solar radiation close to zero indicates night phase (Figure 2[A]). At this study location, the seasonal

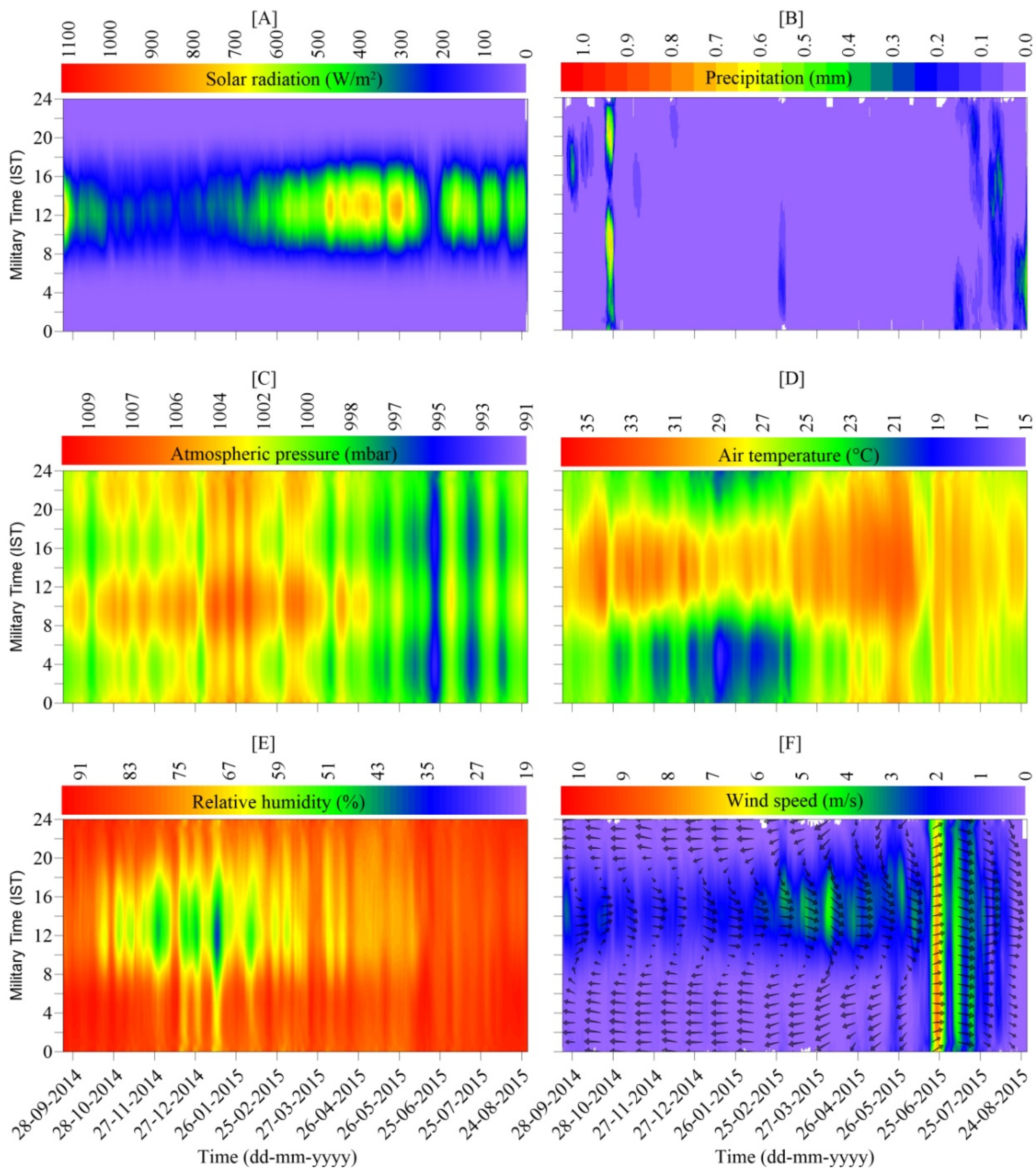

Fig. 2 — Diurnal and seasonal observation of [A] solar radiation, [B] precipitation, [C] atmospheric pressure, [D] air temperature, [E] relative humidity and [F] wind (speed and direction) at Vengurla coast from September 2014 to August 2015 using Automatic Weather Station (AWS) data.

variation of solar radiation showed high intensity (> 600 W/m^2) during the pre-monsoon period. The high solar radiation during pre-monsoon (especial during April and May) was occurring frequently from 11:00 to 15:00 h (IST). The solar radiation was below normal during June 2015 due to sailing of clouds in the troposphere along with result of the summer monsoon. IITM[16] reported that the precipitation over India was about 16% above the long period average during June 2015 and that was 189.5 mm. The solar radiation was medium (500±100 W/m^2) during summer monsoon, however some high solar radiation was observed for short period due to monsoon break in which duration the solar radiation (> 600 W/m^2) transfered without any effective obstruction in the atmosphere. IITM[16] reported that there was total 36 days monsoon break during June to September. Gradually, the solar radiation had weaken (< 400 W/m^2) towards post-monsoon period. Diuranal variation of solar radiation was strong during pre-monsoon due to existence of high solar radiation during noon time. However, the diuranal variation of solar radiation was gradually decreased from pre-mosoon to summer monsoon, and futher towards post-monsoon along with the successive decreased strength in the solar radiation. This observation represents strong diuranal and seasonal variation of solar radiation at Vengurla coast. Further, monthly average of daily basis analysis on the solar radiation showed that the peak solar radiation occurred during 12:00 to 13:30 h. In post-monsoon period, the peak solar radiation was during 12:00 to 12:30 h, whereas that was during 12:30 to 13:30 h in pre-monsoon as well as summer monsoon periods. Histogram plot showed the existence of low solar radiation during more period, whereas the less than zero represents the duration of no solar radiation (Figure 3[A]). The smooth positive skewed curve in the normal distribution plot showed gradually descrease in quantity from low to high solar radiation.

Along this coast, occurrence of high precipitation during summer monsoon is usual phenomenon. The absence of precipitation during June reflects some malfunction in data recording, whereas IITM[16] reported heavy precipitation during this period. Thereby, the description that has given hereafter about the precipitation is based on the available data. During study period, the half an hour interval observation showed that the precipitation was up to 7 mm, and the highest precipitation was during summer monsoon on 2nd August 2015. The high precipitation was recorded for very short period, and hence the peak is not visible in the time series plot (Figure 2[B]). Abnormally, the precipitaion was up to 6.8 mm during the successive four days from 24th to 27th October 2014. Also, observation showed the occurrence of precipitation during pre-monsoon, and that was up to 1.4 mm on 1st March 2015. The annual data analysis exhibited that there was no diurnal variation in occurrence of precipitation, whereas seasonal variation prevails along this coast. Histogram plot showed that most of the recorded precipitation was less than 1 mm, where very negligible quantity of precipitation was up to 7 mm (Figure 3[B]).

During the annual cycle, atmospheric pressure was varying from 991.1 to 1010.1 mbar with an average of 1001.3 mbar. During pre- and post-monsoon periods, the atmospheric pressure was frequently observed more than 1000 mbar, and the peak (1010.1 mbar) was on 22nd January 2015 that is less than the average sea-level pressure (1013.25 mbar). During summer monsoon period, the atmospheric pressure was comparatively low, and the lowest condition (991.1 mbar) was on 21st June 2015. In addition, there was diurnal variation of the atmospheric pressure during pre- and post-monsoon periods, and some period of summer monsoon (Figure 2[C]). The existence of high atmospheric pressure (> 1002 mbar) during mid-night (~00:00 h) as well as morning hours (~09:00 h) was observed; however, that was low during afternoon (~16:00 h) and early morning (~04:00 h). The existence of high atmospheric pressure during mid-night as well as mid-day, and low atmospheric pressure during early morning as well as afternoon showed that the local atmospheric pressure was controlled by more than one parameters apart from the variation of solar radiation. During diurnal scale, the atmospheric pressure was varying gently while the solar radiation was changing rapidly. There was two to three hours phase difference in existence of peak atmospheric pressure and solar radiation. The histogram plot showed that the atmospheric pressure from 1000 to 1002 mbar was existing more period (Figure 3[C]). The symmetric curve in the normal distribution plot showed the existence of low and high atmospheric pressure from the average was almost equal in quantity during the annual cycle.

During this period, air temperature was from 15°C to 36°C with an annual average of 27°C. The lowest temperature was on 14th January 2015, and the peak was on 12th March 2015. During second half of the post-monsoon (December and January) and early

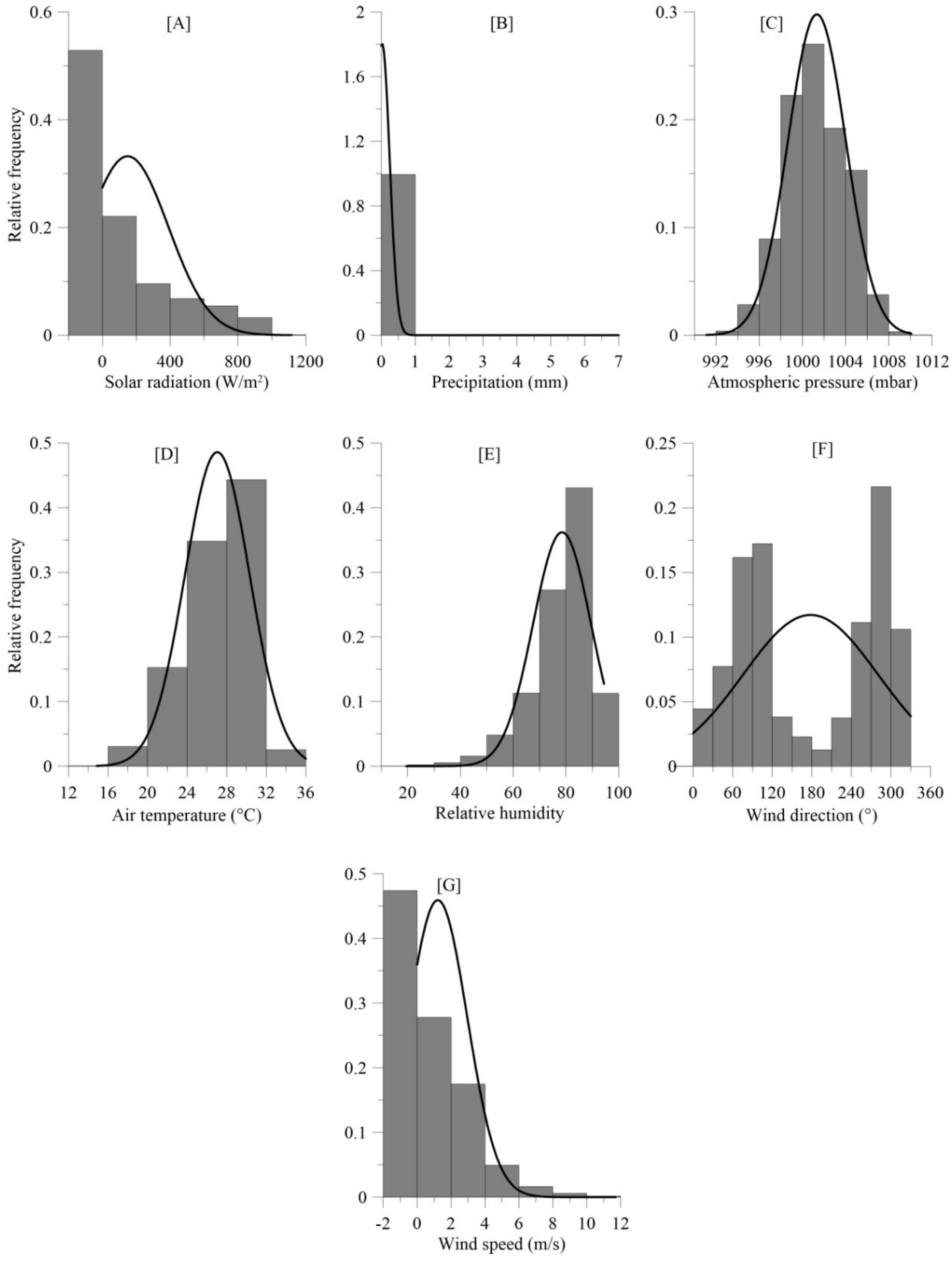

Fig. 3 — Figure 3: Normal distribution of [A] solar radiation, [B] precipitation, [C] atmospheric pressure, [D] air temperature, [E] relative humidity, [F] wind speed, and [G] wind direction data recorded over annual cycle at Vengurla coast.

phase of pre-monsoon (February), the air temperature frequently occurred from low (< 20°C) to moderate (> 20°C & < 30°C). The air temperature was from moderate to high (> 30°C) during remaining period in pre-monsoon (March to May). There was no considerable diurnal variation of air temperature during most of the period in summer monsoon, and the temperature was around 30°C. Diurnal variation of air temperature showed below 20°C during mid-night to early morning in December, January and

February (Figure 2[D]). Further, the existence of air temperature around 30°C during noon time with low solar radiation in November, December and January showed the impact of more than one external phenomenon apart from solar radiation in the diurnal variation of air temperature. The histogram plot showed that the air temperature was from 28°C to 32°C during 44% of total annual cycle (Figure 3[D]). However, the slightly negative skewed curve in the normal distribution curve revealed that the low air temperature (< 28°C) was existing more duration compared to high air temperature (> 32°C).

Consequently, relative humidity was 19 to 94% with an annual average of 78%. During the annual cycle, the lowest relative humidity was during mid-day (~11:30 h) on 11th January 2015, and the highest relative humidity was during mid-night (~23:30 h) on 18th June 2015. During pre- and post-monsoons, there was considerable variation of relative humidity in diurnal scale (Figure 2[E]). However, the relative humidity was almost unchanged during summer monsoon, and that was around 86%. During pre- and post-monsoons, diurnal variation of the relative humidity was inversely proportional to the coexisting air temperature, but there was no strong linear correlation. Histogram plot showed that the relative humidity was from 70 to 80% during 44% of total period (Figure 3[E]). However, the negative skewed curve in the normal distribution revealed that most of the time the relative humidity was below average.

Time series plot of the wind direction showed occurrence of coastal breezes at Vengurla (Figure 2[F]). Histogram plot exhibited that the sea breeze blowing from westwestnorth (270-300°) during most of the period, whereas the land breeze was from easteastsouth (90-120°) and easteastnorth (60-90°). Symetric curve in the normal distribution plot showed consequent existence of coastal breezes (Figure 3[F]). Strength of the wind was more during pre-monsoon than that observed during post-monsoon period. The wind speed was more during sea breeze event compare to the wind speed during land breeze. The sea breeze was blowing from ~10:00 to ~16:00 h during post-monsoon. However, the duration between setup and setdown of sea breeze event gradually extended towards pre-monsoon as the duration as well as strength of solar radiation and air temperature increased. However, the coastal wind during summer monsoon period was dominated by the remotely generated monsoon wind which was frequently blowing towards land from ocean, and hence there was no coastal breeze phenomena. Along west coast of India, in response to the temporal variation of coastal wind pattern, similar result was observed by Glejin et al.[17] at Ratnagiri, ~133 km north from the present study location while the diagonal distance is at 16° tilt towards west from the true north. Also, Dora and Kumar[18] observed similar result at Karwar, ~125 km south from the present study area while the diagonal distance is at 25° tilt towards west from true north. Additionally, it was observed that the atmospheric pressure was high during the setup time of sea breeze (~10:00 h), and gradually the atmospheric pressure was decreased up to the setdown of sea breeze (~18:00 h). This showed a coexisting relation between atmospheric pressure and existence of coastal breezes.

During the annual cycle, the wind was up to 10.3 m/s, and the peak condition was observed during the month of June. The annual average wind speed was 1.21 m/s. Histogram plot showed the existence of low wind speed during most of the periods, whereas the less than zero represents no existence of wind (Figure 3[G]). The positive skewed curve in the normal distribution plot showed a gradually decrease in quantity from low to high wind speed. The sea breeze was usually observed by light air (0.3-1.5 m/s), light breeze (1.5-3.3 m/s) and gentle breeze (3.3-5.5 m/s) along with few quantity of moderate breeze (5.5-7.9 m/s) and fresh breeze (7.9-10.7 m/s). The calm condition (up to 0.3 m/s) of wind blow was found short period during sea breeze. The land breeze frequently existed as calm, where the light air and light breeze were observed short period. Overall, the wind data at Vengurla showed about 48% was in calm condition, 19% in light air, 22% in light breeze, where the remaining data belongs to gentle breeze (8%), moderate breeze (2%) and fresh breeze (1%). Monthly study using wind rose exhibited that the wind during June was frequently from gentle to moderate breeze range during sea breeze event, and blowing from westwestsouth (240-270°) and westwestnorth. However, the wind during July was observed by light and gentle breeze range,and dominated from the westwestnorth direction. During August, a mixture of different wind condition from calm to gentle breeze was observed, and the wind was from westwestnorth and northwest (300-330°).

During September to December, the sea breeze event as well as the strength of wind speed gradually

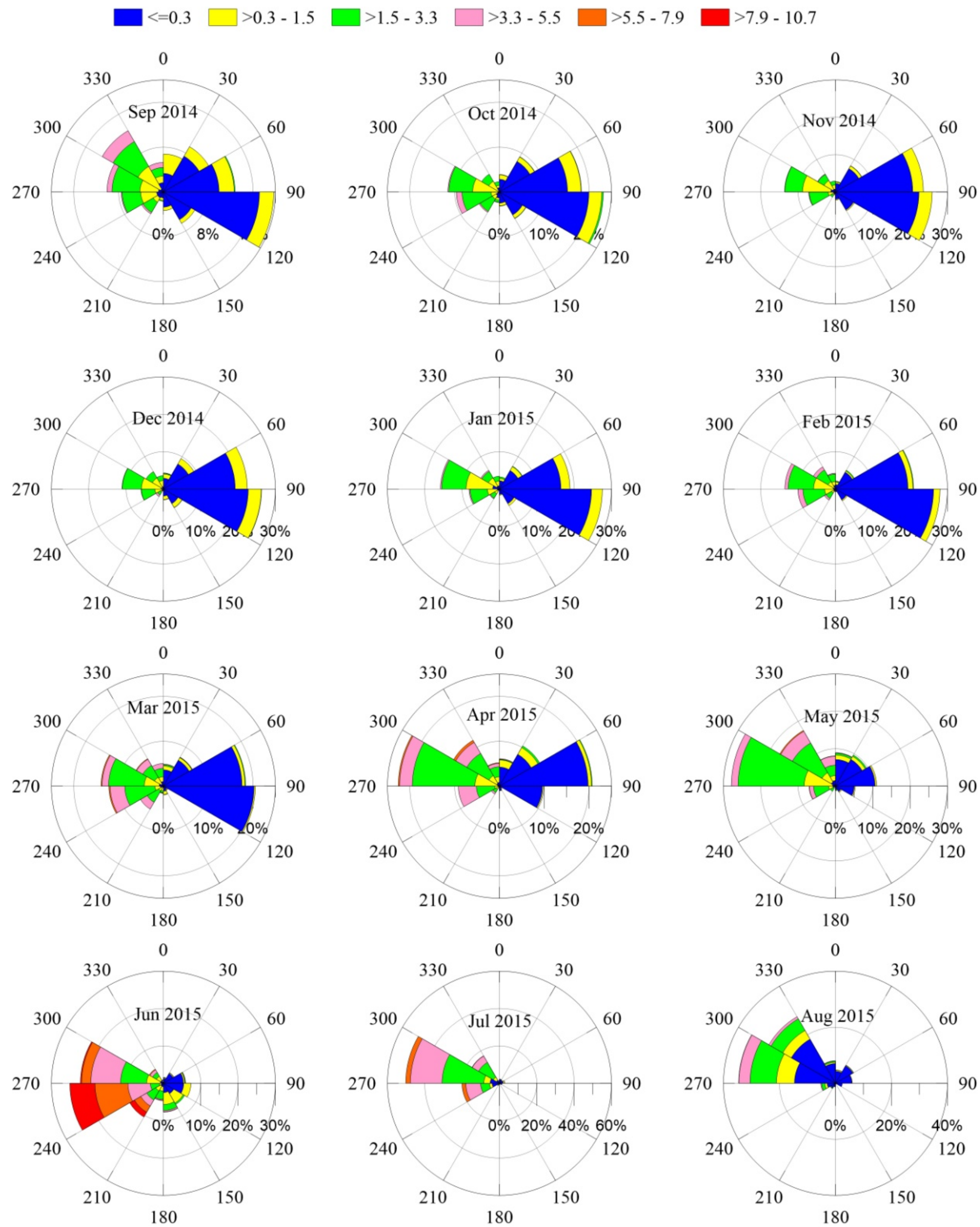

Fig. 4 — Monthly onshore wind pattern based on the Beaufort wind scale at Vengurla, west coast of India.

decreased with increasing land breeze duration which further showed a reversal pattern up to May in both wind direction and speed. During September and October, both the sea breeze and land breeze was observed frequently with mixture of calm, light air, light breeze and gentle breeze. During these months, the wind was blowing from all the directions; however the wind from easteastsouth dominated. During November to March, the wind from easteastnorth and easteastsouth dominated, whereas the coast was dominated by westwestnorth (easteastnorth) during sea (land) breeze event during April. Thereby, the coast during May was dominated by the westwestnorth and northwest wind (Figure 4). The in-depth analysis on wind showed dramatic variation of wind pattern across successive twelve months. Hence, time series wind analysis is essential rather than the considering one month data during each season for representing seasonal variation.

Conclusions

Study on diurnal and seasonal variations of weather revealed that the coastal wind speed and direction is proportional to the co-existing air temperature and solar radiation, however there is some phase lag with the atmospheric pressure. The sea (land) breeze occurs at low (high) humidity, high (low) solar radiation and high (low) air temperature. During summer monsoon, there is no existence of coastal breezes due to the dominant of summer monsoon wind. Diurnal deviation of local atmospheric parameters across the successive seasons reveal the necessity of annual data for prediction of any coastal processes associated with local weather condition.

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