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An Observational Study of Sea Breeze over Nigerian Coastal Region

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Abstract: Characteristics of sea breeze over the south coast of Nigeria were studied. The study used hourly wind (speed and direction) and temperature data for 5 years (1979-1983) over four coastline stations in Nigeria (Lagos, Warri, Port-Harcourt and Calabar) to examine various characteristics of the sea breeze. The spatially average strength (speed) of the sea breeze is about 2 ms^{-1}. Sea breeze occurrences are most frequent in the months of November-April. The results show that sea breeze usually starts as a light onshore surface wind few hours after the sunrise and has a mean duration of about 11 h. The mean onset and cessation time are 1200 and 2200 h, respectively. Average daily hodographs for the stations reveal that the sea breeze circulation is both clockwise and anticlockwise in rotation.

Key words: Sea breeze characteristics, circulation, surface wind, Nigerian coast

INTRODUCTION

Sea breeze, a thermally induced local or mesoscale circulation, develops along coastal regions when temperature difference between two adjacent surfaces is large enough and the geostrophic wind is weak. Sea breeze circulation is mostly observed and has been found to play an important role in coastal areas where industries are located. Despite the importance of this mesoscale feature in coastal environment, it has rarely been studied along the coast of Nigeria. This is largely due to lack of relevant data.

Sea breezes are most common in the spring and summer months due to the existence of temperature gradient between land and sea. This has been confirmed by the studies of Pielke (1973), Atkinson (1981), Maja (2003) and Miao *et al.* (2003). In their study over Sardinia (in mid-latitude), Furberg *et al.* (2002) observed that sea breezes, on a station-wide basis, are most frequent between May and August. Michael (2003) however, showed that sea breezes occur most often from spring to autumn, under generally clear skies, when the land surface becomes warmer that the ocean. At Lower Fraser Valley on Canadian Coast (higher latitude), Steyn and Faulkner (1986) report a maximum number of sea-breeze days in August and a minimum in December/January. This shows that in both middle and high latitudes sea breeze occurs mainly in the summer. However, in the tropics, which are characterized by high temperature, sea breezes tend to be stronger than in middle and high latitudes (Wexler, 1946). Simpson (1994) reported that tropical sea breezes occur on at least two-thirds of the days in the non-monsoon (winter) season. It is thus obvious that in the tropics the frequency of occurrence of sea breeze is higher in the winter.

In this study, surface wind and temperature data for four meteorological stations, in the coastal areas of Nigeria, are analysed to study the characteristics of sea breeze such as its intensity, time of onset and cessation and the average duration. The stations and their locations are shown in Fig. 1a.

MATERIALS AND METHODS

Hourly data of air temperature and wind (speed and direction) for Ikeja, Warri, Port Harcourt and Calabar for 1979-1983 were obtained from the Nigerian Meteorological Agency. The four stations are considered appropriate for the study because of the availability of observational data for the period (Fig. 1b). The stations location indicators are given in Table 1. The wind speeds and direction were measured at a height of 10 m, while the temperature was measured at a height of 2 m above ground surface. The large data sets were analysed to exclude days and months with incomplete and unreliable data. The reduced data sets were therefore, used as input into a set of FORTRAN programs that extracts the sea breeze days. In addition to the hourly air temperatures and winds data, the program also uses monthly averaged sunrise and sunset times, monthly averaged sea surface temperatures and the

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Table 1: Station coordinates and other data to describe the stations

Station	Coast	Longitude (deg. N)	Latitude (deg. E)	Distance from the closest sea (km)	Height above sea level (m)	No. of sea breeze days for 1979-1983
Ikeja	S	3.3	6.5	22.2	39.3	747
Warri	S	5.5	5.5	31.2	8.2	745
Port Harcourt	S	7.0	4.8	46.0	18.0	483
Calabar	S	8.3	4.9	42.1	61.8	676

Table 2: Temperature differences between mean DAT and mean SST (°C)

Station	J	F	M	A	M	J	J	A	S	O	N	D
Ikeja	1.5	2.4	2.7	2.3	1.1	0.5	0.8	0.7	1.4	1.9	2.0	1.0
Warri	1.3	2.0	2.5	2.0	1.2	1.0	1.0	0.9	1.5	1.8	2.3	1.3
Port Harcourt	0.6	2.1	2.1	1.7	0.8	0.7	0.8	0.6	1.2	1.1	1.4	0.9
Calabar	1.2	2.4	2.1	1.3	0.7	0.5	0.6	0.2	1.1	1.2	1.5	1.2

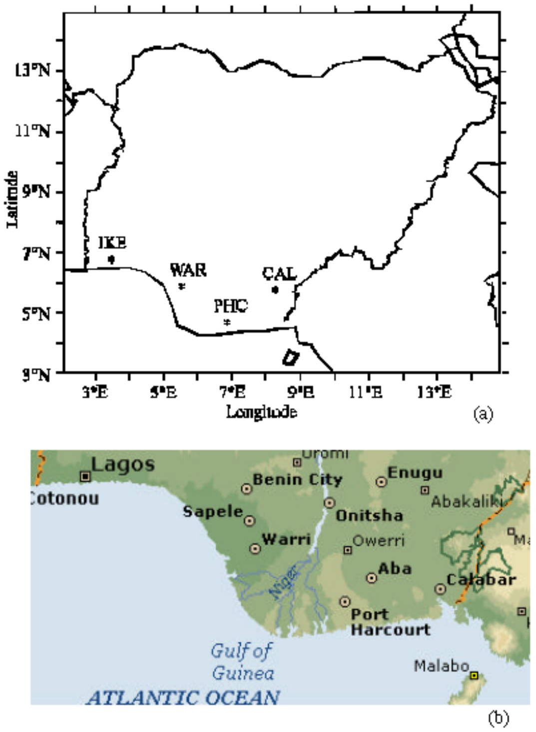

Fig. 1: (a) Map of Nigeria (b) Enlarged map of Southern Nigeria, showing the stations [Ikeja (Lagos), Warri, Port-Harcourt and Calabar] used

onshore and offshore flow quadrant sectors values for each station, to extract the sea breeze days from the data sets. The outputs from the program are therefore, subjected to climatological analysis.

Criteria for selection of sea breeze days: Studies have been carried out to set some criteria for the selection of days with sea breeze from a large data set and at the same time exclude days with large synoptic conditions (Banfield, 1991; Gustavsson *et al*., 1995; Borne *et al*., 1998; Furberg *et al*., 2002; Maja, 2003). In this study, the sudden change in wind direction during a 24 h period, which is the main characteristics of a sea breeze, is used as the first criterion for the onset of sea breeze. Using the hourly surface wind speed and direction and following the work of Furberg *et al*. (2002) and Maja (2003), the wind shift from offshore during the night time to onshore flow during the day time is formulated as:

- Majority of the hourly surface wind from (sunrise-6 h) to (sunrise + 2 h) should be offshore or calm.
- From (sunrise + 2h) to (sunset + 2h), the wind should be onshorefor at least two consecutive hours.
- The mean day temperature over land (T_{Land}) must be greater than the sea surface temperature (T_{sea}), i.e., $T_{Land} > T_{sea}$

The third criterion is based on the fact that sea breeze is a thermally driven circulation, so before a sea breeze can develop there must be an appreciable horizontal temperature gradient (i.e. the temperature difference between land and sea). Due to lack of sea surface temperature data, NCEP reanalysis data of the mean monthly sea surface temperatures over the ocean (Atlantic Ocean) adjacent to the stations were utilised.

RESULTS AND DISCUSSION

Variation of the synoptic forcing: In order to understand the characteristics (onset, cessation, duration and frequency of occurrence) of the sea breeze over a region, it is important to know the relationship between Daytime Air Temperature (DAT) and Sea Surface Temperature (SST), since it is the main driving force for the sea breeze circulation.

Figure 2 shows the variation of the monthly mean of DAT (averaged over the four stations) and the SST. The figure shows that DAT and SST follow the same pattern; both Increasing from January to March/April. This period coincides with northward advance of the sun to the Northern Hemisphere. A decrease in temperature is

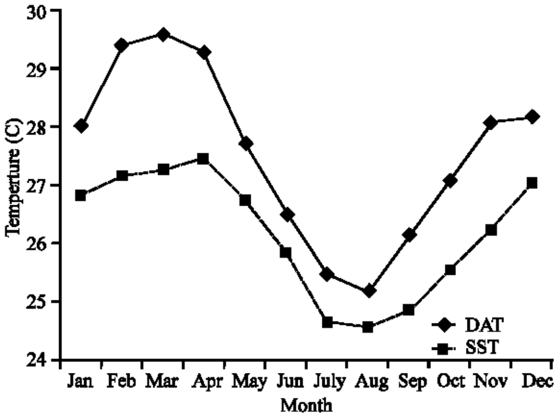

Fig. 2: Monthly variation of mean Daytime Air Temperature (DAT) and mean Sea Surface Temperature (SST). The values are spatially averaged over the 4 stations used in the study

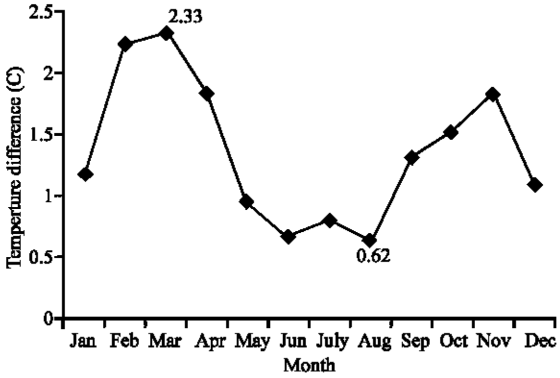

Fig. 3: Monthly variation of the difference between DAT and SST(i.e., DAT-SST)

observed from April to August after which there is again an increase till December. The minimum in August coincides with the period of little dry season. The monthly variation of the contrast (difference) between DAT and SST (Fig. 3) exhibits a similar pattern as those of DAT and SST. This suggests that thermal forcing for the sea breeze is high between September to April where the difference is 1.1°C and above (Table 2).

The maximum difference between mean DAT and SST occurs in March with value of 2.3°C and the minimum of 0.6°C in August (Fig 3). On the station-by-station basis, Port-Harcourt and Calabar have maximum differences in February, while for Ikeja and Warri it is in March.

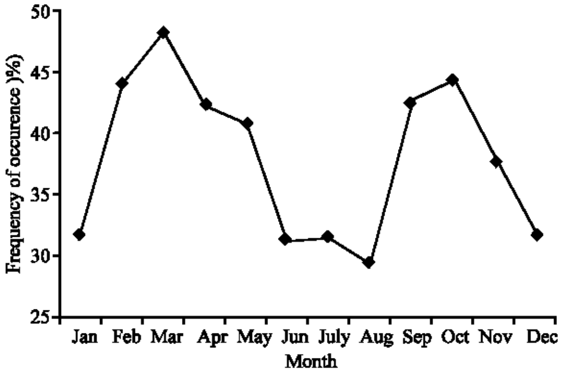

Fig. 4: Monthly frequency of occurrence of sea breeze, spatially averaged over the 4 stations used in the study

Frequency of occurrence: One of the interesting characteristics of sea breeze is the frequency of occurrence. The mean monthly frequency of occurrence of sea breeze days, average over the four stations, is shown Fig. 4. There is a clear similarity between this graph and Fig. 3. Sea breeze is most frequent in February-May and again September-November with more than 40% frequency.

The monthly frequency of occurrence of sea breeze days for Ikeja, Warri, Port-Harcourt and Calabar were shown in Fig. 5. Sea breeze is a yearly phenomenon but less frequent in June to August in Ikeja where the occurrence is less than 40%. The below 40% occurrence in Warri occur in April-June, November and December. The SB occurrence in Port-Harcourt is rather on the lower percentage compared with other stations. Here, below 40% occurrence is an all year phenomenon. In Calabar, the months of January, June to August and December equally experienced less than 40% frequency of occurrence. It is important though to state here that the monthly occurrences are less than 50%. On average, sea breeze is most frequent in February-May and again September-November with more than 40% frequency.

The minimum in sea breeze activity from June-August is consistent with the weak forcing in these months. In a nutshell, the figures show that Port Harcourt which is farthest (46 km) away from the sea has the lowest frequencies throughout the year while Ikeja, situated 22 km away from the coastline has the highest sea breeze occurrences (Table 1).

It is also obvious that, since sea breeze occurs during all the months of the year at each of the stations, hence, the Nigerian sea breeze is not a seasonal phenomenon. This is due partly to the position and the orientation of each station to the local coastline and the fact that the ITD is always at least 3-4° north of the stations except Ikeja where it is 1-2° north in winter.

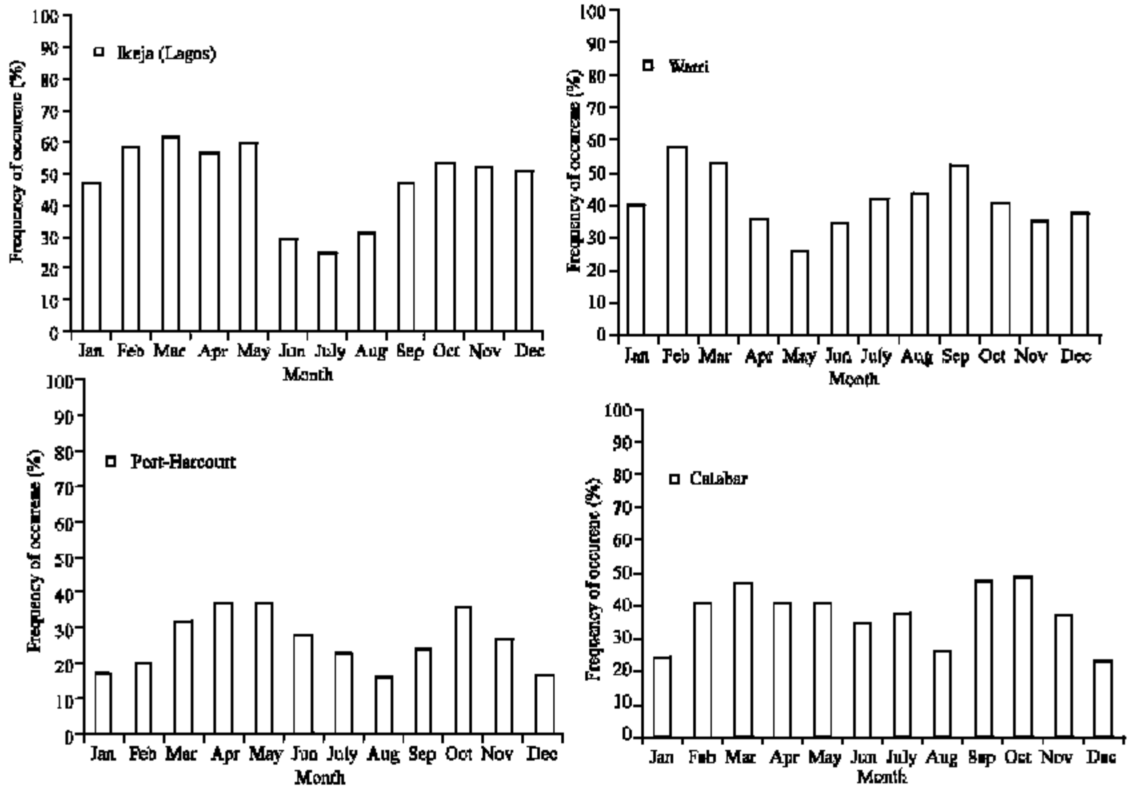

Fig. 5: Monthly frequency of occurrence of sea breeze days

Furthermore, insolation is an all year daily phenomenon. It is pertinent to note that Port-Harcourt and Calabar are characterized by the swamp forest, consisting of fresh water and mangrove swamp forest, both of which are less influenced by the double rainfall pattern. This makes the environment a wetland region and will consequently affect their land/sea temperature contrasts, which in turn leads to the low frequency of sea breeze occurrence.

The sea breeze speeds: Figure 6 displays the mean monthly wind speed of the sea breeze. The speed of the sea breeze varies between a maximum of about 1.5 ms^{-1} in April, weakening to about 1.2 ms^{-1} in May, but picking up

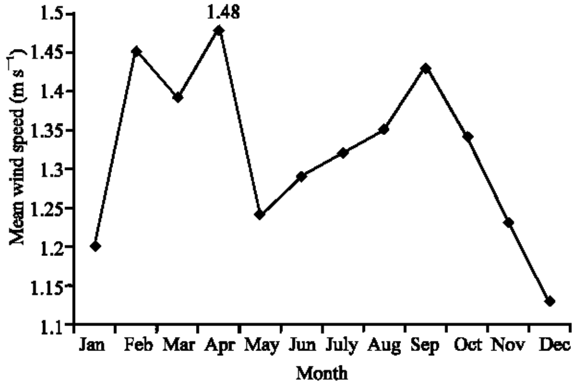

Fig. 6: Monthly mean wind speeds of the sea breeze, spatially averaged over the 4 stations used in the study

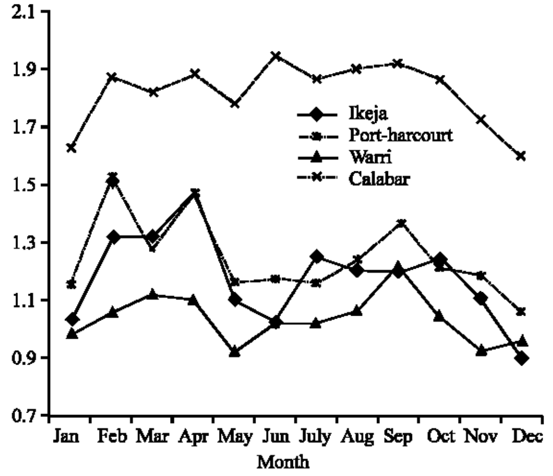

Fig. 7: Monthly variation of mean wind speeds of the sea breeze at each of the 4 stations

again to about 1.4 ms^{-1} in September. There is continuous decline from this month. The monthly variation of sea breeze speed (Fig. 7) at each station follow a similar pattern, but it is clearly stronger and with less variation at Calabar. This may be due to the channelization of the sea towards the station (Fig. 1b). On average, the highest sea breeze speed is observed in winter.

Hodographs: The average hodographs for the four selected stations are shown in Fig. 8a-d. Since the stations are in the Northern Hemisphere, it is expected that the wind vectors should rotate clockwise along an ellipse during the course of a day, as a result of the effect of the Coriolis force (Haurwitz, 1947). On the other hand, Kusuda and Alpert (1983) showed that it is possible to have both clockwise and anticlockwise rotations in the Northern Hemisphere.

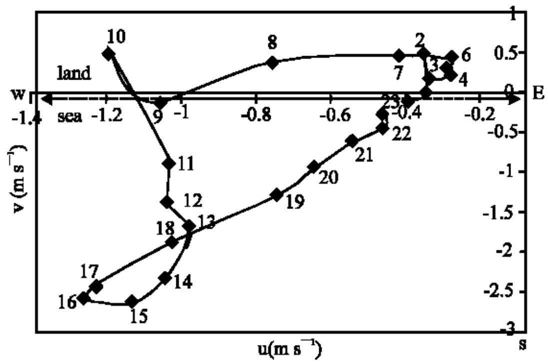

Fig. 8: Hodographs of the average surface wind vectors for Ikeja. The numbers near the squares indicate time of day in hours (GMT). The dashed line represents the direction of the coastline

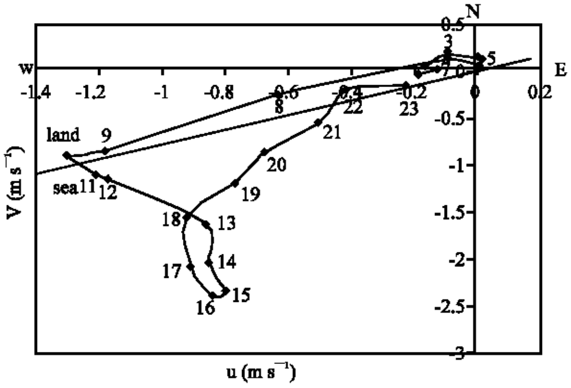

Fig. 9: Same as in Fig. 8, but for Port Harcourt

The observed hodograph for Ikeja (Fig. 8) show an Anti-Clockwise Rotation (ACR) and it is characterized by the late incoming and late cessation of sea breeze. The direction of the wind vectors at morning-time is from NW-NWN with a speed of 0.5 m s^{-1}. This suggests a weak land breeze. The late morning (0800-1000 Z) is a transition period from land breeze to sea breeze. During this period, the wind steadiness is very low compared to the early morning. The sea breeze, which is from WSW to SW, begins to build up at 1100 Z. The sea breeze continues to strengthen till 1600 Z with a speed of about 2.7 ms^{-1}. The anticlockwise rotation persisted for a much longer period, with the southwesterly winds blowing for about 10 h. Port-Harcourt shows similar rotation pattern to Ikeja, but the morning time wind vectors (0100- 0700Z) are perpendicular to the shore and displays a high degree of steadiness. As with Ikeja, a slight clockwise rotation is noticed between 1300-1800 Z after which the hodograph returned to ACR and the wind weakens (Fig. 9).

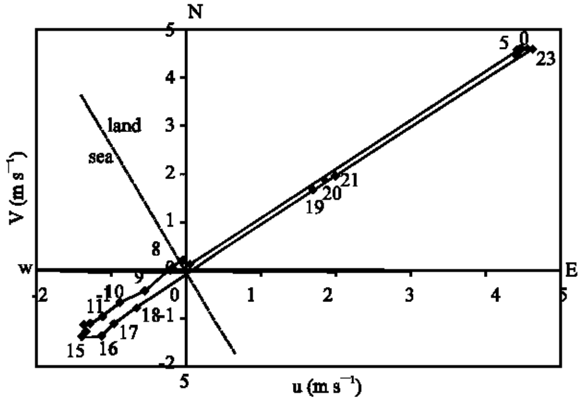

Fig. 10: Same as in Fig. 8, but for Warri

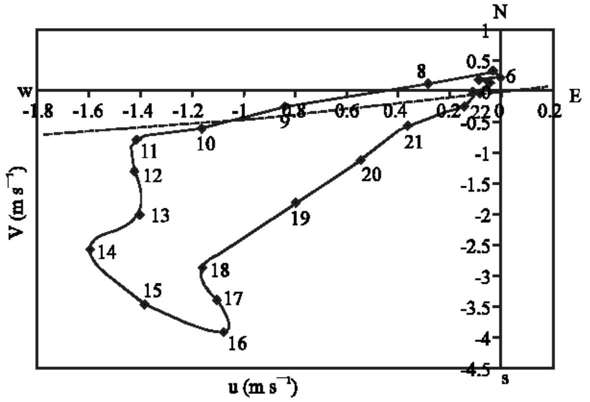

Fig. 11: Same as in Fig. 8, but for Calabar

At Warri (Fig. 10), the shape of the ACR hodograph is completely different from those of Ikeja and Port-Harcourt. The hodograph is not a circular ellipse but is elongated. During the night (1900-0700 Z), the wind vectors are from NE. The land breeze displays a high steadiness with wind strength of about 4.7 ms^{-1}. The onset of the sea breeze is first noticed at about 0800 Z as a weak flow. The sea breeze commences fully at 0900Z from SW. The strength of the wind is about 3 times weaker than the nocturnal flow and displays a high degree of south-westerly steadiness, blowing for nearly 11 h. Both land and sea breeze flows are perpendicular to the shore. It is to be noted that both the western and the southern parts of Warri are facing the ocean due to the shape of the coast. Hence, both sides will be affected by any development from the sea (e.g., sea breeze). In fact, the western part is closer to the sea (31 km) than the southern part, which is 75km away from the coast. In this study, the sector of sea breeze is taken as the side that is nearer to the coastline. Consequently, at Warri, two sea breezes are likely to develop, like any other regions where the coastline changes direction (Abbs and Physick, 1992). Furthermore any sea breeze that develops at the western side affects the station earlier than that from the south. The weak strength of the merging sea breeze flow is a result of the interaction between the two sea breezes. This is consistent with the observation of Xian and Pielke (1991) who suggested that the intensity of merging sea breezes is always weak and that the sea breeze cells over smaller landmasses usually meet before 1200 LST. One would have thought that Warri should experience a late onset of sea breeze because of its location and the merging sea breeze. But it is not so, possibly because Warri is surrounded by a large landmass.

The case of Calabar, which is located closely to mountains, is presented in Fig. 11. At this station, the nocturnal wind vectors are mainly from the N. They blow perpendicular to the shore and are highly steady. The strength of the night time wind vectors is very weak despite the fact that land and downslope breezes exist. The onset of the diurnal flow is observed at 1000Z as a rather weak flow which, as the temperature gradients between land and sea increases, the wind vectors in Calabar, which represents the combination of sea and upslope breezes, continued to increase in strength during the afternoon with a maximum at 1600 Z, after which, there is a decrease in wind strength until 2200 Z. The diurnal flow is from W to SW and it has strength of about 4 $m\ s^{-1}$, which is almost three times stronger than its nocturnal counterpart. The onshore winds blow for almost 13 h.

The reason for the high strength of the onshore wind vectors is the position of the station. Calabar is located at a point bordering the Gulf of Guinea, which makes a concave curvature to the immediate south of the station (Adefolalu, 1984). Also, it is surrounded by Great Kwa and Calabar rivers from the southeast to west. Away from the east, beyond the borders of Nigeria, are the Cameroon Mountains and the Highland ranges, which stretches from north to south. This location makes Calabar distinct from other stations. The sea breezes from the ocean and the smaller water bodies together with the terrain effects of the Cameroon Mountains and the highland ranges directly influences the strength of the diurnal flow.

CONCLUSION

In this study, the characteristics of sea breeze over the Nigerian coast have been presented. The observational data consist of monthly Sea Surface Temperature (SST), hourly surface air temperature, wind speed and direction for 1979-1983. The surface data are analysed to identify the sea breeze days, while the wind, temperature and hodograph pattern for those sea breeze days were used to study their characteristics. Results from the analysis show that:

The observations are consistent with the established fact that thermal difference between land and sea is the driving force for the development of sea breeze. However, the thermal difference is higher during the dry season than in wet season.

On average, the onshore (day-time) flows are stronger than their offshore (night-time) counterpart.

The highest frequency of occurrence of sea breeze occurs in March, while the minimum occurs in August. The frequency of occurrence of sea breeze depends largely on the distance of the station from the coast and the shape of the local coastline.

The mean onset time is about 1200LST, the mean cessation time is about 2200 LST and the mean duration is about 11 h.

The sea breeze hodographs show both clockwise and anticlockwise rotation.

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