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Climatological study of sea and land breezes over Bombay

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ABSTRACT. In the present study, the various aspects of the local winds at Santacruz — sea and land breezes — their frequency, times of onset, accompanying temperature drop and changes in relative humidity have been statistically analysed. The mean monthly surface and upper winds up to 2·1 km have also been studied and the results are discussed.

1. Introduction

Studies of local wind have been made by Ramanathan (1931) for Poona, Ramdas (1932) for Karachi, Roy (1941) for Madras and more recently by Sajnani (1956) for Ahmedabad. The present study for the city of Bombay is based on the autographic charts of Santacruz for the years 1961 to 1964.

The Santacruz Observatory (Lat. 19°7'N, Long. 72°51'E) is in the northern suburb of Bombay city which is on the western coast of the Indian peninsula.

Although the statistical analyses are of limited use for forecasting purposes; they provide the necessary background for development of any theoretical or empirical method for forecasting. In the present study, the various aspects of local winds — sea and land breezes — their monthly frequency, time of onset accompanying temperature drop and changes in relative humidity have been statistically analysed. The mean monthly surface and upper winds upto 2·1 km have been studied with a view to get a rough idea of the component of the local winds at different heights.

The actual wind at the surface and in lower level of atmosphere at a coastal place can be taken as a composite of the gradient and the local wind. The diurnal changes in surface wind are further complicated by the stability — instability in the lower levels which inhibits the mixing during the nights with the upper winds and facilitates the same in the hotter parts of the day. However, the name 'sea breeze' is generally applied to that manifestation of the local wind, which sets in from sea on land generally in the late forenoon or afternoon with a change in direction of the wind and usually in wind speed also.

The land breeze at Bombay also seems to have a component due to katabatic winds from neighbouring mountains; but however the two parts could not be identified separately or even roughly estimated. Hence in the following discussion, the term 'land breeze' is applied to the composite wind of the above mentioned two local wind components.

2. Data and Climatological analysis

The surface data are obtained from the autographic charts of Dines P.T. anemograms Indian standard type wet and dry bulb thermograms and hair hygrograms. The upper air data used are 00 GMT and 12 GMT rawin data.

The above data of Santacruz for 1961 to 1964 have been analysed and the results are summarised below.

(*a*) *Surface wind* — Along the Konkan coast surface gradients are north to south from November to February, the gradient winds have an easterly component during these months. The pressure gradient is reversed in summer months and gradient winds have a westerly component.

During March and October the pressure gradients along the coast are weak. Table 1 gives the monthly average number of days with typical wind shift associated with sea breeze and of days of continuous winds from the sea. During the months of October through April, the phenomenon of diurnal wind shifts is a regular occurrence. The table also shows that Bombay experiences winds from the sea for a few hours practically on every day of the year during this period.

In Table 2 the monthly frequency of the times of onset of the sea breeze from October through May have been given. It is seen from the table that as the insolation increases during the summer months the onset occurs earlier. It is also seen that the variability is greater in autumn and winter months than in summer, showing thereby that the onset is controlled in winter more by the prevailing gradient wind than by the diurnal

TABLE 1

Average number of days of sea breeze during different months

(1961—1964)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
With typical wind shift associated with sea breeze	23·00	28·25	26·75	28·00	27·00	29·50	25·50	10·25
With continued winds from sea	5·50	00·00	1·25	0·75	0·50	0·75	3·75	20·75
With no winds from the sea	1·50	1·25	3·00	2·25	0·75	0·75	0·75	00·00
Total	30·00*	29·50*	31·00	31·00	28·25	31·00	30·00	31·00

*Excluded the day of missing and doubtful data

TABLE 2

Average number of occasions of the setting in of sea breeze at different hours of the day

Hours (IST)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Before 1000	0·3	—	—	0·3	0·5	1·3	7·5	5·3
1000-1059	3·0	0·3	1·0	2·0	1·7	8·3	11·7	3·7
1100-1159	6·3	1·7	2·7	5·0	9·5	14·5	5·7	0·7
1200-1259	2·0	6·3	4·5	8·5	9·3	4·3	0·5	0·3
1300-1359	4·7	10·7	6·7	5·3	3·7	1·3	—	0·3
1400-1459	4·3	5·5	8·0	4·7	1·5	—	—	—
1500-1559	0·7	2·3	3·0	1·5	0·7	—	—	—
1600-1659	2·0	1·3	0·3	0·7	—	—	—	—
1700-1759	0·7	0·3	0·5	—	—	—	—	—
Mean	13·40	13·54	13·36	12·58	12·34	11·36	10·05	10·04

heating. The reverse appears to be true in summer months.

Table 3 gives frequency of duration of winds from the sea during different months. The duration of sea breeze varies considerably from day to day in every month but there is a tendency for the duration to be longer in the hotter months and shorter in the cooler months, which is in keeping with the thermal aspects of sea breeze.

Tables 4 and 5 give the frequencies of the direction and speed of sea breeze at the time of onset in different months. It is seen that the predominant direction from which the sea breeze sets in is WNW'ly and it sets in generally with an initial speed of about 15 kmph.

Compared to sea breeze the land breeze is a much weaker wind. It invariably sets in from a direction between 60 to 100 degrees. The speed is generally 2 to 6 kt; but on rare occasions the speeds are slightly higher. The occurrence of land breeze is fairly regular in winter months. Table 6 gives the monthly frequency of occurrence of land breeze. The land breeze generally sets in during early hours. Table 7 gives the average number of occasions of setting in of the land breeze during different hours in each month. As in the case of sea breeze, the variability of onset time is greater in the winter months than in the summer months. It also sets in earlier in the cooler months.

(*b*) *Temperature and Relative Humidity* — The onset of sea breeze has a profound influence on the temperature of the day. The onset is generally accompanied by the fall in temperature of the order of 2 to 3°C. The onset also arrests further rise in temperature during rest of the day on most occasions. On days when sea breeze sets in late the fall in temperature is greater. Table 8 gives the monthly average number of days with temperature

TABLE 3

Frequency of the duration of sea breeze

(Based on 2-year data 1963-1964)

Duration (IST)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
< 3 hours	2·0	0·5	—	2·5	1·5	1·0	—	—
0300-0429	—	1·5	3·5	5·0	2·0	1·0	—	—
0430-0559	1·5	3·0	4·0	7·5	6·0	2·0	1·0	—
0600-0729	3·5	8·5	8·5	3·5	3·0	3·0	0·5	—
0730-0859	6·0	12·0	7·5	3·5	5·5	6·5	1·5	—
0900-1029	6·0	2·0	3·0	4·5	6·0	8·0	6·0	—
1030-1200	—	—	0·5	1·5	4·5	4·0	6·5	—
> 12 hours	1·5	—	—	—	—	3·0	10·0	11·0
Mean	7·48	7·18	6·58	6·27	7·47	8·36	11·16	>12

TABLE 4

Average monthly frequency of direction of sea breeze at the time of onset in different months

Wind direction (degrees)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
< 240	—	—	—	—	—		—	—
241-260	2·5	7·0	3·7	2·5	3·7	4·3	5·5	1·3
261-280	7·3	8·3	11·5	7·0	12·3	12·5	12·3	2·5
281-300	4·0	4·0	3·3	5·5	4·5	4·0	2·5	3·0
301-320	4·5	5·5	4·2	10·5	7·0	7·3	2·3	3·0
321-340	4·0	3·3	3·2	2·5	2·1	1·5	3·0	0·5
341-360	0·7	—	—	—	—	—	—	—
Average	292	276	284	303	284	283	278	288

TABLE 5

Monthly frequency of the speed of sea breeze at the time of onset

Wind speed (km/hr)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
< 5	—	—	—	—	—	—	—	—
6-10	1·0	0·5	2·0	2·3	2·5	0·7	—	0·5
11-15	5·5	6·7	10·7	12·5	6·7	5·5	3·5	2·7
16-20	15·3	18·7	13·0	12·7	15·0	19·5	18·3	4·0
21-25	1·0	1·5	0·7	0·5	2·5	3·7	3·7	3·0
26-30	0·3	0·3	—	—	—	—	—	—
Average	16·9	16·9	15·4	15·0	16·3	17·1	18·0	17·7

TABLE 6

Frequency of occurrence of land breeze during different months of the year

(Based on data from Jan 1961 to Dec 1964)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
26·0	20·5	22·0	17·3	6·5	No land breeze			3·3	19·5	27·3	26·3

TABLE 7

Average number of occasions of the setting in of the land breeze at different hours of the day

Time (IST)	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Sunset to 2059	—	0·5	1·0	0·5	2·0	1·3	—	0·3	—
2100-2259	0·7	3·7	8·7	5·7	2·3	4·3	1·5	—	—
2300-0059	0·5	6·5	8·0	8·0	6·3	5·0	4·7	2·3	—
0100-0259	1·3	4·7	5·0	6·7	4·7	3·7	5·7	6·0	1·7
0300-0459	0·7	1·3	2·5	3·3	4·0	2·3	6·5	5·5	3·0
0500 to sunrise	—	1·7	2·0	2·0	4·7	4·0	3·5	4·3	1·7

falls of different magnitude with the onset of sea breeze.

Coming from the water surface the sea breeze naturally has a higher relative humidity than the undisturbed air mass at the station. So the onset of sea breeze is accompanied by a rise in relative humidity in all months, the effect being more noticeable in the cooler months. The monthly average number of days with rise in relative humidity of different magnitude accompanying the onset of the sea breeze are shown in Table 9. The table shows wide scatter especially in the winter months. It was noticed that during the winter months even on the days with pronounced relative humidity changes, the relative humidity did not go above 50 to 55 per cent. Apparently the trajectory of the air over the sea surface was not sufficiently long to increase the relative humidity even up to 60 per cent in the lowest levels.

(c) *Mean Vertical Structure*—Estoque (1961) has given a model of vertical circulation of winds of a sea breeze cell. Recently Dixit and Nicholson (1964) and Nicholson (1965) have discussed the character of sea breeze at Bombay based on the observational material collected by the sea breeze traverses of U. S. Weather Bureau Research Flight Facility at and near Bombay during May 1963 and March 1964.

It is seen from Tables 1 and 6 that the land and sea breezes occur on most of the days during the months of January, October, November and December. Also on most days, the sea breeze is quite common in the months of February, March and April. Hence these local wind components should have influence on the mean winds over Bombay in the lower level during the above months. A study of these winds should give an approximate idea of the local wind component at different levels. Such study has been made by Roy (1941) for Madras. Table 10 gives the vectorial difference between the westerly components of the mean winds over Bombay at 00 and 12 GMT at different heights for October through April, *i.e.*,

$$W_d = W_{12} - W_{00}$$

Where W_d is the difference of westerly component at 00 and 12 GMT (W_{00} and W_{12}). It is observed that in the hotter months of April and October the vertical extent of the sea breeze apparently extends right upto 2·1 km and the part of the cycle from land to sea is obviously further aloft. Whereas in cooler months the vertical extent of the winds from the sea seems to fall somewhere between 1·0 and 1·5 km. These results are in general agreement with the schematic pattern of sea breeze cycle discussed by Estoque (1961). The seasonal

TABLE 8

Average number of days with temperature fall of different magnitude caused by the first gust of the sea breeze

Temp. fall (°C)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
0·0 to 0·9	13·5	11·7	11·3	14·0	14·3	19·5	19·7	9·5
1·0 to 1·9	8·7	13·5	12·3	11·3	8·7	9·0	4·7	0·5
2·0 to 2·9	0·5	2·3	2·7	2·5	3·3	1·0	0·7	—
3·0 to 3·9	0·3	—	0·5	0·3	0·7	—	—	—

TABLE 9

Average number of days with rise in relative humidity of different magnitude accompanying the onset of sea breeze

Increase in R.H. (per cent)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
5 or less	5·5	1·3	3·7	5·3	2·0	3·3	11·3	6·5
6 to 10	6·5	.12·0	12·0	13·7	10·3	12·7	9·0	2·7
11 to 15	2·0	4·3	4·3	3·3	4·7	3·7	3·0	0·7
16 to 20	4·5	6·7	3·5	3·5	7·7	5·5	0·5	0·3
21 to 25	2·0	1·5	1·3	0·7	1·7	2·7	0·7	—
26 to 30	1·7	1·0	1·0	0·5	0·7	0·7	0·5	—
31 or more	0·7	1·0	0·7	1·0	0·5	9·7	0·5	—
Average	12·9	13·6	11·7	10·7	13·2	15·7	7·8	5·1

TABLE 10

The difference between the mean westerly component (mps) of 00 and 12 GMT wind in different months of 1956-1960

	Surface	Height (km) a.s.l.				
		0·3	0·6	0·9	1·5	2·1
Oct	3·5	8·4	7·0	5·4	2·6	0·7
Nov	4·4	8·3	5·3	2·4	1·0	—1·2
Dec	4·9	9·2	7·2	4·3	3·2	—1·9
Jan	5·0	9·7	5·5	0·9	—3·5	—2·9
Feb	5·1	8·3	5·9	2·1	—2·5	—3·4
Mar	5·8	8·2	5·4	4·5	—0·6	—1·6
Apr	6·8	8·7	8·0	7·8	7·2	3·0

variation of heights are also in line with the physical processes causing the sea breeze cycle. The observational data presented by Nicholson (1965) and Dixit and Nicholson (1964) show that the sea breeze attains maximum speeds around 0·3 km, a feature also reflected by the data given in Table 10.

3. Conclusion

The mean vertical extent of sea breeze cycle seems to vary month to month being higher in summer months and lower in the winter months. The sea breeze attains maximum speed around 0·3 km. It is apparent from the various tables given in this paper that the climatological background is only of limited help for forecasting purposes.

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