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A study of sea and land breeze over Goa

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ABSTRACT. A statistical analysis of sea and land breeze has been made for Goa. Various aspects, such as, average time of onset, duration, direction at the time of onset and the associated changes in temperature and relative humidity have been studied and the results compared with that of Santacruz. The physical processes taking place have also been discussed.

The main characteristic features are that (i) weaker sea breeze circulation develops over Goa as compared to that over Santacruz, (ii) the surface temperature often continuous to rise and relative humidity often decrease even after setting in of sea breeze and (iii) the maximum strength of sea breeze is at 0.3 km and sharply falls by 0.9 km.

1. Introduction

Studies of local winds have been made by Ramdas (1931) for Karachi, Ramanathan (1931) for Poona, Roy (1941) for Madras, Dixit and Nicholson (1964) and Dekate (1968) for Bombay. Estoque (1962) has developed a theoretical model of sea breeze circulation under different synoptic situations.

The above studies suggest that sea breeze is caused by differential heating of land and sea and it mostly sets in the afternoon. It has some of the characteristics of a cold front. The sea breaze which sets in suddenly, is generally colder, more moist and has a larger velocity than the preceding land breeze. Setting in of sea breeze is thus generally, accompanied by a fall of temperature, rise of humidity, shift of wind direction and increase of wind speed.

The surface wind and temperature constitute important meteorological parameters during landing and take off phases of an aircraft. The knowledge and forecast of surface wind and temperature are of critical value for the present day jet aircrafts and have a great bearing on the safety of aircraft and economy of airlines.

Keeping this in view, a statistical analysis of sea and land breeze over Goa has been made. Various aspects, such as, average time of onset, duration, direction at the time of onset and associated changes in temperature and relative humidity have been analysed to provide climatological background to the forecaster. The physical processes taking place have also been discussed.

The Mormugao Observatory (Fig. 1) is situated on the top of a plateau overlooking Murmugao Harbour down below. It is located at Lat. 15°25′N, Long. 73°47′ E, at an elevation of 60·1 m above mean sea level. The Observatory is at the mouth of the Mormugao Bay formed by the *Zuari* river running from southeast to west with the Arabian Sea to the west of it lying north and south. The terrain is hilly and rocky but there is no hill in the immediate neighbourhood of the Observatory. There is hardly any industry and the territory of Goa is full of lush green vegetation.

2. Data used

The surface data for wind, temperature and relative humidtiy have been analysed for the period 1969 to 1973. The data have been obtained from the autographic records of Observatory at Port Meteorological Office, Mormugao. The upper air data are for the period 1969 to 1971 only and have been obtained from the Office of the Deputy Director General of Observatories (Climatology & Geophysics), Poona.

3. Analyasis and discussion

Surface wind — The average number of days of sea and land breeze during various months, except monsoon period, have been presented in Table 1. It is seen that the frequency of sea breeze is higher in the summer and lower in the winter months. The frequency of land breeze on the other hand is higher in winter months and lower in summer. The average duration of sea and land breeze during various months is presented in Table 2. Duration of sea breeze is more in summer (9-10 hr) and less

TABLE 1

Average number of days of sea land breeze during various months

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Typical wind shift associated with sea/land breeze	21·6/13·8	25·8/21·8	28·8/23·6	24·6/20·4	23·8/20·0	29·6/16·0	27·8/3·8	16·4/6·6
Continuous wind from sea/land	6·0/1·6	1·4/2·4	0/1·6	0/6·4	0/4·4	0/1·2	0/2·2	14·0/0·6
Total	27·6/15·4	27·2/24·2	28·8/25·2	24·6/26·8	23·8/24·4	29·6/17·2	27·8/12·0	30·4/7·2

TABLE 2

Average duration of sea/land breeze during different months

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Average duration	7·1/7·2	7·6/8·8	7·8/9·1	7·9/7·9	8·6/6·8	8·9/4·2	8·9/1.2	10·6/4·8

TABLE 3

Average direction of sea/land breeze and maximum sea/land breeze during different months (at onset)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Sea/land breeze at onset	249/054°	230/048°	225/048°	235/031°	235/039°	229/054°	245/065°	259/058°
Maximum sea/land breeze	256/066°	245/068°	256/065°	257/055°	267/060°	257/071°	250/076°	273/068°

TABLE 4

Average number of days of change in temperature of various magnitudes due to setting in of sea breeze during various months

Temp. change (°C)	Oct		Nov		Dec		Jan		Feb		Mar		Apr		May	
	R	F	R	F	R	F	R	F	R	F	R	F	R	F	R	F
0	4·8	—	3·4	—	4·0	—	2·2	—	2·8	—	4·0	—	4·0	—	4·2	—
⩽ 0·5	4·6	1·0	4·6	3·2	2·6	5·4	6·0	2·6	7·0	2·0	9·4	1·6	10·0	0·6	5·0	0·4
0·6-1·0	5·4	0·8	3·2	2·8	1·4	4·2	5·0	1·8	4·2	0·8	7·0	1·0	8·2	0	3·8	0·6
1.1-2·0	3·2	0·6	1·4	3·6	2·2	5·2	3·4	1·0	5·8	0·6	5·4	0·6	4·6	0	2·0	0·2
2·1-3·0	0·4	0·4	0·4	1·8	0·4	0·6	1·0	1·2	0·8	0	0·4	0·2	0·2	0	0	0·2
>3.0	3·0	0	0	1·4	0·2	0·6	0·2	0	0	0	0	0	0	0	0	0

R—Rise F—Fall

TABLE 5

Average number of days of change in R. H. of various magnitudes due to setting in of sea breeze during different months

Relative humidity (Per cent)	Oct		Nov		Dec		Jan		Feb		Mar		Apr		May	
	R	F	R	F	R	F	R	F	R	F	R	F	R	F	R	F
0	6·8	—	2·0	—	1·6	—	2·2	—	2·8	—	4·0	—	4·0	—	4·6	—
⩽ 0.5	4·2	5·8	8·0	2·6	8·8	1·4	6·0	2·6	7·0	2·0	9·4	1·6	10·0	0·6	3·0	6.2
6-10	1·0	1·8	5·8	0·6	6·0	0	5·0	1·8	4·2	0·8	7·0	1·0	8·2	0	0·8	1.6
11-20	1·2	0	4·8	0	6·4	0	3·4	1·0	5·8	0·6	5·4	0·6	4·6	0	0	0
21-30	0·4	0	1·6	0	2·2	0	1·0	1·2	1·2	0·8	0.4	0·2	0·2	0	0	0
⩾ 30	0	0	0·4	0	0·6	0	0·2	0	0	0	0	0	0	0	0	0

R—Rise F—Fall

TABLE 6

Increase of vapour pressure after setting in sea breeze

Case	Nature	Temp. (TT)	R.H. (%)	Vapour pressure (mb)
Fig. 6	Before onset	29·0	59	23·63
	After onset	30·0	57	24·11
Fig. 7	Before onset	33·8	39	20·52
	After onset	31·3	58	26·51

TABLE 7

Difference between the mean westerly component (mps) of 12 and 00 GMT wind in different months

	Height (km) a.s.l.				
	0·3	0·6	0·9	1.5	2·1
Jan	9·2	6·9	1·6	—0·1	—1.6
Feb	7·9	4·9	2·2	1·0	—2.2
Mar	5·9	5·3	5·5	2·9	—4.5
Apr	9·4	8·2	5·4	0·4	—0.5
May	5·2	3·8	1·3	—1·2	—1.2
Oct	4·5	3·9	1·1	—0·2	—0.1
Nov	7·9	4·5	3·4	—0·7	—2.7
Dec	8·5	3·9	1·7	—0·7	—0.8

in winter (7-8 hr) The average duration of land breeze is 7–9 hours, *i.e.*, more in winter and 4-5 hours, *i.e.*, less in summer. These facts are in agreement with seasonal pressure and wind distribution and their changes over Goa area.

The average time of setting in of sea breeze and land breeze is presented in Fig. 4 and Fig. 5 respectively. The sea breeze sets in earliest in May at 1100 IST, followed by April and October and latest in winter month of December at 1500 IST. The land breeze sets in at about 2330 IST in December followed by October and November and latest in April at about 0500 IST. Thus, during the hot weather period when the synoptic wind is light variable or onshore, the sea breeze sets in early and during the cold weather, period when winds are off shore, the sea breeze sets in late. This is because the seasonal anticyclone over northwest India and consequently the land breeze which is the prevailing wind during greater part of the day is also strongest at that time. Ramdas (1931) has also made similar observation during his

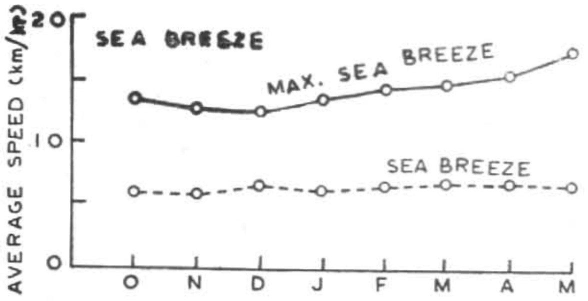
Fig. 1. Map of Goa

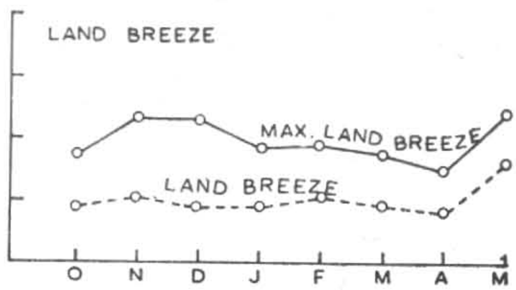
(Reproduced from Tourist map of Goa issued by India Tourism Development Corporation)

study on sea breeze over Karachi. This again is in agreement with the observations of Defant (1951), *i.e.*, whenever prevailing wind is light variable, the sea breeze develops as a small circulation in the immediate vicinity of the shore and whenever the synotptic wind is offshore, the sea breeze develops much out at the sea and advances slowly towards land, reaching the coast much later in the afternoon. It suggests, that , onset of sea breeze and its development depends upon the differential heating of sea and land and on the prevailing synoptic winds.

The average direction of sea breeze at onset and of maximum sea breeze during various months is presented in Table 3. The average direction of land breeze and of maximum land breeze is also presented in Table 3. It is seen that SW/WSW'ly is the predominant direction of sea breeze at the time of onset and maximum sea breeze sets in from WSW/W'ly direction. This suggests that as the circulation becomes more intense it develops a component parallel to the coast due to the effect of coriolis force resulting in the veering of the sea breeze. It is seen from Table 3 that the average direction of land breeze is NNE to ENE and the direction of maximum land breeze is ENE. There is a slight veering tendency for maximum land breeze conforming the effect of coriolis force on the land breeze circulation.

The average speed of sea breeze at the time of onset and the speed of maxiumum sea breeze during various months is given in Fig. 2. It is seen

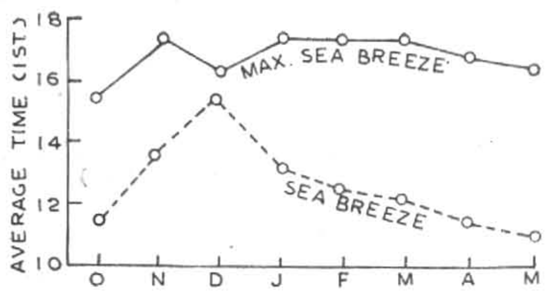


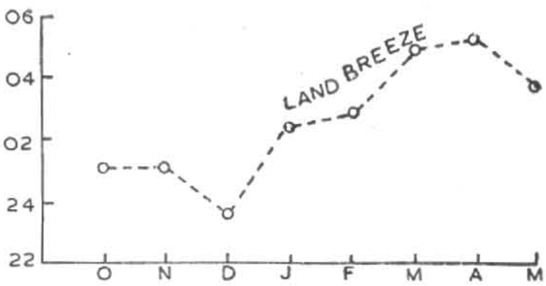


MONTHS

Fig. 2. Average speed of sea breeze at the onset and the speed of max. sea breeze (km/hr) during different months

Fig. 3. Average speed of land breeze at the onset and the speed of max. land breeze (km/hr) during different months





MONTHS

Fig. 4. Average time of setting of sea breeze and of maximum sea breeze during different months

Fig. 5. Average time of setting land breeze during different months and hours (IST)

TABLE 8

Mean maximum and mean diurnal variation of temperature at Santacruz and Mormugao during various months

		Jan	Feb	Mar	Apr	May	Oct	Nov	Dec
Santacruz	(a)	30·6	31·6	32·8	33·3	33·2	32·4	33·1	32·1
	(b)	16·3	16·9	20·2	23·8	26·2	22·9	19·8	17·7
Goa	(a)	29·7	29·0	30·0	30·9	31·3	29·8	31·0	30·5
	(b)	8·3	7·1	6·1	4·8	4·4	5·9	8·2	9·07

(a) Mean maximum temperature (b) Mean diurnal variation

that the average speed of sea breeze at onset is 6 kmph and the maximum average speed is 12-17 kmph. Unlike Santacruz, change from land to sea breeze in the case of Goa is not abrupt. Nicholson (1965), while studying sea breeze at Santacruz, has observed that the shift from offshore wind to onshore wind is extremely sharp, the change being more than 15 kt. Dekate (1968) has shown that the average speed of sea breeze at onset for Santacruz is more than 15 kmph. It may be stated that the sea breeze circulation is primarily dynamical response to differential heating caused by two distinct oscillational regimes (land and sea) with large difference in their amplitudes. To explain the phenomenon of weaker and less abrupt sea breeze at Mormugao as compared to that of Santacruz, Table 8 may be referred to. It is clearly seen from the table that mean maximum temperature and the diurnal variation of temperature at Santacruz are of higher order as compared to that of Goa. Therefore, weaker sea breeze circulation develops over Mormugao, as compared to Santacruz which is situated about 4 km inland. From his studies of sea breeze over Karachi Ramdas (1931) has also observed that the sea breeze front is diffuse near the coast and the transition from land breeze to sea breeze becomes more and more marked as the sea breeze proceeds inland.

The average speed of land breeze at the time of onset and the speed of maximum land breeze during different months is presented in Fig. 3. The average speed of land breeze during various months is 5 kmph and average maximum speed varies from 8 to 12 kmph.

(b) Temperature and relative humidity

The surface temperature at a coastal station is greatly influenced by the sea breeze circulation. It is generally accepted that with the onset of sea breeze the temperature falls and the relative humidity increases. The average number of days of change in temperature and relative humidity of various magnitudes due to setting in of sea breeze during various months are given in Tables 4 and 5 respectively. It is seen from Table 4 that at Goa highest frequencies of fall in temperature occur during December when sea breeze sets in late (Fig. 4), and lowest frequency of fall or almost negligible fall in temperature occurs during hotter months of April and May when sea breeze sets in earliest (Fig. 4). It is seen that during hot weather period the temperature continues to rise even after setting in of sea breeze. Autographic charts of a typical case are presented in Fig. 6. It may be stated that during summer, the sea breeze sets in earlier than the time of maximum temperature. During this period, there is higher rate of insolation causing higher rate of heating. Also, the onset of sea breeze at Goa is weak; therefore, the fall in temperature caused by the onset of sea breeze is over-compensated by the rise in temperature due to insolation, and hence, the temperature continues to rise during hot weather period. In winter, the sea breeze sets in later than the time of maximum temperature; also there is less of insolation during this period and hence, onset of sea breeze causes sharp fall in temperature during winter months even though the sea breeze is weak. Autographic charts of typical case are presented in Fig. 7. It is seen from Table 5, that relative humidity decreases on some occasions even after onset of sea breeze. The moisture content of airmass increases with the onset of sea breeze but since the temperature continues to rise even after onset, the relative humidity decreases on these occasions. The fact that the moisture content increases with the onset of sea

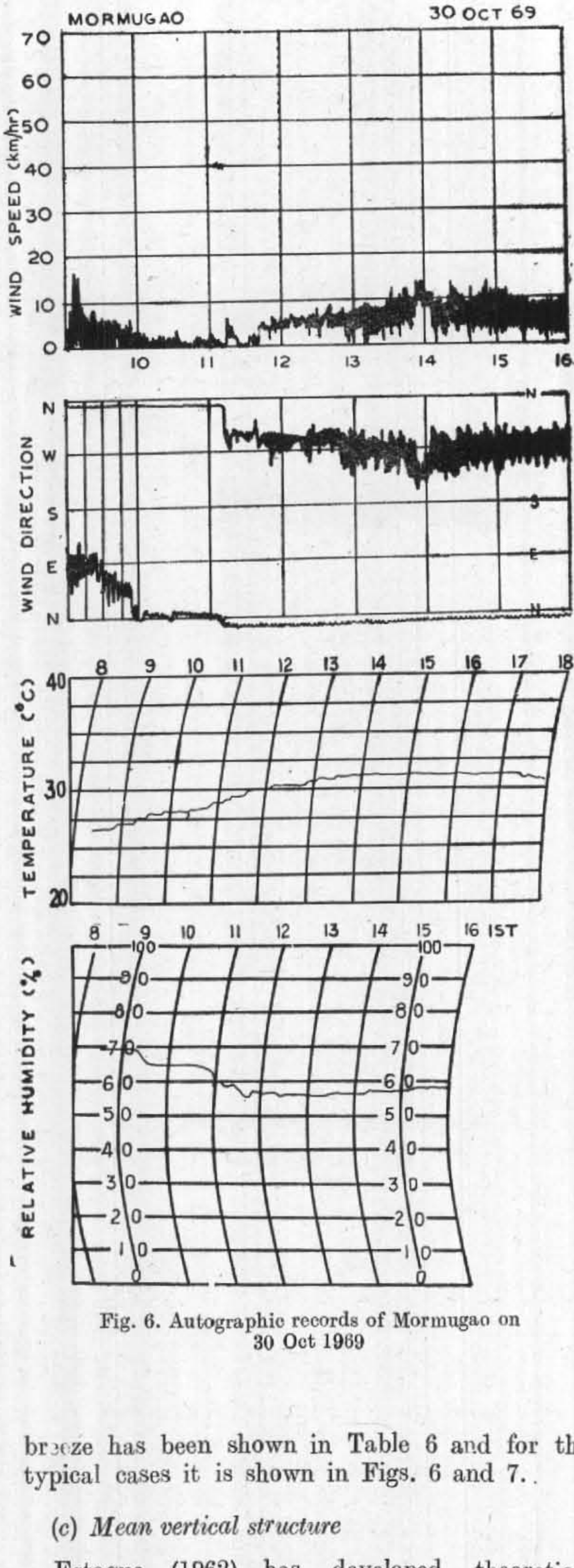


Fig. 6. Autographic records of Mormugao on 30 Oct 1969

breeze has been shown in Table 6 and for the typical cases it is shown in Figs. 6 and 7.

(c) Mean vertical structure

Estoque (1962) has developed theoretical models of sea breeze circulation. Roy (1941) and Dekate (1968) have studied the veritical structure of sea breeze for Madras and Santacruz respectively by taking vectorial differences of mean winds

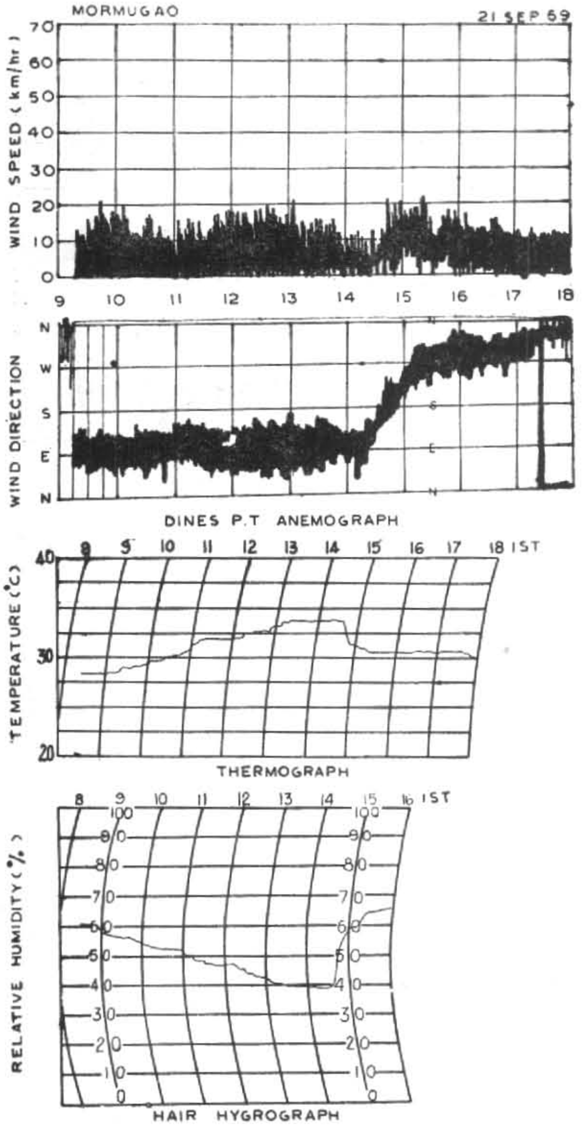


Fig. 7. Autographic records of Mormugao on 21 Nov 1969

for morning and evening ascents. Table 7 gives the vectorial difference between the westerly components of mean winds at different heights over Goa at 12 and 00 GMT, *i.e.*, $W_d = W_{12} - W_{00}$, where W_{12} and W_{00} are the westerly components for 12 and 00 GMT winds respectively. It is seen from the table that the sea breeze circulation in May, October, November, December and January extends between 1·0 km and 1·5 km ; in February, March and April it extends upto 2·1 km and above.

It is also seen from the table that the sea breeze attains its maximum strength at 0·3 km and sharply falls by 0·9 km. This result is in agreement with the findings of Dixit and Nicholson (1964) and Dekate (1968) for Bombay.

4. Conclusions

The main characteristic features of sea and land breeze circulation over Goa are :

(*i*) A weaker sea breeze circulation develops over Goa as compared to that over Santacruz.

(*ii*) The surface temperature often continues to rise even after setting in of sea breeze. The frequency of fall in temperature is highest when the sea breeze sets in late and lowest when the sea breeze sets in earliest.

(*iii*) The relative humidity does not necessarily increase after the onset of sea breeze. This is so because the temperature increases even after onset.

(*iv*) The maximum strength of sea breeze is at 0·3 km and sharply falls by 0·9 km. The circulation generally extends upto 1·5 km only.

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