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An observational study of the Sea Breeze at an Equatorial Coastal station

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ABSTRACT. The paper contains a preliminary study of the sea breeze at Thumba (08°32′ N, 76° 52′E) based on observations on 392 days, spread over a period of three years (1963-1966).

Analysis on hourly wind observation reveals that the northeasterly or northerly land breeze is replaced by westerly or southwesterly sea breeze before mid-day during October to May. It is also seen that November to April are favoured most by the sea breeze at Thumba. Southerly setting, late onset as well as early cessation of the sea breeze have been noticed on a few occasions. The wind is always above 5 kt after the incidence of the sea breeze and it may vary to a maximum speed of 22 kt and oscillates between 180°—300° depending on the prevailing synoptic situation. The vertical extent of the sea breeze is about 1 km and 0·8 km in summer and winter respectively.

The frontal characteristics of the sea breeze are not very marked at Thumba. There is no significant temperature fall associated with the sudden onset of the sea breeze, but slight rise in relative humidity is 5-10 per cent recorded on a few occasions. The reversal of land and sea breeze is illustrated by an example giving hourly tower wind and pilot balloon wind data.

1. Introduction

The sea breeze study is important from the point of view of (*i*) time of onset, (*ii*) maximum intensity, (*iii*) cessation (*iv*) frequency in terms of time, speed and direction and (*v*) the manner in which the land breeze gives way to the sea breeze or *vice versa*, *i.e.*, whether by backing or veering. A knowledge of the shift in wind direction and change in velocity due to the onset of sea breeze and the influence of the time of onset on the direction and speed variation will be of immense help for aviation and naval purposes and for Thumba, especially, it will be useful for wind weighting during rocket launching days.

It has been experienced that the land and sea breezes do not lend themselves to accurate forecasting in terms of the above elements. Sea breeze studies have been done extensively both theoretically and by observation in and outside India by several workers like Estoque, Fisher, Schmidt, Defant, Ramanathan, Ramdas, Roy, Rao and others. However, sea breeze studies over equatorial stations are only very few.

An observational study of the sea breeze was taken up at Thumba, near Trivandrum — an equatorial station (08° 32′N, 76° 52′E) situated on the west coast of India almost at the southern tip of the Peninsula. Besides being a full fledged meteorological observatory with self-recording instruments, facilities for accurate low level wind observations from a 60-ft meteorological pole and a 200-ft meteorological tower with distant indicating wind equipments (DIWE) at seven levels are available at the Thumba Equatorial Rocket Launching Station. For the determination of wind above the level of meteorological tower, pilot balloon observations are taken both by single and double theodolite methods. Self-recording electrical anemographs have been installed very recently at three levels on the met. tower. Hourly wind observations are noted from the wind panel during 0530-2130 IST.

A more or less continuous sea breeze prevails at the station during the southwest monsoon season. The effect of land and sea breezes are more marked during November to April. The characteristics of the sea breeze are found to be different in autumn, winter and summer seasons. November, January and April may be taken as the representative months of the above three seasons for studying the variations in the characteristics of the sea breeze.

2. Data and analysis

The hourly wind observations from the met.pole and met. tower were utilised in assessing the main elements of the sea breeze. 392 instances of sea breeze days spread over a period of three years (1963—1966), as shown in Table 1, were analysed in this study. Doubtful cases and days for which no observations were available have been omitted.

For determining the time of onset, maximum intensity and the cessation of the sea breeze, the data have been classified into 4 time intervals and indicated under column 1 of Table 2. The number of occasions in each case and the percentage frequencies during Autumn, Winter and Summer are given in Table 2. Table 3 presents the frequency distributions of wind directions at 10° intervals from 180° to 300° for the above seasons. The sea breeze wind has been analysed in six speed groups as shown in Table 4.

The influence of the time of onset of sea breeze on direction is studied in four time intervals and

TABLE 1

No. of sea breeze days during 1963-1966

(November to April utilised for analysis)

	Nov	Dec	Jan	Feb	Mar	Apr	Total
1963	—	24	—	—	—	—	24
1964	20	25	30	21	29	30	155
1965	16	15	27	26	24	19	137
1966	—	—	30	26	30	—	86
Total	36	64	87	73	83	49	392

TABLE 2

Frequency of time of onset, maximum intensity and cessation of sea breeze in Autumn, Winter and Summer

Time (IST)	Autumn (Oct-Nov)	Winter (Dec-Feb)	Summer (Mar-May)	Total
	ONSET OF SEA BREEZE			
Before 1000	17 (50)	22 (10)	42 (33)	81 (21)
1000—1059	6 (18)	47 (20)	40 (32)	93 (24)
1100—1159	9 (26)	128 (57)	46 (32)	183 (47)
After 1200	4 (6)	27 (12)	4 (3)	35 (8)
	MAXIMUM INTENSITY			
Before 1300	3 (9)	16 (7)	19 (16)	38 (10)
1300—1359	8 (22)	47 (20)	39 (29)	94 (24)
1400—1459	18 (50)	129 (58)	51 (38)	198 (50)
After 1500	7 (20)	42 (15)	23 (18)	62 (16)
	CESSATION OF SEA BREEZE			
Before 1900	13 (39)	40 (18)	22 (16)	75 (19)
1900—1959	6 (18)	31 (13)	9 (9)	46 (12)
2000—2059	5 (15)	54 (23)	33 (27)	90 (23)
After 2100	12 (37)	101 (46)	68 (50)	181 (46)

Figures given in brackets indicate percentage frequency

the results are presented in Table 5. The variations of wind speed with the time of maximum intensity is investigated in six groups. Table 6 gives the results obtaind in this respect.

The vertical extent of the sea breeze is estimated by analysing the mean monthly velocity components of 00 and 1200 Z winds normal to the coast line up to 3-km height. The tower and pilot balloon wind data relating to this aspect are shown in Tables 7 and 8 respectively.

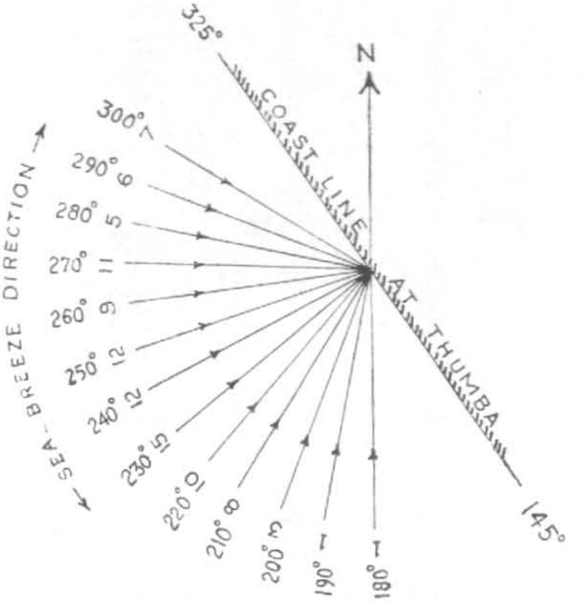

Fig. 1. Normal frequency diagram of sea breeze direction with respect to the coast line (145°—325°) at Thumba

3. Discussion

The chief characteristics of the sea breeze are discussed briefly below.

(*i*) *Time of onset* — Instances of onset of the sea breeze earlier to 1000 IST are more in autumn and summer seasons. The favourable time of onset during winter is 1100—1159 IST and late setting, after 1200 IST is possible in rare cases.

(*ii*) *Maximum intensity* — The sea breeze attains full strength in the afternoon. Maximum instances are noticed during 1400—1459 IST in all the seasons. The maximum vertical wind shear at 1430 reported by Rao *et al.* (1965) supports the above inference. In summer, it may be slightly earlier.

(*iii*) *Time of cessation* — Sea breeze becomes less marked after 2100 IST. Cases of sea breeze cessation after 2100 IST are more or less equally distributed in all the seasons with a slightly higher percentage in summer. The early withdrawal, *i.e.*, before 1900 IST, may be as a result of local thunderstorms in the evening which are quite frequent in autumn and summer.

(*iv*) *Direction* — The normal distribution of sea breeze direction is shown in Fig. 1. The coastline at Thumba is also marked therein. It is quite evident that the sea breeze is normal to the coast line at about 230° with a more or less symmetrical distribution. The main features of sea breeze

TABLE 3

Frequency of direction of sea breeze

Season	Direction in degrees													Total
	180	190	200	210	220	230	240	250	260	270	280	290	300	
Autumn (Oct, Nov)	—	—	—	—	1 (3)	2 (6)	2 (6)	4 (10)	9 (25)	2 (6)	3 (8)	6 (16)	7 (20)	36
Winter (Dec—Feb)	3 (2)	1 (1)	8 (4)	21 (9)	34 (15)	40 (17)	36 (15)	28 (12)	16 (8)	17 (8)	8 (4)	5 (2)	7 (3)	224
Summer (Mar—May)	—	1 (1)	5 (4)	10 (7)	5 (3)	18 (13)	8 (6)	15 (12)	11 (10)	23 (21)	9 (8)	13 (10)	14 (9)	132
Total	3 (1)	2 (1)	13 (3)	31 (8)	40 (10)	60 (15)	46 (12)	47 (12)	36 (9)	42 (11)	20 (5)	24 (6)	28 (7)	392

Figures given in brackets indicate percentage frequency

TABLE 4

Frequency of speed of sea breeze

Season	Range of speed (kt)						Total
	5—7	8—10	11—13	14—16	17—19	20—22	
Autumn (Oct, Nov)	—	3 (9)	10 (28)	16 (44)	7 (20)	—	36
Winter (Dec Jan, Feb)	15 (17)	40 (23)	98 (42)	50 (21)	6 (3)	3 (1)	224
Summer (Mar, Apr, May)	—	29 (21)	52 (42)	36 (27)	9 (7)	6 (4)	132
Total	15 (4)	72 (18)	160 (40)	102 (26)	22 (6)	9 (1)	392

Figures given in brackets indicate percentage frequency

TABLE 5

Frequency of effect of time of onset on sea breeze direction

Time (IST)	Direction in degrees													Total
	180	190	200	210	220	230	240	250	260	270	280	290	300	
Before 1000	—	—	1 (1)	3 (4)	3 (4)	12 (15)	12 (15)	15 (19)	8 (10)	5 (6)	7 (9)	7 (9)	8 (10)	81
1000—1059	—	—	2 (2)	6 (6)	11 (12)	15 (16)	8 (9)	9 (10)	12 (13)	11 (12)	7 (8)	5 (5)	7 (8)	93
1100—1159	3 (2)	2 (1)	8 (4)	20 (11)	21 (12)	29 (15)	19 (10)	20 (11)	16 (9)	22 (12)	5 (3)	10 (5)	8 (4)	183
After 1200	—	—	2 (6)	2 (6)	5 (14)	4 (1)	7 (20)	3 (9)	—	4 (11)	1 (3)	2 (6)	5 (14)	35

Figures given in brackets indicate percentage frequency

TABLE 6

Frequency of effect of time of maximum intensity on sea breeze wind speed

Time (IST)	Wind speed (kt)						Total
	5—7	8—10	11—13	14—16	17—19	20—22	
Before 1300	—	13 (16)	15 (10)	10 (10)	2 (8)	—	40 (10)
1300—1359	—	8 (10)	48 (30)	25 (24)	5 (23)	4 (44)	90 (23)
1400—1459	11 (73)	57 (67)	74 (46)	48 (47)	9 (42)	3 (33)	202 (51)
After 1500	4 (27)	6 (7)	23 (15)	19 (19)	6 (24)	2 (23)	60 (15)
Total	15 (4)	84 (21)	160 (40)	102 (26)	22 (6)	9 (2)	392

Figures given in brackets indicate percentage frequency

TABLE 7

Difference between the mean velocity components of 00 and 12 GMT winds normal to the coast line at different levels on the Met. Tower

	Height in ft						
	8	33	58	83	100	136	200
January	2·9	9·5	10·5	13·5	11·5	10·0	11·9
February	3·9	10·0	10·4	9·9	11·8	11·9	10·9
March	3·7	9·5	11·0	14·3	12·3	11·3	12·4
April	4·7	9·2	9·9	10·9	10·4	10·7	11·1
May	3·2	7·9	7·5	13·0	12·4	14·3	16·0
June	2·3	4·0	3·2	5·9	5·8	3·5	4·9
July	3·2	4·6	4·2	5·6	6·7	0·2	5·4
August	2·6	4·8	3·9	4·7	6·3	0·6	6·8
September	3·3	7·4	4·8	7·4	8·6	8·7	10·1
October	4·5	7·5	10·3	6·9	9·7	10·7	9·7
November	3·1	7·0	7·5	7·5	7·3	7·4	10·0
December	2·8	6·5	10·3	7·2	6·9	7·4	7·4

All values are negative

direction are (a) a bias for 260° and 300° during autumn which shift to 230° and 270° in winter, (b) southerly setting in winter and (c) more than two favourable direction 210°, 230°, 250° and 270° in summer.

(*v*) *Speed*—The breeze wind speed is always above 5 kt and may vary upto a maximum 22 kt. It is quite strong during autumn and relatively light, but more pronounced in winter due to clear skies. Wind speed above 20 kt and below 8 kt are observed in a few cases in winter and summer. The most favourable speed is 10–15 kt.

(*vi*) *Influence of time of onset on initial direction*—The initial direction of the sea breeze is found to depend on the time for onset. The earlier the onset the more northerly is the component of sea breeze.

(*vii*) *Strength of sea breeze in terms of time*—The sea breeze attains full strength after 2–3 hours of its incidence. Fig. 2 shows graphically the variation of the sea breeze strength with time. During 1300—1359 IST the speed is more biased to 12 kt. It can assume any speed ranging from 6 to 22 kt during 1400—1459 IST. Another interesting characteristic feature is that the sea breeze has never attained more than 18 kt before 1300 IST.

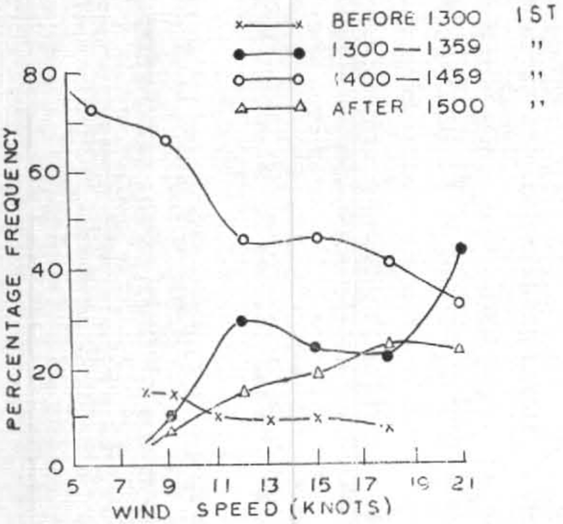

Fig. 2. Frequency distribution of maximum intensity of sea breeze speed at different time intervals

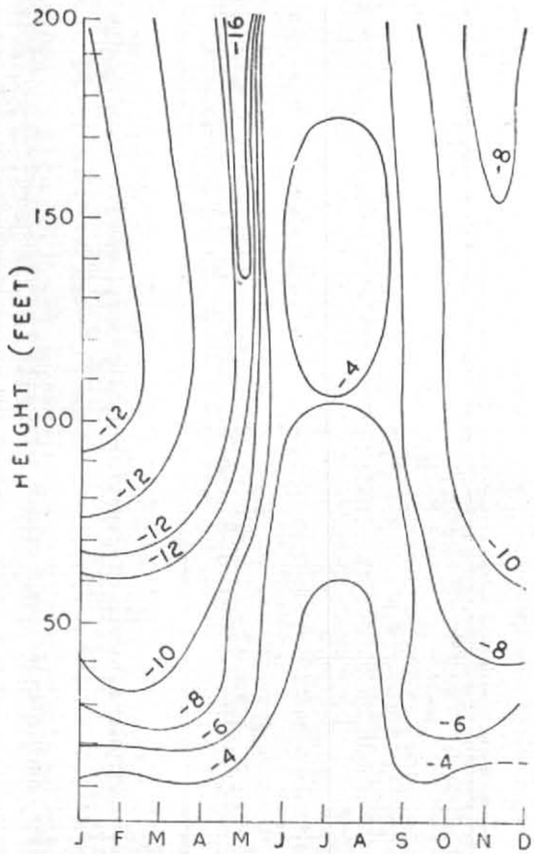

Fig. 3. Mean monthly tower wind analysis upto 200 ft

TABLE 8

Difference between the mean component of 00 and 12 GMT wind normal to the coast line at different heights during 1963-1966

	Height in km							
	Surface	·15	0·3	0·6	0·9	1·5	2·1	3·0
January	—5·7	—13·9	—12·3	—2·8	1·3	3·6	4·5	4·5
February	—5·8	—15·8	—14·7	—12·6	0·2	5·2	4·7	4·6
March	—5·8	—17·9	—14·8	—12·6	—10·2	1·8	3·2	—3·5
April	—3·7	—13·6	—11·1	—9·1	—7·1	—0·8	3·7	0·0
May	—3·2	—11·4	—6·2	—2·1	—1·7	2·3	—2·6	—0·9
June	—2·5	—5·8	—5·7	—0·3	—0·1	—9·5	0·9	—3·8
July	—2·5	—8·4	—3·9	0·8	0·9	1·5	2·3	—1·2
August	—2·8	—6·9	—3·9	—2·3	—3·9	3·8	2·7	1·3
September	—3·3	—8·0	—6·5	—4·3	—2·5	2·0	—0·7	—6·1
October	—3·4	—10·7	—8·4	—6·6	—13·0	—4·5	—6·1	—7·3
November	—4·5	—12·5	—10·9	—3·9	0·2	2·0	1·6	1·3
December	—3·2	—14·2	—12·4	—7·3	0·8	2·4	1·5	0·8

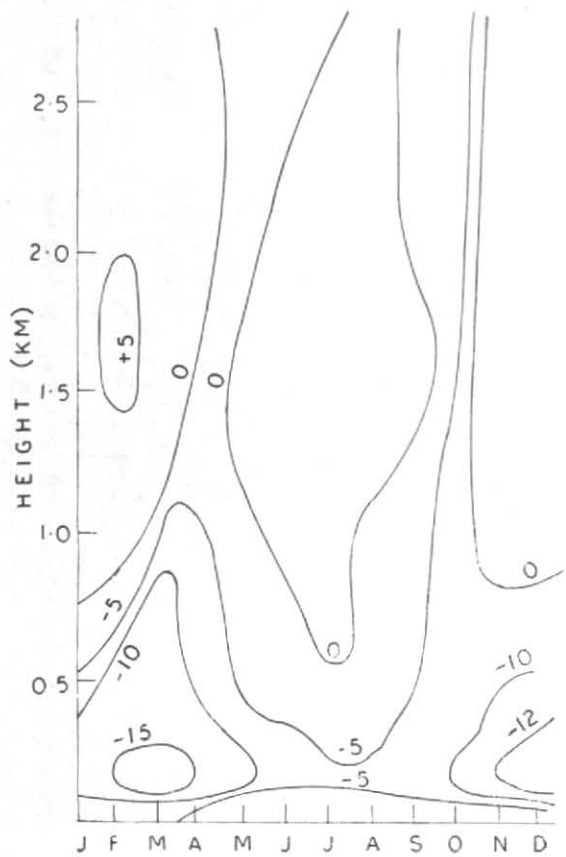

Fig. 4. Mean monthly upper air analysis upto 3 km

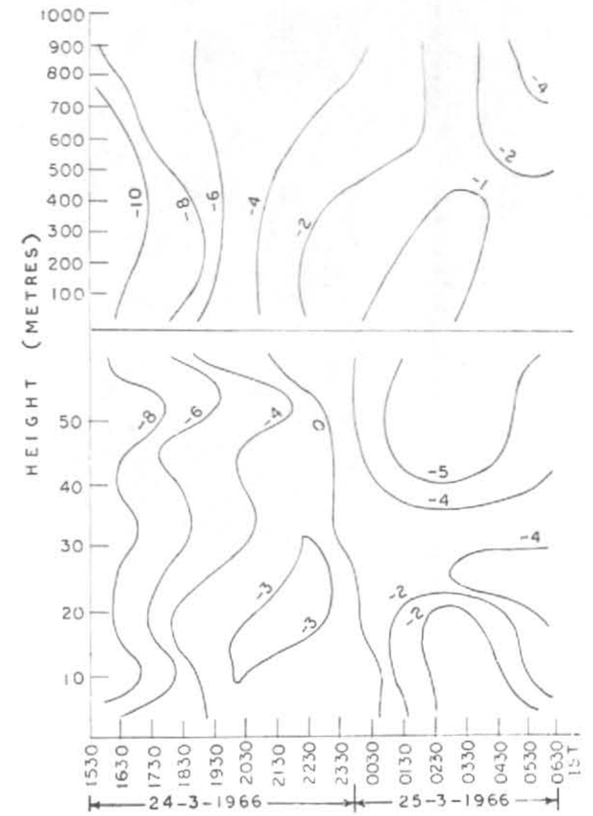

Fig. 5. Hourly Tower wind and Pilot Balloon wind analysis from 1530—0630 IST on 24—25 March 1966

(*viii*) *Vertical extent* — A low level wind analysis of the mean monthly difference in the velocity components of 00 and 12 GMT winds at various levels on the met. tower, normal to the coast line is presented in Fig. 3. The sea breeze effect is more pronounced at a level of about 50 ft above ground during October to May. A similar upper air analysis upto 3 km is shown in Fig. 4. The sea breeze extends to about 1 km during summer. In winter it is upto 0·8 km only. Maximum wind speed is at a height of 150 m above ground. The upper air analysis confirm the favourable months for sea breeze as October to May.

4. Reversal of land and sea breeze

The manner in which the sea breeze gives way to the land breeze or *vice versa* — whether by backing or veering has been investigated. Generally at Thumba, the sea breeze sets in by backing through north and veers in course of time when the prevailing wind is northerly or northeasterly. This is true in majority of the cases. When it is calm or easterly, land breeze may give way to sea breeze veering through south. Several previous studies of Schmidt (1947) and Defant (1951) have indicated that the direction of sea breeze veers with time. This is found to hold good in the case of the equatorial coastal station Thumba also.

The hourly tower wind and pilot balloon observation of 24-25 March 1966 (from 1530 to 0630 IST) given in Table 9 reveals the reverse of land and sea breezes. The velocity component normal to the coast line upto 900 m are analysed against time and shown in Fig. 5. The sea breeze ceased at about 2100 IST giving way to the land breeze.

5. Frontal characteristics of sea breeze

Sudden onset of sea breeze is usually accompanied by a fall in temperature, rise in humidity, shift in wind direction and increase in wind speed. The thermograph of Thumba do not show any appreciable fall in temperature at the time of onset of

TABLE 9

Tower wind and Pilot Balloon wind observations at Thumba to show vertical wind profile on 24-25 March 1966

Time (IST)	Height (metres a.g.l.)											
	Tower								Pilot Balloon			
	2	10	18	25	30	41	48	61	150	300	600	900
1530	315/08 (—1·4)	295/14 (—7·0)	300/14 (—5·9)	295/17 (—8·5)	280/15 (—8·6)	290/16 (—9·2)	275/16 (—12·3)	295/18 (—9·0)	287/21 (—12·8)	286/20 (—10·7)	290/14 (—8·6)	296/17 (—8·5)
1630	315/10 (—1·7)	280/14 (—9·9)	290/13 (—7·5)	290/14 (—8·0)	280/12 (—8·5)	300/15 (—6·3)	285/14 (—10·7)	300/14 (—5·9)	293/17 (—9·1)	290/20 (—11·5)	297/26 (—11·5)	— —
1730	290/08 (—4·6)	290/14 (—8·0)	300/12 (—5·1)	295/15 (—7·5)	280/11 (—7·8)	300/14 (—5·9)	280/14 (—9·9)	295/15 (—7·5)	289/15 (—8·6)	295/16 (—10·3)	292/09 (—4·8)	— —
1830	290/08 (—4·6)	295/12 (—6·0)	305/10 (—8·4)	300/12 (—5·1)	280/10 (—7·1)	300/12 (—5·1)	290/11 (—6·3)	300/12 (—5·1)	290/17 (—9·8)	285/13 (—8·4)	290/12 (—6·9)	— —
1930	290/05 (—2·9)	315/08 (– 1·4)	300/09 (—3·8)	300/11 (—4·6)	280/07 (—4·9)	300/11 (—4·6)	290/11 (—3·3)	310/11 (—2·8)	— —	— —	— —	— —
2030	290/04 (—2·3)	305/09 (—3·1)	305/08 (—2·7)	305/11 (—3·8)	290/09 (—5·2)	310/10 (—2·6)	290/10 (—5·7)	310/10 (—2·6)	290/09 (—4·5)	303/12 (—4·6)	304/11 (—3·8)	303/10 (—3·4)
2130	315/05 (—0·9)	310/07 (—1·8)	310/07 (—1·8)	305/12 (—4·1)	300/08 (—3·4)	315/10 (—1·7)	295/09 (—4·5)	315/10 (—1·7)	301/10 (—2·7)	303/11 (—3·4)	303/11 (—4·2)	318/17 (—4·2)
2230	360/02 (—1·1)	310/06 (—1·6)	310/06 (—1·6)	305/09 (—3·1)	300/07 (—3·0)	315/10 (—1·7)	300/09 (—3·8)	320/10 (—0·9)	— —	— —	— —	— —
2330	360/02 (—1·1)	020/02 (—0·8)	015/02 (—0·8)	005/05 (—3·2)	350/03 (—1·3)	360/05 (—2·9)	340/06 (—1·6)	355/07 (—3·0)	320/12 (—1·0)	320/14 (—1·2)	315/14 (—2·4)	315/09 (—1·6)
0030	Calm (0·0)	025/01 (—1·7)	020/03 (—2·5)	010/02 (—1·4)	355/04 (—2·0)	005/06 (—3·9)	350/06 (—2.5)	005/07 (—4·5)	323/11 (—0·5)	320/14 (—1·2)	313/14 (—3·0)	308/14 (—4 2)
0130	360/04 (—2·3)	020/04 (—3·3)	340/05 (—1·3)	360/06 (—3·4)	350/05 (—2·1)	010/7 (—4·9)	345/08 (—2·7)	360/09 (—5·2)	316/13 (—2·3)	316/14 (—2·4)	307/14 (—4·2)	304/14 (—4·8)
0230	020/03 (—2·5)	020/03 (—2·5)	350/04 (—1·7)	010/05 (—3·5)	350/05 (—2·1)	010/06 (—4·2)	350/07 (—3·0)	005/08 (—4·5)	330/11 (—1·0)	326/12 (0·0)	317/13 (—1·6)	314/13 (—1·1)
0330	025/02 (—1·7)	040/03 (—2·9)	025/02 (—1·7)	030/06 (—5·4)	015/02 (—1·5)	030/07 (—6·3)	360/07 (—4·0)	015/08 (—6·1)	329/10 (—0·9)	324/12 (0·0)	316/13 (—1·4)	320/13 (—0·9)
0430	360/01 (—0·6)	015/02 (—1·5)	350/04 (—1·5)	005/07 (—4·5)	350/06 (—2·5)	005/08 (—5·1)	350/08 (—3·4)	360/09 (—5·2)	318/11 (—1·4)	316/15 (—2·4)	312/15 (—3·2)	312/14 (—3·0)
0530	360/02 (—1·1)	015/03 (—1·9)	360/05 (—2·9)	360/07 (—4·0)	355/07 (—3·5)	010/08 (—5·7)	350/09 (—3·8)	360/10 (—5·7)	— —	— —	— —	— —
0630	350/03 (—1·3)	020/04 (—3·3)	020/06 (—4·9)	020/07 (—5·7)	010/04 (—2·8)	020/08 (—6·6)	360/08 (—4·6)	015/09 (—6·9)	345/14 (—4·8)	319/19 (—1·7)	319/17 (—1·5)	319/17 (—1·5)

Figures in brackets indicate velocity component normal to the coast line (*i.e.*, E-W component 35° added to the original direction)

sea breeze. The sea breeze front appears to be somewhat diffuse near the coast. Due to the proximity of the sea air, the land air near the coast does not attain appreciable contrast so as to show a significant temperature change with the incidence of sea breeze. Hygrogram shows slight abrupt rise in relative humidity of the order of 5–10 per cent on a few occasions.

6. Summary and conclusions

The sea breeze analysis at Thumba reveals that the northeasterly or northerly land breeze is replaced by westerly or southwesterly sea breeze during October to May.

Its common characteristics are as follows — velocity 10–15 knots, direction 220°–270°, time of onset forenoon (0900–1200 IST), time of maximum intensity afternoon (1300–1500 IST) and time of cessation early night (1900–2100 IST). Southerly setting, late onset as well as early cessation have been noticed on a few occasions. The wind speed is always above 5 kt after the incidence of the sea breeze and it may vary to a maximum speed of 22 kt and to a direction 180° to 300° depending on the prevailing synoptic situation. The vertical extent is about 1 km in summer and 0·8 km in winter. As Thumba is located right on the coast no appreciable frontal characteristics could be noticed.

The data of October and May have not been included in the statistical analysis, as part of these two months shows monsoon characteristics and thunderstorm activity is also predominent in these months. The characteristics of the sea breeze during October and May will be similar to those during November and April respectively.

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