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The diurnal and seasonal variations of the Surface Wind at Visakhapatnam

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ABSTRACT. The present paper discusses the diurnal and seasonal variations of the wind at Visakhapatnam at a height of 56½ ft above ground based on three years' data 1939-41. Curves showing the mean diurnal variation of the wind speed for the twelve months of the year are given and discussed; these curves show a strong maximum in the early afternoon. A rough estimate of the value of the co-efficient of eddy diffusion works out to be 137 in C.G.S. units. Tables of frequencies of prevailing wind direction at 3-hourly intervals for each month of the year are given and their main features are described; a table showing the diurnal variation of 'calms' is also included. The general characteristics of land and sea breezes occurring at the station are briefly mentioned The annual variation of the speed and direction of wind as well as its steadiness is also briefly discussed. The mean monthly steadiness is found to vary from 60 to 92 per cent.

1. Introduction

In a previous paper (Agarwala 1951) the author had discussed the gustiness of wind and the occurrence of gusts at Visakhapatnam (Lat. 17° 42′ N Long. 83° 20′ E) which is an important station situated on the east coast of the Indian peninsula. In the present paper the diurnal and seasonal variations of the speed and direction of the surface wind at the station have been discussed. The data utilised are those derived from the records of the Dines' Pressure Tube Anemograph at the Visakhapatnam Observatory for the period January 1939 to December 1941 (3 years).

2. Exposure of the Anemograph

The Dines' Pressure Tube Anemograph was installed on the roof of a building at the Visakhapatnam harbour with its head 56½ ft above ground level and 19 ft above the building. The exposure of the anemograph head was good in all directions during the period of the observations.

3. Method of tabulation of data

The hourly values of the speed and direction of the wind at any hour refer to the mean speed and direction of the wind during the period of 10 minutes only ending at that hour, *e.g.*, the mean values of the wind speed and direction during the period 1050 to 1100 IST were taken as the hourly values for 1100 IST and so on. The values of wind speed were estimated correct to 1 mile per hour and those of direction according to sixteen points of the compass.

4. Diurnal variation of the speed of wind

Fig. 1 shows the mean diurnal variation of the speed of wind irrespective of direction at the level of the anemograph head (56½ ft above ground) for different months of the year and for the whole year. The curves show a strong and marked maximum in the early afternoon which is well pronounced throughout the year. On the whole, it would appear that the diurnal variation is almost of the same type throughout the year and during any one season this variation is very similar. While the principal maximum of wind speed occurs in the afternoon in all the months, the epoch of minimum varies from month to month.

Table 1 gives the mean monthly values of the day and night maximum and their ratios. The ratio of the night maximum to the day maximum varies considerably in different months. It has the lowest value (0·37) in September and the highest (0·80) in June. As will be seen from the curves, the epoch of commencement of the day oscillation occurs at 0600 to 0800 IST and that of termination at 1900 to 2100 IST generally. These epochs lag behind

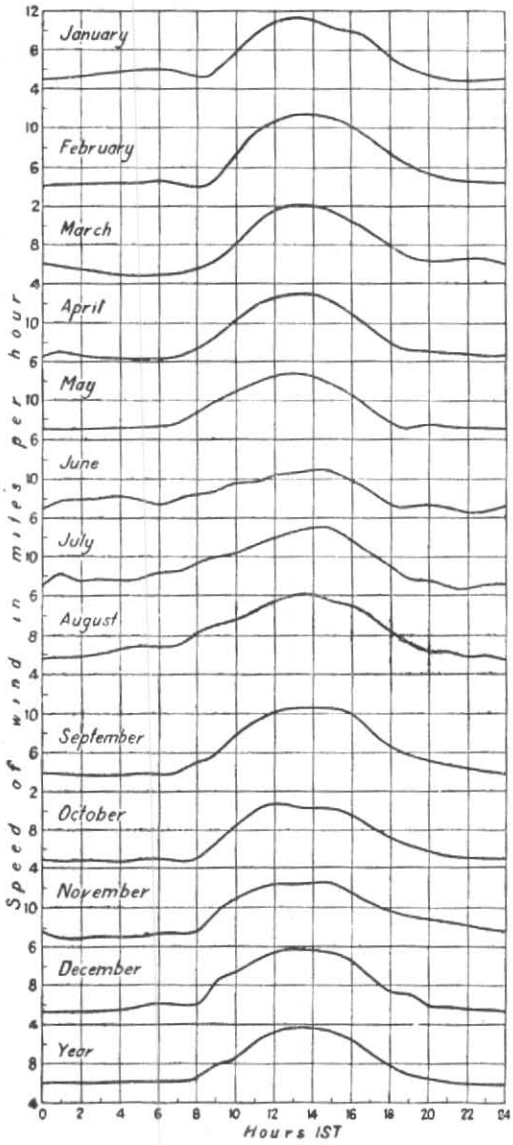

Fig. 1. Diurnal variation of speed of wind at Visakhapatnam

the times of sunrise and sunset respectively by 1 to 2 hours. The period of day oscillation is generally 13 to 14 hours and is well defined in most of the months.

Table 1 also gives the mean hourly wind speed, the amplitude of its diurnal variation and the ratio of the latter to the former together with the mean hourly maximum and minimum speeds for each month. The amplitude of the diurnal variation is a maximum in March and April and a minimum in June. The ratio of the amplitude of diurnal variation to the mean hourly wind speed is the highest (1·14) in the month of February and the lowest (0·52) in June. It is also noticed that the mean hourly speed of the wind is the highest in July and the lowest in September.

5. Co-efficient of eddy diffusion

The heating of the ground at about sunrise produces eddy motion in the layers of air adjacent to the ground which generally diffuses upwards as the day advances, at a definite rate depending upon the value of the co-efficient of eddy diffusion. The day variation of wind at the level of the Dines' head commences only when the eddy motion has reached that level. According to Taylor's equation, the co-efficient of eddy diffusion $K = Z^2/4t$ where Z is the height and t the time. Taking $Z = 56\frac{1}{2}$ ft and $t = 1{\cdot}5$ hours for Visakhapatnam, we get $K = 137$ in C.G.S. units.

The value of t being uncertain, the above estimate of K is only a rough one. It is, however, comparable with the value of the co-efficient of eddy diffusion estimated at Agra (Barkat Ali 1930). It may be mentioned that the co-efficient of eddy diffusion K is subject to diurnal variation.

6. Annual variation of the velocity, direction and steadiness of the wind

The year at Visakhapatnam may conveniently be divided into the following four seasons—

(*i*) The dry season—January to March,

(*ii*) The hot season—April and May,

(*iii*) The southwest monsoon season—June to September and

(*iv*) The northeast monsoon season—October to December.

Table 2 gives the direction (*Dn*) and Velocity (*Vr*) of the mean monthly resultant wind, mean velocity of wind irrespective

TABLE 1

Diurnal variation of speed of wind

Month	Mean wind speed			Hourly wind speed				
	Day Max (a)	Night Max (b)	Ratio b/a	Mean (a_1)	Max X	Min N	Amplitude (b_1)	Ratio b_1/a_1
Jan	11·1	6·0	0·54	7·0	11·1	4·8	6·3	0·90
Feb	11·2	4·7	0·42	6·5	11·2	3·8	7·4	1·14
Mar	11·9	6·5	0·55	7·5	11·9	4·9	7·0	0·93
Apr	13·2	7·1	0·54	8·5	13·2	6·2	7·0	0·82
May	12·9	7·8	0·60	8·9	12·9	7·0	5·9	0·66
Jun	10·9	8·3	0·80	8·4	10·9	6·5	4·4	0·52
Jul	13·2	8·3	0·63	9·2	13·2	6·8	6·4	0·70
Aug	12·1	7·0	0·58	8·3	12·1	5·5	6·6	0·80
Sep	10·6	3·9	0·37	6·2	10·6	3·7	6·9	1·11
Oct	10·5	5·2	0·50	6·8	10·5	4·7	5·8	0·85
Nov	12·8	7·6	0·59	9·3	12·8	6·8	6·0	0·65
Dec	12·0	6·3	0·53	7.7	12·0	5·3	6·7	0·87
Year	11·9	6·6	0·55	7·4	11·9	5·5	6·4	0·83

of direction (Vm) and the steadiness ($100\ Vr/Vm$) of the wind. The mean monthly resultant velocity is the smallest during the months of September and October. It attains the maximum value in the month of April. Steadiness varies from 60 per cent in October to 92 per cent in April indicating that the wind at Visakhapatnam is fairly steady. The mean yearly value of the resultant direction is 209°, that of velocity 6·1 mph and that of steadiness 77 per cent.

During the dry season (January to March) the resultant direction of wind is 144° and the wind is comparatively weak. In the hot season (April and May), on the other hand, the wind is about the strongest and the most steady. The resultant direction of the wind is 203° in this season.

The period June to September is typical of the southwest monsoon conditions. The resultant direction of wind for this season is 225°. Winds are comparatively steadier from June to August, but there is a weakening of the wind in September. The mean steadiness of the wind during this season is 76 per cent.

During the months October to December the northeast monsoon sets in. The resultant direction of the wind is 44°. The wind is quite strong in November and December but these conditions become less pronounced towards the end of December although they often continue in January. During this season the weather at Visakhapatnam is fairly squally. The steadiness of the wind which is 60 per cent in October, increases to about 80 per cent in November and December.

7. Diurnal variation of the direction of wind

Table 3 gives the frequencies of prevailing wind directions in 8 points of the compass only at Visakhapatnam at 3-hourly intervals for each month of the year. If the wind at a particular hour on a particular day is southsouthwesterly, it is counted as ½ day for southerly and ½ day for southwesterly and so on.

These tables bring out the following points of interest—

(*i*) During the early morning hours the most frequent wind direction is westerly or southwesterly and this generally continues upto about 9 A.M. when the wind suddenly changes direction to southerly; this is

TABLE 2

Annual variation of wind

Month	*Vm*	*N*	*E*	*Vr* (mph)	*Dn* (o)	Steadiness (%)
Jan	7·0	+1·1	+1·5	5·1	54	73
Feb	6·5	—2·3	+0·3	4·4	172	68
Mar	7·5	—4·6	—2·4	6·2	207	83
Apr	8·5	—6·1	—3·7	7·8	202	92
May	8·9	—5·8	—2·5	6·8	203	76
Jun	8·4	—4·4	—3·8	6·1	220	73
Jul	9·2	—5·0	—5·7	7·7	229	84
Aug	8·3	—4·3	—4·7	6·8	228	82
Sep	6·2	—2·2	—1·9	4·1	221	66
Oct	6·8	+1·4	+2·0	4·1	55	60
Nov	9·3	+5·5	+4·1	7·8	37	84
Dec	7·7	+3·7	+3·1	6·1	39	79
Year	7·9	—2·0	—1·1	6·1	209	77

Vm : Mean velocity of wind irrespective of direction

N : North component of the mean monthly resultant velocity

E : East component of the mean monthly resultant velocity

Vr : Mean monthly resultant velocity

Dn : Mean monthly resultant direction

Steadiness : $\frac{Vr}{Vm} \times 100$

TABLE 3

Frequencies of wind directions

Direction	S	SE	E	NE	N	NW	W	SW	Calm
Hours (IST)									
				JANUARY					
3	0	0	0	0	3½	12	15	½	0
6	0	0	0	½	5	9	16	½	0
9	0	1	½	6	5½	3	9	5	1
12	1½	7	15	7½	0	0	0	0	0
15	2½	9	16	3	0	0	0	½	0
18	4	7½	11	7	0	0	0	1½	0
21	2	2½	4	11	1½	1½	5	2½	1
24	0	½	1	1½	4	7	16	0	1
				FEBRUARY					
3	½	0	0	½	1	5	18	2	1
6	0	0	½	1	1½	7½	15½	1	1
9	1½	2	1½	4	1½	½	5½	6	5½
12	10	8½	7½	1½	0	0	0	½	0
15	11½	8	7½	½	0	0	0	½	0
18	13½	5½	5	1	0	0	0	3	0
21	3½	1½	3	3	½	1	7½	6	2
24	½	½	1	1½	½	3½	14	4½	2

TABLE 3 (*contd*)

Frequencies of wind directions

Direction	S	SE	E	NE	N	NW	W	SW	Calm
Hours (IST)									
				MARCH					
3	1	½	0	0	0	4½	16	6½	2½
6	½	0	½	½	1	4	15½	5	4
9	3½	2½	2½	1	0	½	7	11	2½
12	20	4	2½	1	0	0	½	3	0
15	22	3	3	0	0	0	0	3	0
18	16½	2	1	½	0	½	½	9½	½
21	5	0	½	½	0	½	½	9½	13	2
24	2½	1	½	½	½	1	13½	11	½
				APRIL					
3	2	½	0	0	0	2	10½	13½	11
6	1	0	½	½	0	2	14	10½	1½
9	9	2	½	0	0	0	6½	12	0
12	22	2½	0	0	0	0	½	5	0
15	22	2	0	0	0	0	½	5½	0
18	13½	1	½	0	0	0	2½	12½	0
21	4	½	½	½	1	½	6	16	1
24	2½	½	½	0	0	1½	10	13	2
				MAY					
3	2½	1	½	1	1	1	6	14	4
6	1½	½	½	1	1	1	8	14	3½
9	8½	1½	1½	½	½	0	2½	15	1
12	22	3	2	½	0	0	0	3½	0
15	23	4½	1½	1	0	0	½	4	0
18	11½	3½	1	1	1	½	1	10½	1
21	5	2	1½	1½	1	1	3½	13½	2
24	3	1	½	1	1½	1	5	15	3
				JUNE					
3	2	0	0	1½	½	2½	7½	12½	3½
6	2	0	0	½	1	2½	8	13	3
9	4	1½	1	½	1	1	7	12	2
12	12½	3	½	1	0	1	4	7	1
15	13	2½	½	½	½	1	2½	9½	0
18	8	1½	1	½	½	2½	4½	10	1½
21	3	0	½	1	½	3	8	12	2
24	3½	½	½	½	½	3	6½	12	3
				JULY					
3	2	½	0	0	0	3	12½	11½	1½
6	1	½	0	0	½	4	11½	12	1½
9	3	1	0	0	0	1	8½	17	0
12	10½	1½	0	0	0	0	4½	14	0
15	8½	1	1	0	1	1	5½	13	0
18	7½	1	½	½	½	1½	5½	13½	0
21	3	½	0	1	0	3	10½	11	2
24	2½	½	0	0	0	4½	10	10	3½

TABLE 3 (*contd*)

Frequencies of wind directions

Direction	S	SE	E	NE	N	NW	W	SW	Calm
Hours (IST)									
				AUGUST					
3	2½	½	½	½	0	4	11½	9	2½
6	1	0	0	0	0	3½	15½	8	2
9	3	0	0	0	0	1	11	15	1
12	12	1	½	0	0	1	5	11½	0
15	14	2	0	0	0	1	4½	9	0
18	7½	1	1	½	0	2½	5½	12½	1
21	2	0	0	½	1	2½	10½	10	4
24	2	0	0	½	0	4	14½	7	2½
				SEPTEMBER					
3	0	0	0	1	½	6½	13	5	4
6	½	0	½	½	½	8	15	2½	3½
9	3	1½	1½	1	1	1	9½	10½	1
12	12½	5	3	½	1	½	1½	6	6
15	13	3½	3	1	½	½	2	6½	0
18	8½	1½	2	1	1	½	4½	10	1
21	3	1½	1½	2	½	3	6½	9½	3
24	1	½	½	2	1	5	12½	5	2½
				OCTOBER					
3	½	½	0	1	5½	11½	9	2½	½
6	0	1	1	2	5½	9½	8½	2	1
9	1	2	4	9½	5	1	5	3	1
12	3	7	11½	7	1	½	½	1	0
15	4	6½	12½	4½	1	½	½	1½	0
18	4½	5	9	7½	1½	½	1	2½	0
21	1	1	3½	8	3½	3½	3½	4	3
24	½	0	1½	5	5½	6½	8	2	1½
				NOVEMBER					
3	0	0	0	4½	10	7	7	½	½
6	0	0	0	5	12	7½	5	½	0
9	½	0	½	13	11	2½	1	½	0
12	0	½	10½	15	2½	½	0	½	0
15	0	2	15½	11	1	0	½	0	0
18	0	1½	9	18½	1	0	0	½	0
21	0	1	6	16½	4	1½	1	0	0
24	0	0	½	9½	7½	5½	6½	½	0
				DECEMBER					
3	0	0	0	1	6½	12½	10	1	0
6	0	½	0	2	8½	11	6½	1	1
9	½	0	1½	12½	9	2½	3	1½	0
12	1½	2½	10½	15	½	½	0	0	0
15	2	3	16	9	1	0	0	0	0
18	1½	2½	10	15	1	0	0	½	0
21	0	½	4	15	5	1½	2½	½	2
24	0	½	1	5½	8	8	6½	1	1

clearly noticeable during the summer months February to May.

(*ii*) The southerly wind, which is the sea breeze, continues upto late in the evening —sometimes upto 9 P.M. when the land breeze starts from the west or southwest.

(*iii*) During the southwest monsoon period June to September, the most prevalent direction of the wind is southwesterly or westerly. A change takes place in the months of October—November when northeasterly is the most frequent direction on account of the onset of the northeast monsoon, which continues during December.

(*iv*) In January the frequency of northerly or northeasterly direction decreases considerably and westerly winds in the mornings followed by easterly winds in the afternoons become more predominant.

8. Diurnal variation of 'Calms'

Table 4 gives the mean number of 'calm' at 3-hourly intervals for each month of the year and for the whole year. The wind was classified under calm when the mean speed of wind recorded by the anemograph was less than half a mile per hour. The table shows that for the year as a whole calms are rare at 1200 and 1800 IST and that they are more frequent during the night. It is also noticed that the largest number of calms occur at midnight (2400 IST) and the smallest—almost nil—at 1500 IST. As regards the annual variation, calms are rare during the months November to January and appear to be most frequent in June and September.

9. Occurrence of Squalls

The wind at Visakhapatnam shows a fair amount of squalliness in the premonsoon and southwest monsoon seasons. Each fluctuation of speed is accompanied by a change in the direction of wind. This rise in speed, *i.e.*, difference between the peak speed and the speed at the time of commencement of the squall is sometimes noticed to be 30 to 40 miles per hour in the Dines' P.T. records at Visakhapatnam.

TABLE 4

Frequencies of ' calms '

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Hours (IST)													
3	0	1	2·3	1·3	3·7	3·3	1·3	2·3	3·7	0·3	0·3	1·7	21·2
6	0	1	3·7	1·3	3·3	2·7	1·3	1·7	2·7	1·3	0	0·7	19·7
9	1	5·3	2·3	0	1	1·7	0	1	1·3	1	0	0·3	14·9
12	0	0	0	0	0	1·3	0·3	0	0	0	0	0	1·6
15	0	0	0	0	0	0·3	0·3	0	0	0	0	0	0·6
18	0	0	0·3	0·3	1·3	1·7	0·3	1·3	1·3	0·3	0	0	6·8
21	1	2	1·7	1·3	2	2	2·3	4	3	3·3	0	2	24·6
24	1	2	0·7	2	2·7	3·3	3·3	2·3	2·7	1·3	0·3	0·7	22·3

With the onset of the squall the wind generally changes its direction to southerly and the occurrence of the squall is generally associated with disturbed weather. The duration of a squall is found to vary from a few minutes to about an hour.

10. Land and Sea breezes

These breezes are regular and well-marked at Visakhapatnam during the months of January to April. The sea breeze with an easterly to southerly direction sets in generally between 0800 and 1000 IST in the morning and continues to blow till late in the evening. After commencement, the sea breeze gradually gains strength and the maximum speed is reached sometime in the afternoon. Thereafter there is a slow fall in speed until the sea breeze dies down. On days of strong monsoon winds, the sea breeze is not distinguishable on the records.

The land breeze commences between 1800 and 2100 IST generally, when there is a sudden change in wind direction to westerly or southwesterly, and it continues till 0800 to 1000 IST next morning. Sometimes there is a calm after the sea breeze dies down and before the land breeze sets in.

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