551.533.11: 551.524(548)

Sea breeze and maximum temperatures in Madras

K. P. RAMAKRISHNAN and R. JAMBUNATHAN

Meteorological Office, Madras

(*Received 13 September 1957*)

1. Introduction

At coastal stations, in months when the temperature difference between land and sea is pronounced, a sea breeze starts a little before noon near the coast and gradually extends inwards. When the general weather situation is not disturbed or changing fast, the arrival of the sea breeze is very sharp, being characterised by a rise in wind speed, a change in wind direction (unless the gradient wind is also from sea to land), a fall in the temperature of 2 to 3 degrees and more striking than all these, a sharp rise in relative humidity of 10 to 20 per cent, at times as much as 40 per cent. Aerodrome stations, which are called upon to supply winds frequently, have to reckon the changes that may be caused by sea breeze.

2. Previous work

The sea breeze at different parts along the coast of India (including what is now Pakistan) has been studied, from various aspects, in the past, for instance Jones (1908), Ramanathan (1931), Ramdas (1931), Roy (1941), Hatcher and Sawyer (1947), Ray Choudhuri (1948) and Venkateswara Rao (1955).

In the west coast, to the eastern side of the Khandala gap, the sea breeze is known to extend to Poona, a distance in the direction of the breeze of about 70 miles (Ramanathan 1931). It is supported by autographic meteorological records. Farther south, in the Palghat gap, it is also known to extend at least 60 miles inland, but there being no suitable station with autographic meteorological records, one has only the subjective experiences of the residents of Palghat in support of the same.

In the summer of 1932, more or less as an offshoot of Ramanathan's study of the sea breeze at Poona, one of the present authors made a few observations with a portable anemometer and a thermograph at some stations to the east of Poona along the railway line. No hygrograph was taken. The only definite observation that could be made was that on 21 April 1932. The sea breeze on this day did reach a station (Yevat) about 25 miles to the east of Poona at 1715 IST, $2\frac{1}{4}$ hours after it had reached Poona. The average speed of wind at Poona when the sea breeze was on, was about 12 mph.

3. The sea breeze at Madras and the special observations made

When a full complement of self-recording instruments were installed at Nungambakkam, the city observatory of Madras, in 1949 attention was naturally drawn to the arrival of the sea breeze as evidenced by the charts. The direction of the sea breeze at Madras has been found to be almost always SE, being at times SSE. On a suggestion by Shri P.R. Krishna Rao, then Director of the Regional Meteorological Centre, a first attempt to trace the sea breeze inland at Madras was made in June 1950. Readings of a portable anemometer were taken at frequent intervals at Villivakkam, a railway station west of Madras. In the SE-NE direction, *i.e.*, the direction of the sea breeze, it is about 6 miles from the sea. The Nungambakkam observatory itself is some 3 miles from the sea in the same direction. On 1 June 1950, the sea breeze arrived at the Nungambakkam observatory at 1415 IST, marked by a sharp rise of 7 per cent in the relative humidity. The sea breeze reached Villivakkam at 1540 IST $\pm$ 10 minutes.

In the summer of 1951, the work was taken up again and this time, considering the sharpness of rise in humidity characterising the arrival of the sea breeze, it was decided to try to follow it by a set of hygrographs. One

TABLE 1

Times of commencement of sea breeze as fixed from hygrograms at Madras Harbour, Nungambakkam, Meenambakkam, Trivellore and Tiruvalangadu

Date	Time (IST) of commencement at				
	Madras Harbour	Nungambakkam	Meenambakkam	Trivellore	Tiruvalangadu
June 1951					
12	1450	1500	1540		
13	1438	1508	1625		
14	1540	1627	1640		
15	1345	1422	1620		
16	1521	1606	1631		
17	1314	1430	1622		
18	1331	1427	1510		
19	1335	1402	1508		
20	1315	1345	1408		
21	1432	1510	1606		
22	1527	1550	1532*		
23	1930	No sea breeze	No sea breeze		
24	1947	1955	2014		
25	1431	1505	1608		
26	1751	1832	1850		
27	1408	1421	1458		
28	1320	1330	1346	1825	
29	1135	1232	1412	1610	
30	1340		1425	1745	
July 1951					
1	1230		1350		
2	1100		1245		
3	No sea breeze		No sea breeze		
4	Do.		1600		
5	1415		1545	1840	No sea breeze
6	1125		No record	1800	1800
7	1130		No sea breeze	1935	No sea breeze
8	1145		1502	1820	Do.
9	1255		1525	1805	Do.
10	No sea breeze		Not clear	1650	Do.
11	1200		1330	1315	1610
12	1200		1350	1530	1645
13	1750		1925	No sea breeze	No sea breeze
14	1205		1440	1640	1735
15	1115		No record	1620	1645
16	No sea breeze		Do.	1645	Not clear
17	1140		1410	No record	Do.
18	No sea breeze		No sea breeze	Do.	No sea breeze
19	Do.		Do.	Do.	Do.
20	1555		1650	1415	Do.
21	1445		1725	No sea breeze	Not clear
22	1450		1500	1415	1435
23	No sea breeze		No sea breeze	No sea breeze	No record
24	Do.		Do.	Not clear	Do.
25	Not clear		Do.	No sea breeze	Do.
26	1500		Not clear	Do.	Do.
27	1525		1650	Do.	No sea breeze
28	1315		1438	1630	Not clear
29	1120		1635	No sea breeze	No sea breeze
30	No record		1635	Do.	Do.
31	Do.		1930	Do.	No record

* Rather doubtful

was installed at the Harbour as representing the coast where the Port Trust staff were kind enough to change the charts daily for about a month. Regular instruments, maintained by departmental staff, were functioning at Nungambakkam and Meenambakkam. A fourth one was run as a mobile unit, at different railway stations along the line from Madras to Arkonam, with the kind cooperation of the railway staff at the stations. With the limited facilities, it was possible to make the observations only for a period of a little over a month.

The times of arrival of sea breeze at Harbour, Nungambakkam, Meenambakkam, Trivellore and Tiruvalangadu on all days when the arrival could be unmistakably identified are given in Table 1. The sudden increase in percentage relative humidity at each of these stations when the sea breeze arrived are given in Table 2.

Fig. 1 shows relevant portions of the anemograms at Madras Harbour (only speed and no direction) and Meenambakkam and hygrograms at Harbour, Nungambakkam, Meenambakkam and Avadi on 21 June 1951.

Fig. 2 shows relevant portions of the anemograms at Harbour and Meenambakkam and hygrogram at Harbour, Nungambakkam, Meenambakkam and Trivellore on 28 June 1951.

Fig. 3 shows the relevant portions of the hygrograms only at Harbour, Nungambakkam and Meenambakkam for eight consecutive days from 13 to 20 June 1951.

Fig. 4 shows the relative positions of the different sites where hygrographs were kept for this investigation.

4. Discussion of the special observations

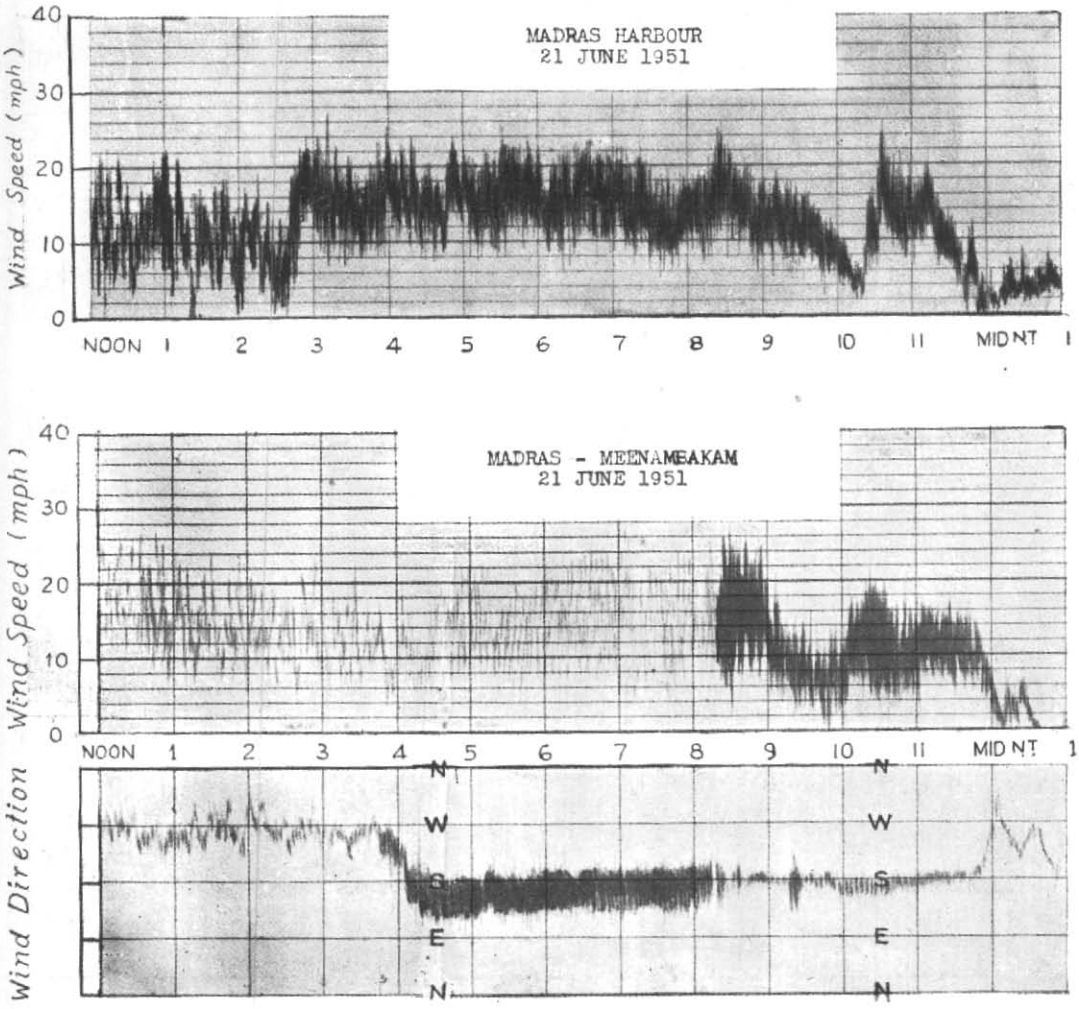
Table 1 and Figs. 1 and 2 bring out fairly clearly that, on most days, the sea breeze reaches the successive stations with a fairly uniform speed. There are of course a few exceptional days when its times of arrival at the different stations do not fit properly into this scheme. For instance, it is surprising that on 14 June 1951, it should have started at Meenambakkam within such a short interval as 13 minutes. On 22 June 1951, it apparently started at Meenambakkam soon after it started at the Harbour and 18 minutes before it reached Nungambakkam. The breeze as it arrives at different points inland must have started at different points along the coast and the explanation for anomalies of the kind mentioned must lie in the fact that variations must exist in its time of commencement at different points along the coast, and on occasions these may be large. It is also known that even at a specified place, its times of commencement on successive days vary considerably. Making due allowance for such exceptions, the study definitely shows the possibility of predicting the time of arrival of the sea breeze and its consequent effects on wind and temperature at any particular point—which may well be an important aerodrome like Meenambakkam—by having one or more hygrographs at suitable points and obtaining information on phone about arrival of sea breeze at those points. The average interval between incidence of sea breeze at Harbour and Meenambakkam is 65 minutes and that between its incidence at Nungambakkam and Meenambakkam is 45 minutes (neglecting the very exceptional days). If, therefore, we have a system of knowing the times of incidence at the Harbour and Nungambakkam we could on most days predict the time of arrival at Meenambakkam with a high degree of success.

The next broad result of an interesting nature that is fairly clear from this study is that near Madras, in the months, June and July, the sea breeze definitely penetrates some 25 miles inland (Trivellore) but rarely does so as far as 35 miles (Tiruvalangadu). On the East Coast, therefore, it apparently goes much less inland than along the West, where it is known to go even as far as 100 miles. The probable reason is that in the West Coast, the sea breeze direction is almost the same as the general gradient wind and so it has nothing to fight against, except when a strong land wind develops. On the

TABLE 2

Increase in relative humidity (%) on arrival of sea breeze at Madras Harbour, Nungambakkam, Meenambakkam, Trivellore and Tiruvalangadu

Date	Madras Harbour	Nungam-bakkam	Meenam-bakkam	Trivellore	Tiruvalan-gadu
June 1951					
12	34	18	19		
13	36	7	30		
14	45	24	10		
15	32	14	18		
16	34	26	34		
17	40	25	53		
18	40	32	53		
19	26	12	12		
20	40	22	14		
21	42	15	12		
22	27	16	32		
23	40				
24	39	26	38		
25		14	23		
26		24	59		
27	41	17	12		
28	30	14	17	16	
29	32	8	38	11	
30	48		38	7	
July 1951					
1	30		24		
2	26		11		
3	No sea breeze		No sea breeze		
4	Do.		26		
5	24		25	7	
6	22			8	4
7	15		No sea breeze	4	No sea breeze
8	12		15	8	Do.
9	22		10	16	
10	No sea breeze			5	
11	26		18	21	9
12	20		16	13	5
13	28		26	No sea breeze	No sea breeze
14	7		9	11	
15	16			8	4
16	No sea breeze			7	
17	23		20		
18	No sea breeze				
19	Do.				
20	22		10	4	
21	6		40	No sea breeze	
22	11		22	16	5
23	No sea breeze		No sea breeze	No sea breeze	
24					
25					
26	15				
27	41		39		
28	34		20	16	
29	22		22		
30			16		
31			27		


MADRAS HARBOUR
21 JUNE 1951
Wind Speed (mph)
40
30
20
10
0
NOON 1 2 3 4 5 6 7 8 9 10 11 MID NT 1
MADRAS - MEENAMBAKAM
21 JUNE 1951
Wind Speed (mph)
Wind Direction
N
W
S
E
N

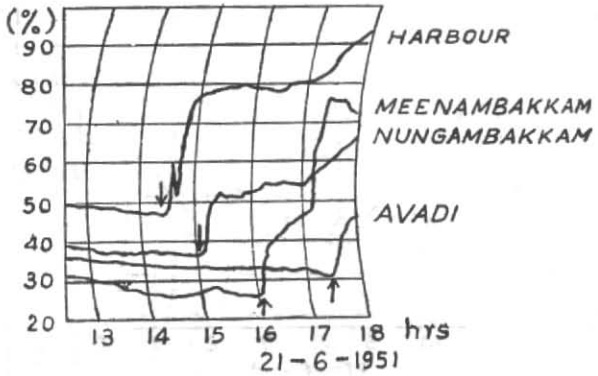
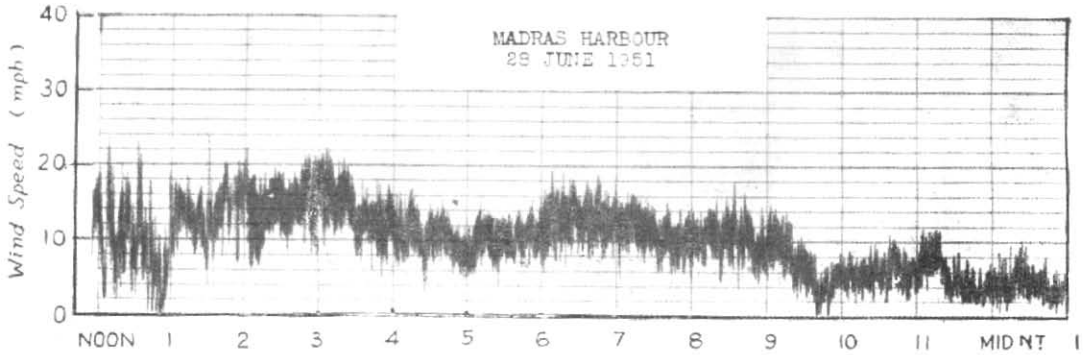
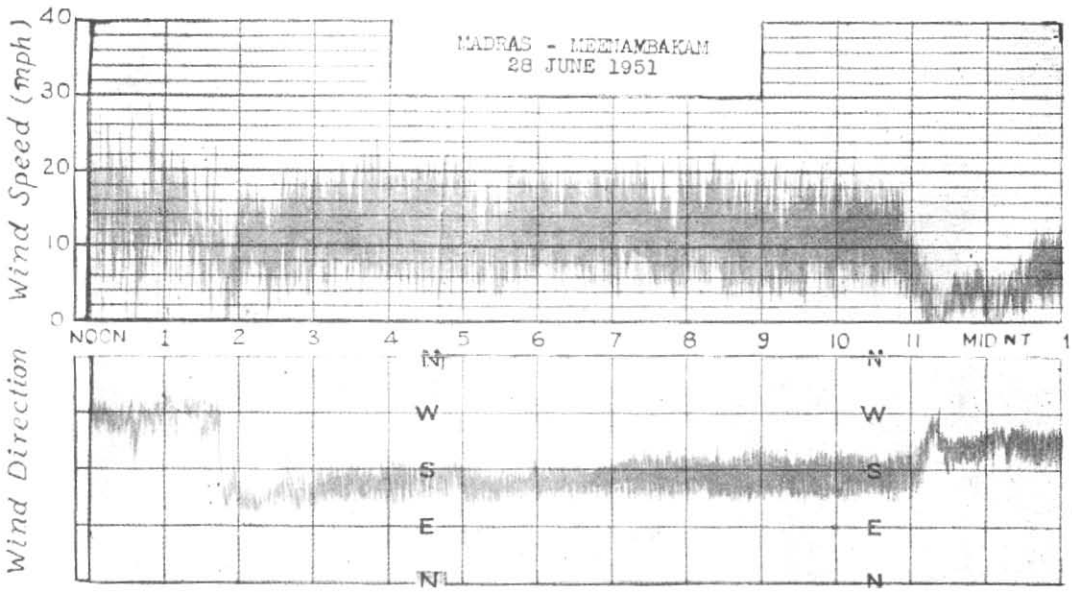

(%)
90
80
70
60
50
40
30
20
HARBOUR
MEENAMBAKKAM
NUNGAMBAKKAM
AVADI
13 14 15 16 17 18 hrs
21-6-1951

Fig. 1


MADRAS HARBOUR
28 JUNE 1951
Wind Speed (mph)
40
30
20
10
0
NOON 1 2 3 4 5 6 7 8 9 10 11 MIDNT 1


MADRAS - MEENAMBAKAM
28 JUNE 1951
Wind Speed (mph)
40
30
20
10
0
NOON 1 2 3 4 5 6 7 8 9 10 11 MIDNT 1
Wind Direction
N
W
S
E
N

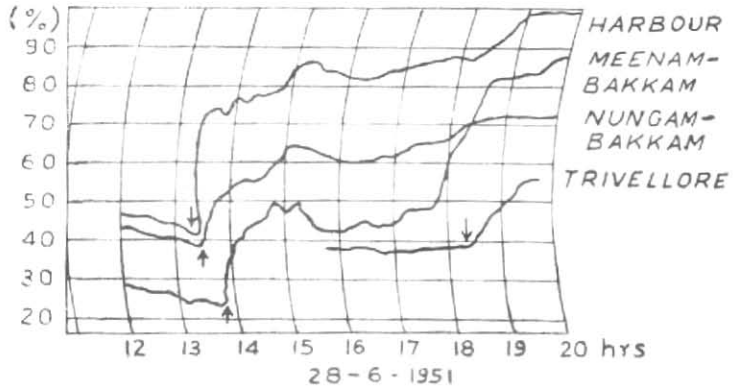
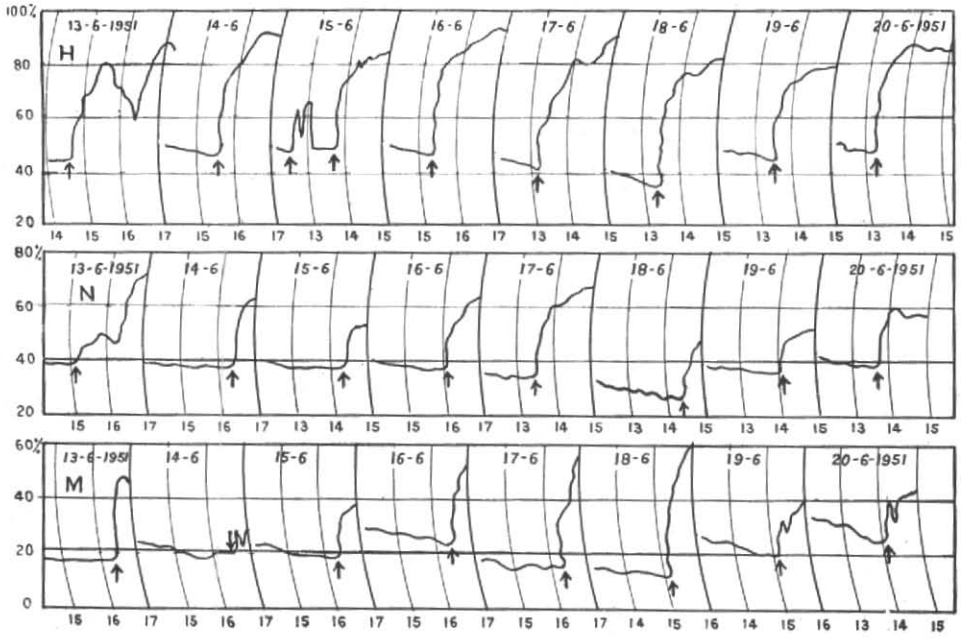

(%)
90
80
70
60
50
40
30
20
HARBOUR
MEENAM-BAKKAM
NUNGAM-BAKKAM
TRIVELLORE
12 13 14 15 16 17 18 19 20 hrs
28-6-1951

Fig. 2



INCIDENCE OF SEABREEZE AT THREE SITES IN MADRAS.

M - *Meenambakkam*. N - *Nungambakkam*. H - *Madras Harbour*.

Fig. 3

East Coast on the other hand, the sea breeze has to fight against the gradient wind.

Yet another interesting feature well brought out by Figs. 1 and 2 is that the distinctive nature of the sea breeze or its contrast with previous conditions, as shown by the magnitude of the sharp rise in relative humidity gradually decreases as we go inland, showing the effect of more and more mixing.

Of meteorological phenomena, the local circulations represented by land and sea breezes are among those most amenable to being fairly well understood. The special observations with hygrographs described above have shown sufficiently well that, for following and mapping the progress of the sea breeze, or for an extensive survey of its variations from place to place along coasts, at the surface, the hair hygrograph is a valuable and sufficient instrument. For effectively tracing the topography of advance of the sea breeze a number of instruments have to be used in conjunction. The maintenance of a network of a dozen hygrographs at selected spots will mean very much less effort and cost than installing and maintaining a single Dines' anemograph or one series of aeroplane ascents as was done by Hatcher and Sawyer (1947).

5. Effect of sea breeze on the maximum temperature

The sea breeze has an interesting effect on the maximum temperature, producing substantial variations in the maximum temperatures over comparatively short distances. Let us consider the effect in a simplified, idealised way.

In Fig. 5, A, B, C, D and E are five different stations at, say, 0, 5, 10, 15 and 20 miles respectively away from the coast in the direction of the sea breeze. The thin full lines represent the diurnal variation of temperature that these places would normally have had, with the maximum

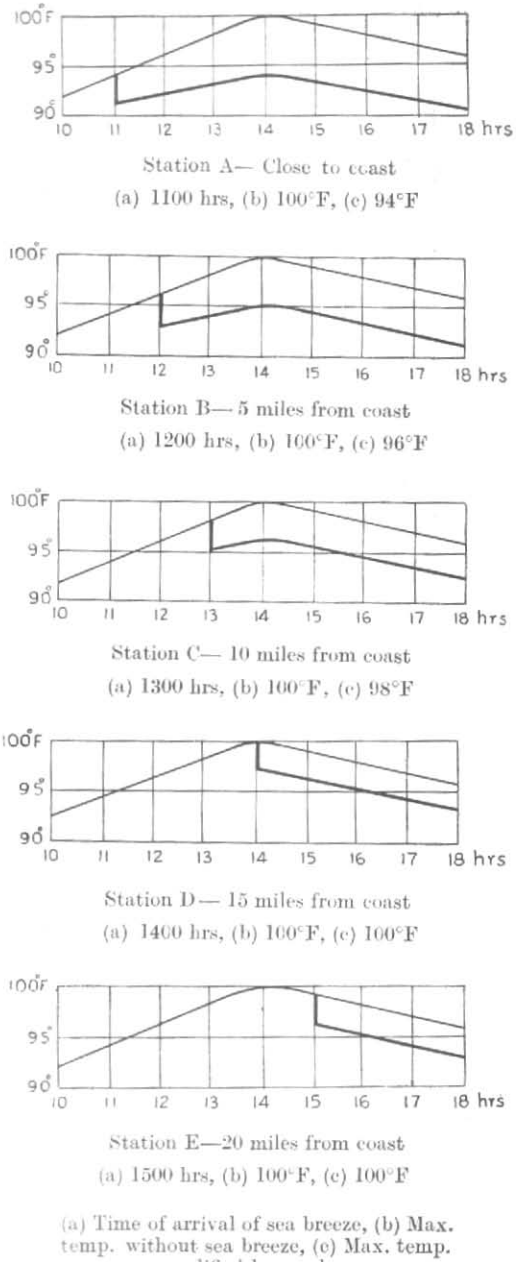
Fig. 4

occurring at each place at 14 hours, which is the usual time, had there been no sea breeze. Let us assume that the sea breeze starts at A at 11 hrs and travels at 5 mph, arriving at the other four stations B, C, D and E at 12, 13, 14 and 15 hrs (*i.e.*, two hours before time of maximum, an hour before it, at the time of maximum and an hour after it); the sea breeze front causes a sharp fall of 2–4 degrees and also, by increased turbulence, reduces the rate of rise of temperature after it has come. The modified temperature variation under these circumstances for the period after arrival is shown by thick curves. It is easy to see that the actual maximum temperature itself progressively increases from A to B and B to C but at and beyond D where it arrives at or after the epoch of maximum, it has no effect on the maximum temperature of the day.

At Madras, Nungambakkam and Meenambakkam, the two sites for which the maximum temperatures (along with other meteorological elements) are published in the Madras Regional Daily Weather Report as well as in the city newspapers will fall roughly into categories B and C in Fig. 5.

6. Maximum temperatures of Nungambakkam and Meenambakkam

For each day of the four years 1951 to 1954, the values of the maximum temperatures of Meenambakkam and Nungambakkam, their difference, times of arrival of the sea breeze at Meenambakkam and Nungambakkam as obtained from the respective hygrograms and their difference were tabulated.



(a) Time of arrival of sea breeze, (b) Max. temp. without sea breeze, (c) Max. temp. as modified by sea breeze

Fig. 5. Idealised picture showing effect of sea breeze on maximum temperature at stations at different distances from the coast

(Thin curve represents the course of temperature had there been no sea breeze. The thick curve shows the course of temperature as modified by sea beeeze)

TABLE 3

Correlation table between $T_M - T_N$ and $X_M - X_N$ in summer (March-July)

$T_M - T_N$ (minutes)	$X_M - X_N$ (°F)						
	<1·5	1·5 to 2·5	2·5 to 3·4	3·5 to 4·4	4·5 to 5·4	5·5 to 6·4	6·5 and above
< 30	1	1					
30— 45	4	7	1				
46— 60	8	11	5	1			
61— 75	2	8	13	1			
76— 90	3	5	9	5	2		
91—105		3	7	5	5		
106—120		1	6	8	7	2	
121—135			1	3	2		
136—150				4	5	—	1
<150				1	—	3	5

T_M, T_N—Times of arrival of sea breeze at Meenambakkam and Nungambakkam respectively
X_M, X_N—Maximum temperatures at Meenambakkam and Nungambakkam respectively

TABLE 4

Distribution of $X_M - X_N$ with different times of arrival of sea breeze at Nungambakkam
($T_M - T_N = 1\frac{1}{2}$ hours)

$X_M - X_N$ (°F)	T_N (IST)		
	1000–1100	1100–1200	1200–1300
<1·5	..	..	..
1·5—2·4	2	1	4
2·5—3·4	4	5	2
3·5—4·4	7	3	2
4·5—5·4	8	1	..
5·5—6·4	..	1	..

The tabulation showed—

(1) The difference in the maximum temperatures of Meenambakkam and Nungambakkam is of the order of 2 to 3°F in the summer months, *viz.*, March to July. Meenambakkam always records a higher maximum temperature than Nungambakkam. The difference is as high as 4 to 5 degrees on some occasions and rarely goes even to 6 degrees.

(2) In the months of August, September and October, the difference in the maximum temperatures is generally of the order of only 1-2 degrees. This is so because the sea breeze in these months is found to arrive after 1400 IST at both the places, too late to influence the maximum temperature.

(3) In the remaining months, *i.e.*, November, December, January and February, the difference in the maximum temperatures is hardly a degree. This is to be expected because

the sea breeze as experienced in the other months is absent in these months (excepting a very few occasions in February) and the prevailing surface wind both at Nungambakkam and Meenambakkam is from the sea (generally a northeasterly wind) throughout the day.

(4) On days when sea breeze was absent both at Meenambakkam and Nungambakkam, the maximum temperatures were practically the same.

The data for the summer months, March to July may be examined in some greater detail. Table 3 is a correlation table between differences in times of arrival of the sea breeze at the two sites and differences in the maximum temperatures. The general increase of the difference between the maximum temperatures of the two sites with larger and larger intervals between the times of arrival of the sea breeze at the two sites is well brought out by Table 3.

A given difference between times of arrival of sea breeze, causes a larger difference in maximum temperatures, the earlier the actual time of arrival at the nearer station, *viz.*, Nungambakkam, as can be seen from Table 4.

REFERENCES

Hatcher, R. W. and Sawyer, J. S.	1947	*Quart. J.R. met. Soc.*, **73**, p. 391.
Jones, R. L.	1908	*Mem. India met. Dep.*, **20**,Pt. 5.
Ramanathan, K. R.	1931	*India met. Dep. Sci. Notes*, **3**, 30.
Ramdas, L. A.	1931	*Ibid.*, **4**, 41.
Ray Choudhuri, S. N.	1948	*Ibid.*, **10**, 119.
Roy, A. K.	1941	*Ibid.*, **8**, 97.
Venkateswara Rao, D.	1955	*Indian J. Met. Geophys.*, **6**, 3, p. 233.