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# SEA BREEZES AT WORTHY DOWN, WINCHESTER

By S. P. PETERS, B.Sc., A.Inst.P.

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## SEA BREEZES AT WORTHY DOWN, WINCHESTER

By S. P. PETERS, B.Sc., A.Inst.P.

**Introduction.**—Although Worthy Down is situated some 15 miles from the head of Southampton Water, about 25 miles from the Solent and Spithead, and nearly 40 miles from the southern extremity of the Isle of Wight, sea breezes are evident there from time to time during the spring and summer months. It is not very often, however, that the sea breeze is sufficiently pronounced for it to be readily apparent to the casual observer, and a study of the records of autographic instruments is, in most cases, necessary to detect or confirm its existence. Owing to the fact that the sea breeze is usually superimposed on a pre-existing gradient wind due to the general pressure distribution, its intensity and degree of prominence depend on the direction and strength of such gradient wind. Since in the absence of any previous definite air flow the normal sea-breeze direction at Worthy Down will be southerly, it is evident that the most prominent effects will be observed on the anemograms when the sea breeze has displaced a northerly gradient wind. On occasions when the gradient wind has a well-marked southerly component, it becomes difficult and, at times, impossible to determine from the anemograms whether or not a sea breeze was actually superimposed on it.

**Period investigated ; annual and monthly distribution of sea breeze.**—From general considerations it is to be expected that sea-breeze occurrences at Worthy Down will be confined almost entirely to the spring and summer, during which seasons the greatest positive differences between land-surface and sea-surface temperatures will occur. A preliminary inspection of the records from the Dines pressure tube anemometer at Worthy Down failed to reveal any sea breeze occurring earlier in the year than March or later in the year than September. It was therefore decided to limit the investigation to the seven months March to September, and the years considered were 1927-32, inclusive. Over this period there were found to be 58 occasions on which evidence was forthcoming of the development of sea breeze, but, whilst for some of these occasions the evidence was well marked and unmistakable, for certain others the effects on the autographic records were very slight. Instances of the latter type were, however, only included after investigation of the general meteorological conditions on the days in question had shown them to be not unfavourable for sea breeze. Undoubtedly some occasions on which a gradient wind from between SE. and SW. has been reinforced by a sea breeze from a similar direction have been unavoidably excluded, but from a practical point of view these cases, being seldom productive of

any appreciable meteorological changes, are of minor importance. The 58 examples were distributed over the individual years according to Table I.

TABLE I

1927	1928	1929	1930	1931	1932
8	12	18	4	4	12

The high value for 1929 was contributed to by 5 consecutive days at the end of March in that year. The distribution amongst the months March to September is shown in Table II.

TABLE II

March	April	May	June	July	August	September	Total
8	4	11	11	7	9	8	58

Here, again, the 5 consecutive days at the end of March, 1929, are responsible for undue weighting of the number of occasions for the month of March. The frequency of sea breeze is seen to show a maximum in May and June. The earliest occurrence was on March 18, and the latest September 25.

**Time of onset, and duration.**—The time of onset of sea breeze is shown in Table III in relationship to the seven different months. The times used throughout this paper are G.M.T.

TABLE III—TIME OF ONSET OF SEA BREEZE

G.M.T.	1200-1259	1300-1359	1400-1459	1500-1559	1600-1659	1700-1759	1800-1859	1900-1959	2000-2059	2100-2159
March	..	1	..	2	..	2	2	1	..	..
April	..	..	..	..	1	1	1	1	..	..
May	..	1	..	2	2	2	1	1	1	..
June	..	1	..	..	3	2	2	2	1	..
July	..	..	1	2	..	2	2	..	..	..
August	..	..	..	..	4	1	1	1	1	1
September	..	..	..	..	3	2	1	2	..	..
Total	..	1	3	1	6	13	12	10	8	3

The time of onset varies mainly between 1300 and 2100, with a maximum frequency between 1600 and 1800. The isolated occurrences before 1300 and after 2100 were not well-defined occurrences of sea breeze.

Table IV shows the distribution of sea-breeze duration in the different months; there is a maximum duration frequency of between 2 and 4 hours. This, in conjunction with the evidence of Table III, serves to indicate approximately 1700–2000 as the most frequent period of sea breeze.

TABLE IV—DURATION OF SEA BREEZE

Hours			< 1	1-1.9	2-2.9	3-3.9	4-4.9	5-5.9	6-6.9	7-7.9	8-8.9
March	..	..	1	1	3	2	..	..	..	..	1
April	..	..	..	..	1	2	1	..	..	..	..
May..	..	..	1	2	1	2	2	1	..	2	..
June	..	..	1	..	5	2	1	1	1	..	..
July	..	..	..	..	2	2	1	..	2	..	..
August	..	..	1	2	2	3	1	..	..	..	..
September	..	..	2	4	1	..	1	..	..	..	..
Total	..	..	6	9	15	13	7	2	3	2	1

**Pressure distribution and sea breeze.**—As has already been indicated, the sea breeze is most strikingly apparent when it displaces an opposing northerly gradient wind, but its development is, of course, favoured by the absence of any general pressure gradient. The latter condition is a specially suitable one on fine days, on account of the added facility with which the air over the land becomes heated on such occasions. It is therefore to be expected that the most prominent sea breezes will usually be associated with anticyclones or with areas of uniform pressure distribution, and such conditions did actually obtain on almost all the occasions of sea-breeze occurrence under discussion. On some 65 per cent. of them, Worthy Down, if not covered by an area of irregular and nearly uniform pressure or the centre of an anticyclone, was on the south or south-east side of an anticyclone in a region of north-easterly to easterly gradient.

**Characteristics of the sea breeze and of its onset.**—The effects of sea breeze arrival on the surface and upper winds, temperature, absolute and relative humidity, weather and visibility were ascertained from instrumental and eye observations so far as these permitted.

**Surface wind.**—The speed and direction of the sea breeze at Worthy Down largely depends, as previously remarked, on the speed and direction of the preceding wind on which it is superimposed. The effects of its arrival therefore vary between a reversal of direction amounting to as much as 180°, or the mere reinforcement of the existing wind without appreciable change of direction. In the former case, the onset of the sea breeze may be sudden, exhibiting features characteristic of a well-defined cold front, or alternatively, though much less frequently, it may take the form of a gradual change, either continuous or by stages. In the case, likewise, of a mere reinforcement there may be a sudden increase in speed on the arrival of the sea breeze, or else the effect may only be a transformation of a wind of convectional type into one of frictional type.

**Upper wind.**—For about one-third of the occasions of sea breeze, pilot balloon observations at Worthy Down were available before and after its onset at the surface, and some of these give definite indications regarding its vertical extent in individual cases. In Table V are to be found some of the results.

TABLE V

Date	Arrival of sea breeze	Time of pilot balloon ascent	Wind at						Approximate height of sea breeze
			500 ft.	1,000 ft.	1,500 ft.	2,000 ft.	2,500 ft.	3,000 ft.	4,000 ft.
			° m.p.h.	° m.p.h.	° m.p.h.	° m.p.h.	° m.p.h.	° m.p.h.	° m.p.h.
May 25, 1927	1530	1215	.. ..	calm	.. ..	342 4	360 5	323 6	.. ..
		1710	.. ..	164 8	.. ..	135 5	146 4	40 5	.. ..
May 26, 1927	1345	1223	.. ..	56 4	.. ..	72 7	79 6	.. ..	.. ..
		1722	.. ..	185 8	.. ..	203 9	211* 7*	.. ..	.. ..
June 13, 1927	1600	1233	.. ..	162 2	.. ..	72 5	349 3	63 3	31 3
		1715	.. ..	208 13	.. ..	217 11	225 9	235 7	280 3
May 9, 1928	1745	1145	.. ..	76 7	.. ..	115 11	117 5	90 4	.. ..
		1720	.. ..	90 3	.. ..	153 4	180 4	159 5	.. ..
July 17, 1928	1820	1720	.. ..	22 6	.. ..	23 5	45 3	63 5	60 5
		1830	.. ..	76 3	.. ..	328 13	339 8	335 8	332 9
August 2, 1928	1815	1715	.. ..	85 16	88 18	90 20	95 18	.. ..	.. ..
		1833	.. ..	152 9	125 9	113 9	108 11	.. ..	.. ..
March 18, 1929	1530	1215	95 8	107 9	.. ..	133 10	165 7	.. ..	.. ..
		1717	172 9	132 9	.. ..	78 11	81 12	.. ..	.. ..
March 26, 1929	1710	1225	.. ..	37 11	.. ..	25 9	27 11	.. ..	.. ..
		1700	.. ..	59 7	.. ..	45 5	45 5	.. ..	.. ..
March 27, 1929	1530	1225	.. ..	40 7	38 9	40 10	.. ..	.. ..	.. ..
		1700	.. ..	172 8	75 7	57 11	.. ..	.. ..	.. ..
May 17, 1929	1645	1230	.. ..	52 7	41 10	45 7	.. ..	.. ..	.. ..
		1740	.. ..	198 4	11 3	30 5	.. ..	.. ..	.. ..
June 6, 1930	1620	1218	.. ..	106 8	93 8	85 7	65 9	.. ..	.. ..
		1650	184 14	190 13	212 5	135 3	9 7	.. ..	.. ..
April 10, 1931	1830	1645	23 10	27 8	45 6	50 9	.. ..	.. ..	.. ..
		1950	183 9	180 7	34 2	70 13	.. ..	.. ..	.. ..
June 23, 1932	1335	1230	.. ..	143 5	.. ..	155 5	143 3	78 5	.. ..
		1705	.. ..	187 15	.. ..	183 9	185 7	calm	.. ..

\* 2,400 ft.

*Temperature.*—About half the cases examined were accompanied by no definite temperature changes, but in the remaining half there were either sudden drops of from one to four degrees Fahrenheit at the onset of the sea breeze, or the abrupt commencement of a pronounced diurnal fall of temperature.

*Humidity.*—About one-third of the cases were characterised by no definite changes in relative humidity, but the remainder evidenced some striking increases with the arrival of the sea breeze. Rapid rises of between five and ten per cent. were recorded, and increases of twenty-five or thirty per cent. within about half an hour following the onset of the sea breeze occurred in several cases.

The vapour pressures before and after the sea breeze commenced were computed from the dry- and wet-bulb observations at the nearest reporting hours, or failing that from the thermograms and hygrograms, provided that these records revealed significant changes in temperature or relative humidity or both. There were 38 cases for which such computations could reasonably be made, and in 34 of these the vapour pressure after the arrival of the sea breeze was greater than before its arrival. The mean values of vapour pressure before and after for the 38 cases were 11.2 mb. and 12.9 mb. respectively. The largest rise on an individual occasion was from 9.8 mb. at 1600 to 14.6 mb. at 1800, the onset of the breeze having been at 1730.

*Weather.*—There were no cases in which any change in general weather or sky conditions were reported to have accompanied the onset of the sea breeze. Cloudless or almost cloudless skies characterised the days with sea breeze on about half the occasions examined, and in the majority of the remaining cases, the clouds were detached cumulus with or without high cloud.

*Visibility.*—The available observations do not reveal any occasions on which deteriorations or improvements in visibility occurred that could definitely be attributed to the arrival of sea breeze, in fact there appear to be very few cases in which any appreciable changes in visibility took place. Since, however, it is to be expected that any such changes would normally be quite small, it is probable that for their detection more detailed and frequent observations of visibility would need to be made than has been the case over the period examined.

**Maximum day temperatures at Worthy Down, Calshot, and St. Catherine's Point, Isle of Wight.**—The maximum temperatures on sea-breeze days at Worthy Down were first tabulated for Worthy Down and Calshot, and Table VI indicates the frequencies with which the difference between the maximum at Worthy Down and the maximum at Calshot attained certain values (°F.).

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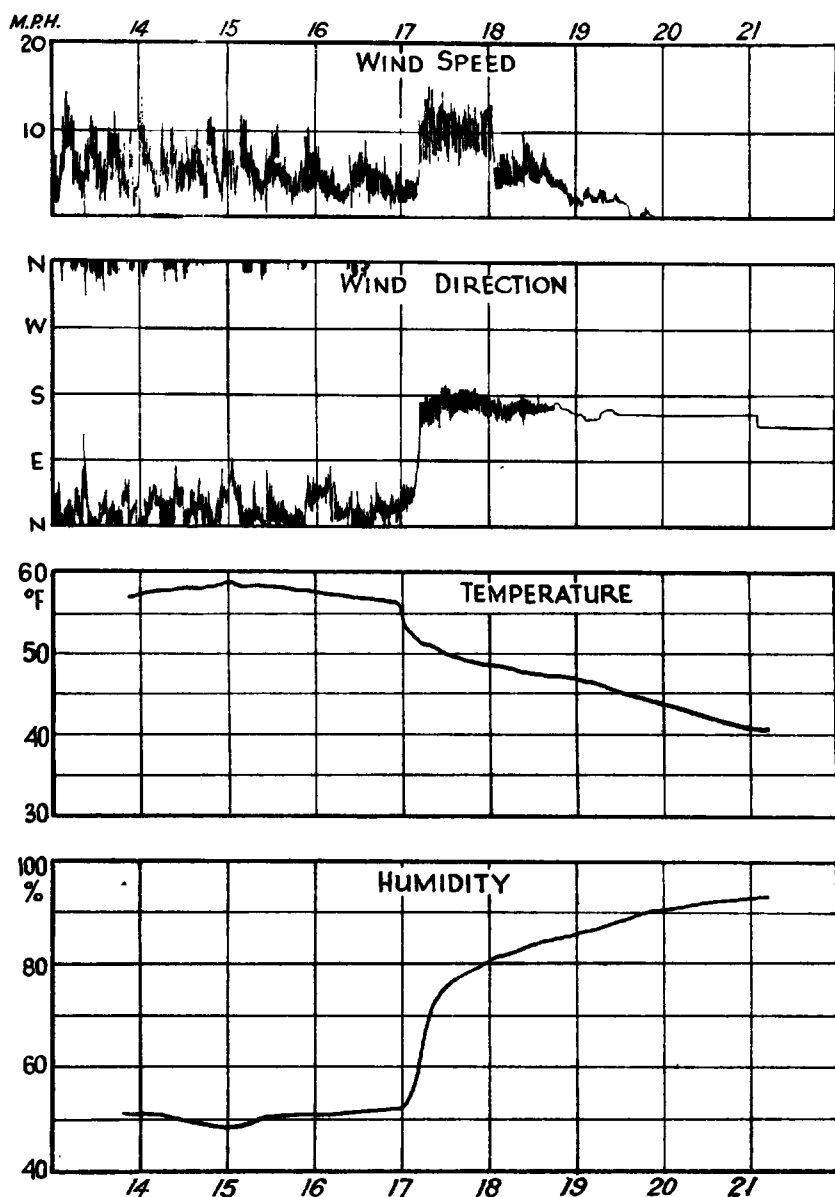


FIG. 1. AUTOGRAPHIC RECORDS, WORTHY DOWN  
MARCH 26, 1929

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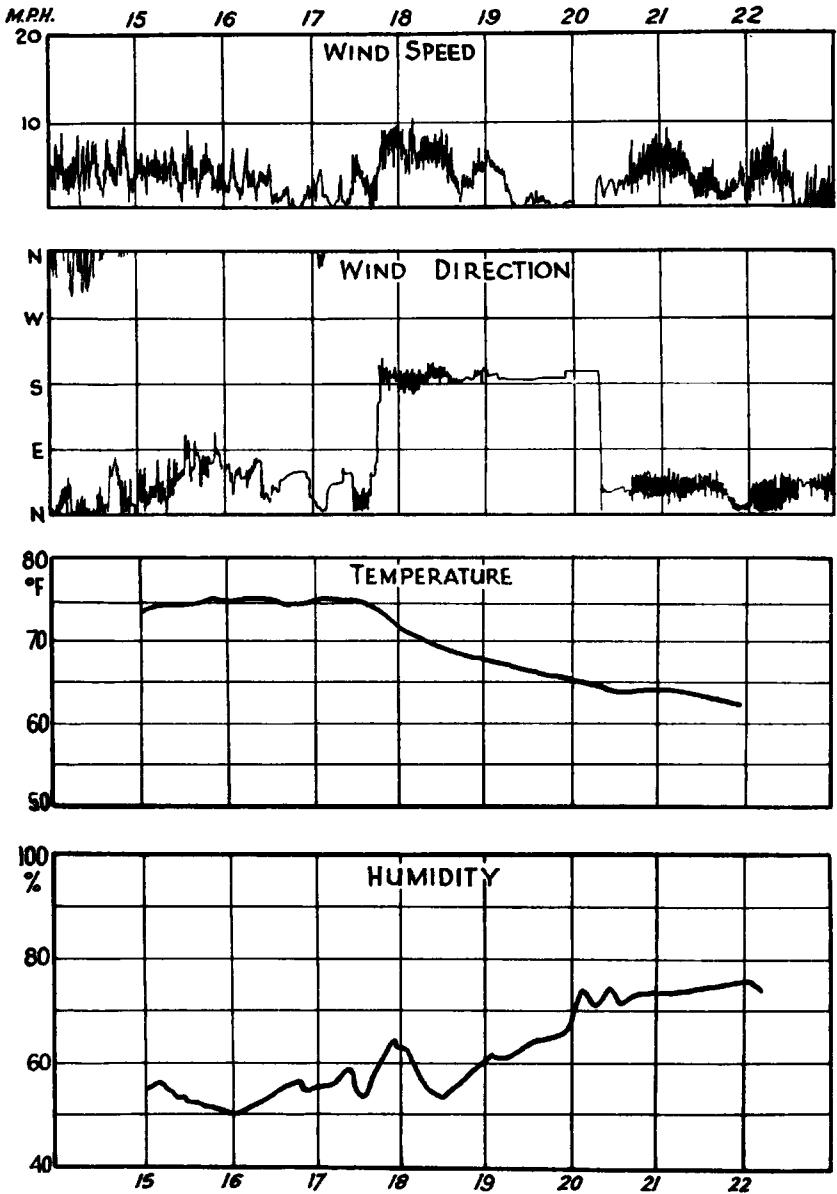


FIG. 2. AUTOGRAPHIC RECORDS, WORTHY DOWN  
MAY 29, 1928



TABLE VI

No. of occasions on which Max. (Worthy Down)—Max. (Calshot) was

>+11°	+11°	+10°	+9°	+8°	+7°	+6°	+5°	+4°	+3°	+2°	+1°	0°	-1°	-2°	-3°	-4°	-5°
2	1	0	2	2	1	6	2	6	3	3	7	4	7	7	4	1	0

Thus in 35 cases the maximum day temperature was lower at Calshot than at Worthy Down, whilst in 19 cases it was higher. The highest positive difference was one of 18° F.

A similar tabulation was then carried out for Worthy Down and St. Catherine's Point, Isle of Wight, which station may be taken as more representative than Calshot of coastal conditions in the Isle of Wight area. The results are given in Table VII.

TABLE VII

No. of occasions on which Max. (Worthy Down)—Max. (St. Catherine's Point) was

>+11°	+11°	+10°	+9°	+8°	+7°	+6°	+5°	+4°	+3°	+2°	+1°	0°	-1°
5	2	5	2	9	6	7	5	6	4	2	3	1	1

This table indicates that the maximum day temperature at St. Catherine's Point was lower than at Worthy Down on 56 out of the 58 occasions, the most frequent condition being a maximum temperature at Worthy Down 8° F. in excess of that at St. Catherine's Point. The greatest excess was one of 21° F. A comparison of Table VI with Table VII affords an indication of the sheltering effect of the Isle of Wight which is enjoyed by Calshot.

**Description of typical examples.**—This description of the general features associated with sea breezes at Worthy Down is best concluded by briefly indicating the main characteristics of certain actual occurrences for which the appropriate autographic records are reproduced in Figs. 1 to 5.

*March 26, 1929. Sea breeze commenced at 1710. Fig. 1.*—On this occasion an anticyclone covered the British Isles and there was no definite pressure gradient, but a light N. to NE. wind of convectional type occurred at Worthy Down prior to the arrival of the sea breeze. The onset of the sea breeze was sudden, the surface wind veering to SSE. and increasing from 3 to 10 m.p.h., gusting to 16 m.p.h.; this wind was of frictional type. It lasted for about 3 hours, when conditions became calm and the previous northerly wind did not reassert itself. The visibility was recorded as J (6¼ miles) at 1600, and H (2½ miles) at 1800, i.e. after the arrival of the sea breeze.

The Worthy Down day maximum temperature was 62°F, that at Calshot being 56° F. and St. Catherine's Point 54° F.; the day was almost cloudless,

The Calshot anemogram for this day indicated that the wind there was light and variable until 1115 when it became SSW. to S., but remained very light. At 1400 it backed to between S. and SE. and increased to 5-10 m.p.h. If this is regarded as the onset of sea breeze at Calshot then assuming it to travel to Worthy Down with an average speed of 7.5 m.p.h., its arrival there at about 1700 would be indicated. It actually set in at 1710.

The vapour pressure at Worthy Down was 8.5 mb. at 1700 and 10.9 mb. at 1800.

*May 29, 1928. Sea breeze commenced at 1745. Fig. 2.*—The southern part of England was an area of almost uniform pressure, such gradient as existed being for light easterly winds. At Worthy Down the wind varied between E. and N., with speed not exceeding 5 m.p.h., but the arrival of the sea breeze at 1745 was characterised by a veer from NNE. to SSW. and an increase of speed to about 8 m.p.h. The sea breeze died away between 1900 and 2000, and at about 2030 a NE. wind was re-established.

This was a case in which sea breeze occurred on a cloudy day, and also when the day maximum temperature at Calshot (79° F.) exceeded that at Worthy Down (77° F.). At St. Catherine's Point, however, the maximum temperature was only 74° F.

The arrival of the sea breeze at Calshot was not well defined on this day.

*July 12, 1928. Sea breeze commenced at about 1710. Fig. 3.*—A belt of high pressure covered southern England and there was no definite pressure gradient. Prior to the sea breeze the wind was fickle from between S. and W., with gusts to 20 m.p.h. and lulls to 2 m.p.h. The arrival of the sea breeze was marked by the establishment of a steady wind from S. with mean speed about 7 m.p.h.

This was a cloudless day with a maximum temperature of 72° F. at St. Catherine's Point, 83° F. at Calshot, and 82° F. at Worthy Down. The vapour pressure was 11.0 mb. at Worthy Down at 1700 and 14.3 mb. at 1800.

The sea-breeze onset at Calshot was rather gradual, but it appeared to have become established there by 1130.

*April 21, 1929. Sea breeze commenced at 1750. Fig. 4.*—An anticyclone was situated north-west of Ireland, giving a gradient for N. or NE. winds of a magnitude which would have been thought to be too great to permit of the development of a sea breeze. The average speed at the surface of the N. to NE. wind at Worthy Down before the sea breeze was 10 m.p.h., but gusts of over 20 m.p.h. were occurring. On the arrival of the sea breeze a rapid veer to SSE. took place accompanied by a drop in speed from 10 m.p.h. to 5 m.p.h., but an increase to 9 m.p.h. followed at 1800. The sea breeze died away gradually between 1900 and 2100, and at 2130 the north-easterly wind reasserted itself.

Temperatures were relatively low on this day, the maximum at St. Catherine's Point being 49° F., at Calshot 52° F., and at

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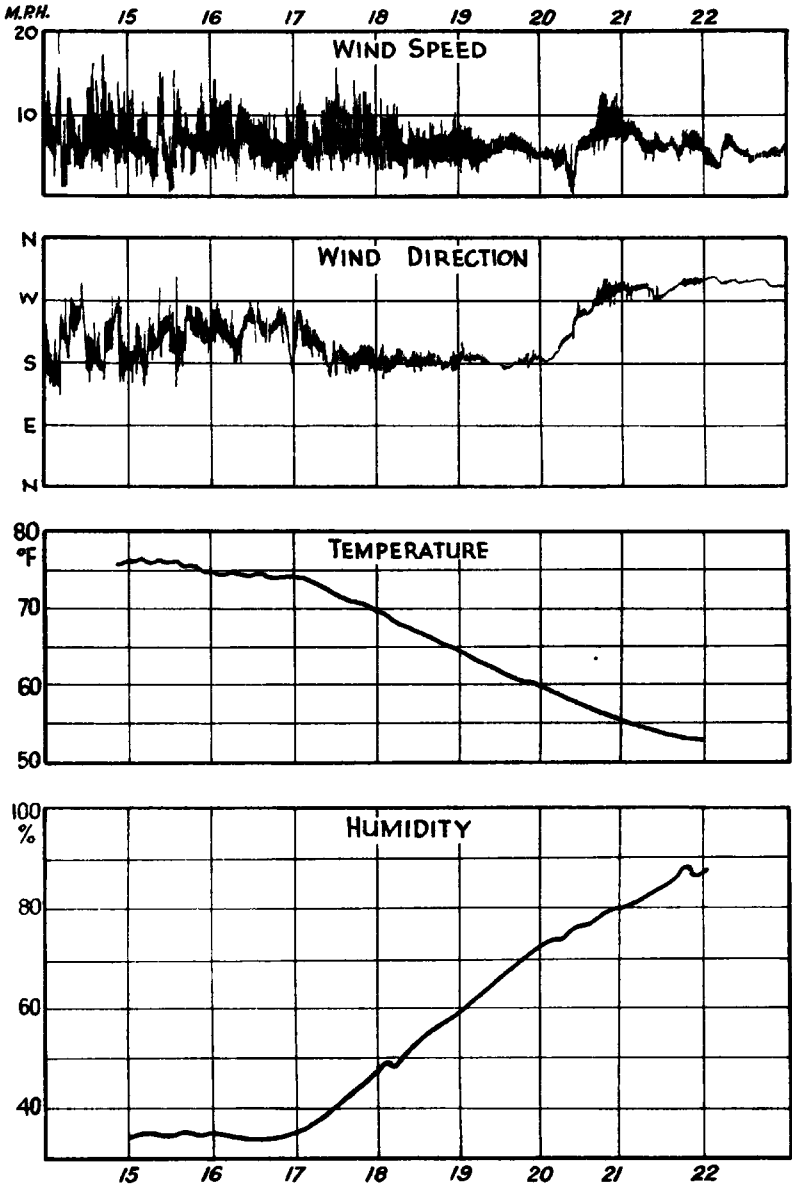


FIG. 3. AUTOGRAPHIC RECORDS, WORTHY DOWN  
JULY 12, 1928

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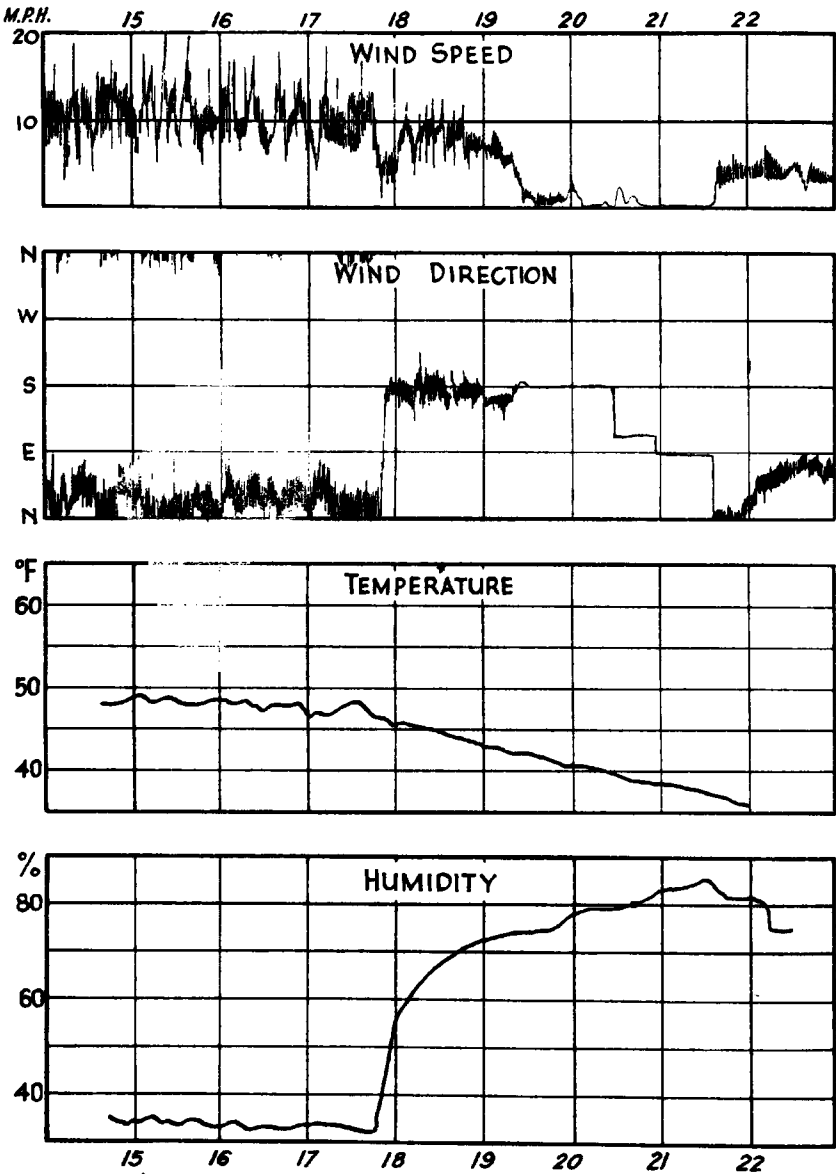


FIG. 4. AUTOGRAPHIC RECORDS, WORTHY DOWN  
APRIL 21, 1929.

Worthy Down 53° F. The day was almost cloudless. At Calshot the wind until midday was NE. 20–25 m.p.h., then decreasing to 10–20 m.p.h. until 1350, when the sea breeze set in abruptly from ESE., with a speed of 15–20 m.p.h.

*September 4, 1929. Sea breeze set in gradually. Fig. 5.*—Pressure was uniform over the British Isles. As the day progressed, the wind from being light and variable gradually settled from a southerly point, and at 1620 the convectional character of the direction trace disappeared and a definite wind from SE.'S. occurred, which veered gradually to SSW. by 1800. The speed of the wind averaged about 5 m.p.h. until about 1600 and then slowly increased to 8 m.p.h. by 1645. The sea breeze died out at 1900.

This case was selected as being illustrative of those which were not accompanied by any well-marked features.

The day maximum temperature at Worthy Down was 86° F., at Calshot 77° F., and at St. Catherine's Point 79° F.; the day was cloudless.

**Horizontal extent of sea breezes.**—The demonstration which these records and observations afford that sea breezes may occur as far inland as Worthy Down, prompts an inquiry into how much further they may penetrate, in favourable circumstances. It is also pertinent to inquire whether sea breezes at Worthy Down are, in general, a purely local phenomenon, due possibly to particular topographical effects, or whether they may cover considerable areas to eastward and to westward of that station.

The existence of meteorological stations at Larkhill, Porton and Boscombe Down, to westward of Worthy Down, and at South Farnborough to eastward, all four stations being situated further inland from the south coast than is Worthy Down, permitted some consideration being given to these questions.

The positions of these stations are given in the following table.

Station	Distance from Worthy Down	Distance inland from south coast of England
	miles	miles
Larkhill .. .. .	22 to west-north-west .. ..	33
Porton .. .. .	17 to west by north .. ..	28
Boscombe Down ..	19 to west-north-west .. ..	31
South Farnborough ..	28 to north-east by east ..	35

Larkhill is 6 miles and South Farnborough 11 miles north of the latitude of Worthy Down.

Such autographic records as were available for these stations for the investigated occasions of sea breeze at Worthy Down were examined, and the following is a summary of the results which emerged :—

(a) Evidences of the occurrence of sea breezes were found at all four stations.

(b) At Larkhill, the station for which the most complete series of records was available, a sea breeze was experienced on some 50 per cent. of the Worthy Down occasions.

(c) There was considerable difficulty in identifying the arrival of sea breezes at South Farnborough owing to the absence of records of wind direction for that station; there were, however, some 10 occasions on which features of the thermograms, hygrograms, and wind speed records served to indicate sea breezes with a fairly high degree of certainty.

(d) On six of the occasions at South Farnborough just referred to, sea breezes were also experienced at Larkhill, the most westerly of the four stations; in these cases it may therefore be considered that a sea breeze had penetrated 35 miles inland over a zone at least 45 miles in width.

(e) The times of onset of sea breeze at Larkhill, Worthy Down and South Farnborough on the six occasions referred to under (d) are given in Table VIII, together with values of mean surface wind direction and speed in miles per hour attained by the sea breeze at its onset:—

TABLE VIII

Date	Larkhill		Worthy Down		South Farnborough	
	Time of onset	Wind at onset	Time of onset	Wind at onset	Time of onset	*Wind at onset
1927						
April 18	1715	S.11	1635	SSE.9	1830	3
May 25	1745	SSE.15	1530	SSE.10	1515	5
May 26	1900	S'E.14	1345	S'E.8	1650	8
June 13	1550	SSE.15	1600	S.15	1715	13
1929						
May 20	2015	ESE.10	1815	SE'S.10	1855	8
1932						
June 23	1430	SSW.7	1335	S.14	1330	5

\* No direction records for South Farnborough.

It will be observed that for all the occasions, with the exception of May 26, 1927, the times of onset at the three stations show some measure of mutual agreement; the late onset at Worthy Down on May 20, 1929, is, for instance, reflected in the times for Larkhill and South Farnborough for that day, and likewise in the case of the early onset on June 23, 1932. It appears, however, that the wind speed at the onset of the sea breeze at Worthy Down cannot generally be used to anticipate with any accuracy the time of onset at other stations; this is not surprising, in view of the fact pointed out in the introduction to this note that the intensity of a sea breeze depends on the character of the gradient wind on which it is superimposed, and considerable differences in this gradient wind may occur at places situated 50 miles apart. It may, nevertheless, be noted that the time of arrival of the sea breeze at Larkhill on

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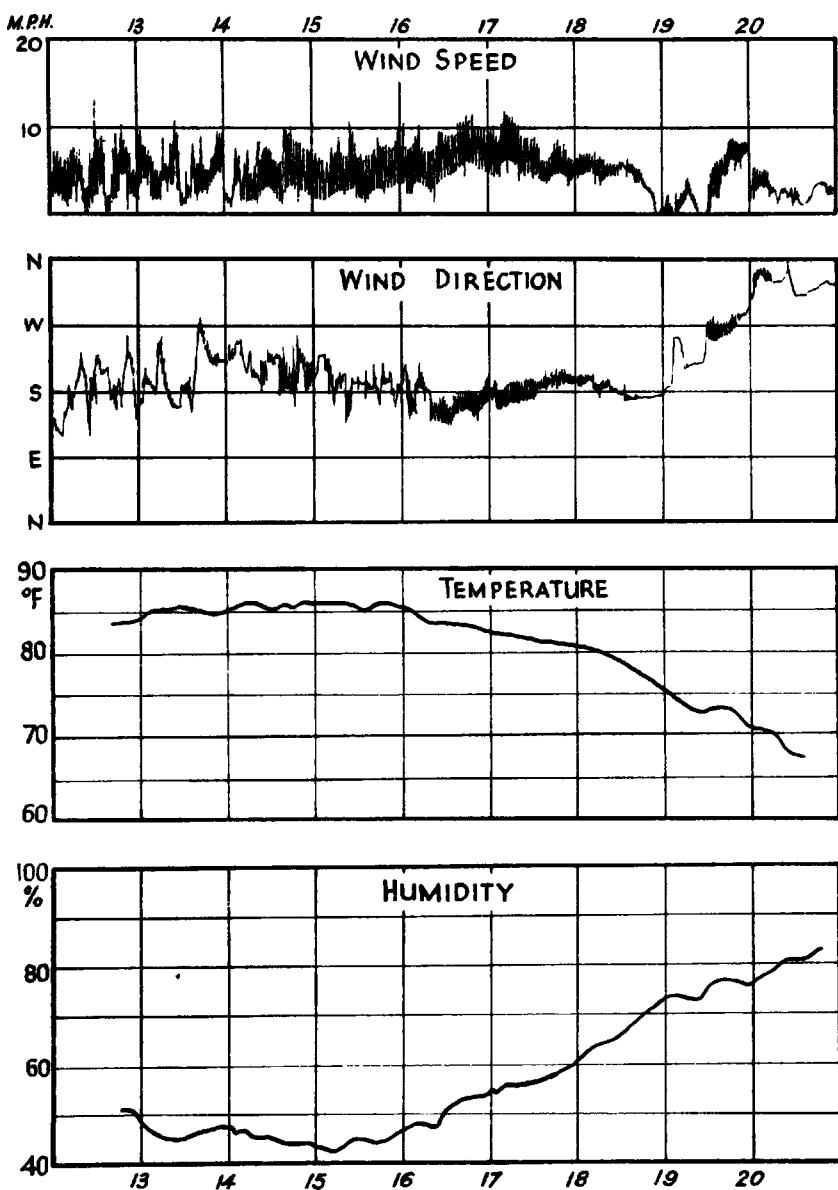


FIG.5. AUTOGRAPHIC RECORDS, WORTHY DOWN  
SEPTEMBER 4, 1929.





April 18, 1927, is in good agreement with the assumption of a movement of the sea breeze "front" northward from the latitude of Worthy Down at a speed of 10 m.p.h., whilst its arrival at South Farnborough is in accord with a speed of propagation of 6 m.p.h., which is the mean of the speeds of the sea breeze on its arrival at Worthy Down and at Farnborough respectively.

**Conclusion.**—The records and observations which have been examined in the preparation of this note reveal that sea breezes may penetrate as much as 35 miles inland from the south coast of England, which is considerably further than has been commonly supposed, judging from statements in textbooks that they are seldom experienced more than 10 to 15 miles inland. Evidence has also been adduced to show that their vertical extent may sometimes be considerably in excess of 1,000 ft., a height that has often been regarded as the normal upper limit to a sea breeze.

#### APPENDIX

Mr. C. V. Ockenden, the present Meteorological Officer at Boscombe Down, had noted a few striking cases of sea breeze effects at Worthy Down before he was succeeded at that station by Mr. Peters. He states that :—

"The sea breeze effect is primarily of academic interest; its effect on the general weather conditions (usually settled) is comparatively unimportant. A forecaster should, however, keep in mind the possibility of the breeze setting in on favourable occasions, for the following reasons :—

(a) With a very weak pressure gradient, the time of formation of valley mists or fog is usually very much earlier on nights when the moist southerly air has penetrated far inland during the evening than on other occasions.

(b) If the pressure gradient is appreciable, and particularly if the prevailing wind is easterly, the re-establishment of the normal wind after the sea breeze has died away may result in the formation of cloud. Actually, this formation has been observed only very occasionally, partly owing to the lateness of the hour.

(c) Although the breeze itself is of small concern to aircraft because its factor of gustiness is very low and its mean speed is usually slightly less than 10 m.p.h., it is of some importance to pilots to know, if possible, whether the wind is likely to become merely light and variable later, or whether, as sometimes happens an increase is to be expected with the abrupt reassertion of the wind appropriate to the general pressure gradient."

