An Introduction to the Sea Breeze Front

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On a sunny day the temperature at the surface of a land area rises more quickly than that of an adjoining sea surface, the sea being heated to a greater depth than the land. Therefore the air over land is heated more quickly than that over the sea, and if the sea air is colder than that over the land then, in calm, light or possibly moderate winds, the horizontal temperature gradient across the coastline is intensified.

An early consequence of this differential heating across the coastline is an almost imperceptible rise of pressure over land at a height of about 3000 ft. (1000 m) or more accompanied by a slow seaward flow of air at about the same level. As a result of this upper air movement the pressure over land decreases very slightly and air at low levels flows inland from the sea. At first this landward flow, called the sea breeze, blows almost directly across the coast but as the M.S.L. pressure inland continues to fall (still only slightly) the sea breeze increases in strength and begins to veer. At the coast it is often at its strongest and is directed at about 40 degrees to the coastline by midday, but from then on the speed decreases, although the direction continues to veer until by late afternoon the breeze is almost along the coast.

The distance inland to which the sea breeze penetrates depends on the duration and strength of the sunshine, on the height to which the heat from the sun is distributed, on the direction and speed of the superimposed general wind flow and on the sea temperature. In the tropics sea breezes are felt at distances up to about 150 naut. miles (300 km) inland from the shore, while in temperate latitudes about 50 naut. miles (100 km) is considered a deep penetration. But these figures form only a rough guide; on a hot July day [1] in 1949 a sea breeze from the Thames estuary (England) was detected as far as 100 naut. miles (200 km) inland from the upwind coast. Figure 1 shows isochrones marking the leading edge of the sea breeze as it passed meteorological observing stations in southern England, and the items below are extracts from observations recorded at twelve of these stations.

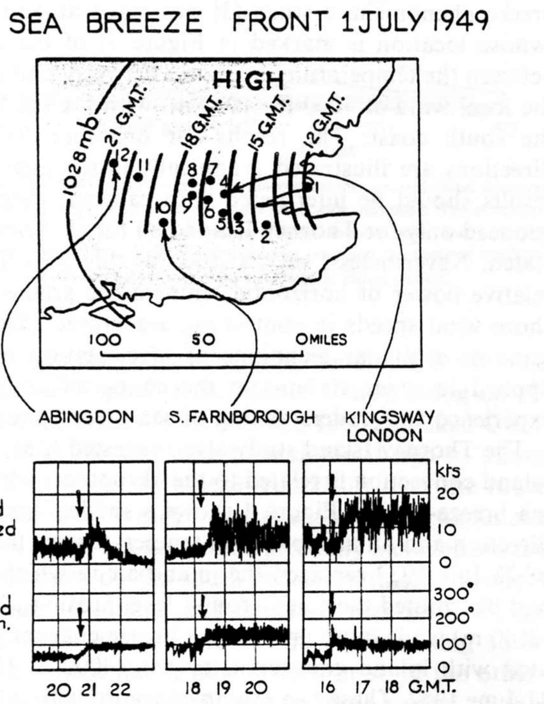

Fig. 1 Observations from the meteorological offices labelled 1–12 and named in the text were used to plot the hourly isochrones of the position of the sea breeze front which advanced inland from the Thames estuary. The autographic records illustrate the changes in wind speed and direction at the passage of the front

Sea breeze across London, 1st July 1949

Ref. in Fig. 1 Place	Time of arrival of sea breeze GMT	Wind direction in degrees and speed in knots		Highest gust in knots	Air temperature in deg. F.		Relative humidity	
		B	A	A	B	A	B	A
1. Shoeburyness	1130	080/1	130/7	8	64	63	56	65
2. W. Malling	1530	060/7	060/14		75	70	46	60
3. Biggin Hill	1550	030/2	060/10		76	69	40	62
4. Kingsway	1605	030/6	090/12	23	76	72	46	63
5. Croydon	1610	030/4	060/10	18	78	73	38	60
6. Kew	1640	050/6	100/15	22	77	72	37	59
7. Hendon	1650	050/6	100/8	—	77	72	35	59
8. Northolt	1725	040/10	100/13	—	77	71	36	57
9. London Airport	1730	030/6	080/15	20	79	71	34	54
10. South Farnborough	1810	070/3	120/9	20	77	69	40	68
11. Benson	1950	360/6	060/10	—	—	—	—	—
12. Abingdon	2040	060/4	100/8	16	—	—	—	—

B = Before the arrival of the sea breeze
A = After the arrival of the sea breeze

The sea breeze front

Before the arrival of the sea breeze of 1st July 1949 winds were light and mostly NE'ly but the air from the sea spread inland as a slightly stronger flow from between 060 and 130 degrees, and the rapidity of the change was well marked on the autographic records at those stations equipped with pressure tube anemometers. Equally abrupt changes registered in the measurements of temperature and humidity showed the transition zone between the cool moist sea air and the drier inland air to be very narrow. In fact this transition zone was frontal in that it comprised a horizontal temperature gradient which after an initially gradual tightening had triggered off an intricate self accelerating process which tightened the temperature gradient even more—and persisted for a while even after the original cause (in this case differential heating) had disappeared. Thus the *sea breeze front* can be considered as a shallow ephemeral species of cold front; warm inland air rises ahead of the wedge-like advance of cool air from the sea.

Sea breeze conditions

To glimpse both the force and the fickleness of the sea breeze phenomenon let us look at the autographic wind, temperature and humidity records [2] for three days in June at Gdansk on the coast of Poland. They are reproduced in Figure 2. During the morning and early afternoon of the first day,

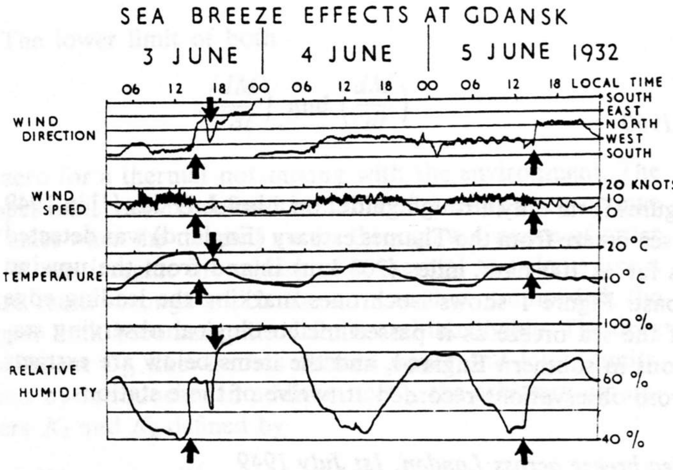

Fig. 2 Arrows indicate sea breeze effects on the autographic records

3 June, a gusty 12 knot (24 km/h) WSW'ly airstream was maintained by the prevailing pressure gradient while bright sunshine produced an appreciable rise in temperature. This rise continued until, quite suddenly, at 1420 hours local time, the sea breeze arrived from a NE'ly direction bringing with it cool and moist air from the Baltic. The recorded rise in humidity is even more abrupt than the temperature fall. A sea breeze is not necessarily stronger or more gusty than the winds inland and perhaps the light wind speed, of only 5 knots (10 km/h), in this sea air at Gdansk on 3 June was an indication that the sea breeze was not as firmly established as the autographic records suggested, for at 1620 hours, wind, temperature and humidity changes marked the return of the inland air which persisted for an hour before the sea breeze set in once again with a repetition of its earlier effects.

During the night of 3–4 June the wind became practically calm and, of course, the indicated wind direction in such conditions is of little or no significance. A slight change of the general pressure pattern occured during the night and when the wind speed did increase after dawn on 4 June it brought from a NW'ly direction air cool enough to reduce the rise in temperature which the day's sunshine would otherwise have produced. So on the second of the three days there was not enough heating to bring the sea breeze to Gdansk.

After another night of light winds the morning and early afternoon of 5 June was characterised by 10 knots (20 km/h)

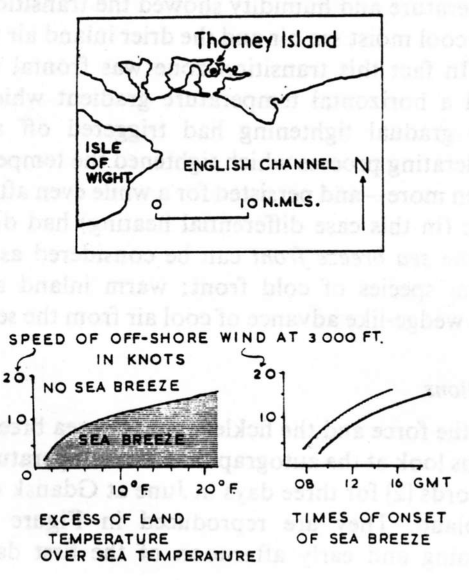

Fig. 3 When wind and temperature conditions are represented by points in the shaded section of the diagram on the left then a sea breeze is likely to reach Thorney Island some time in the interval indicated by the shaded band on the right

W'ly winds, convection cloud and a temperature rise to 16 °C (61 °F). This early afternoon temperature was no higher than that attained on the previous day, yet at 1430 hours on 5 June the sea breeze from the NNE set in with very sharp changes in wind, temperature and humidity. Notice that during the sea breeze period, between 1430 hours and 2100 hours, the wind speed showed four more or less regularly spaced oscillations between about 4 and 9 knots (8 and 18 km/h). Mathematical analysis has shown that wind speed pulsations such as these are not inconsistent with other more distinctive features of sea breeze phenomena, but it is practically impossible to predict just whether or not these pulsations will be significant or discernible in any particular sea breeze. It is, in fact, difficult in many temperate latitude countries to predict

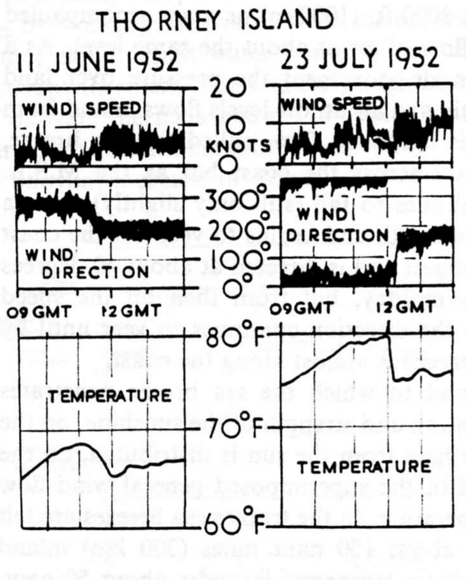

Fig. 4 Autographic records showing sea breeze effects on a day of shallow convection (11 June 1952) and deep convection (23 July 1952)

whether or not the sea breeze will occur at all on any particular day.

In an attempt to devise simple rules for forecasting sea breeze phenomena a study [3] was made at Thorney Island (whose location is marked in Figure 3) of the relationship between the temperature difference between land and sea and the local wind at 3000 ft. (1000 m) with the sea breeze from the south coast. The results for off-shore 3000 ft. wind directions are illustrated graphically in the figure, but these results should be interpreted with caution; they have been deduced only for Thorney Island and for the wind directions stated. Nevertheless, such a study as this does illustrate the relative power of horizontal temperature gradients and off-shore wind speeds in controlling sea breeze effects, and the same or a similar technique of investigation may well be applied to other stations in the course of acquiring more experience and understanding of sea breeze phenomenon.

The Thorney Island study also suggested that the depth of inland convection is related to the abruptness with which the sea breeze sets in. Figure 4 shows a sudden change in wind direction and an abrupt fall in temperature as the sea breeze of 23 July 1952 replaced the inland air in which convection had distributed the sun's ground level heating up to 8000 ft. (2500 m) while more gradual sea breeze changes were associated with inland convection to only 4000 ft. (1300 m) on 11 June 1952. These two examples accord with other observations that the arrival of a sea breeze is likely to be established suddenly (in about 10 minutes) on days of deep convection but gradually, with perhaps fluctuations over a period of 1 to

2 hours, when convection from the ground is limited to a shallow layer in the atmosphere.

Soaring at the sea breeze front

The upward motion of the air at a sea breeze front is occasionally strong enough for soaring flight. On 6 July 1946, J.K. Mackenzie [4] soared under a line of cumulus marking a sea breeze front for most of a late afternoon three hour flight in the neighbourhood of Lasham, England. With the sea breeze front orientated ENE–WSW and moving inland from the English south coast at about 5 knots (10 km/h), lift, occasionally as strong as 1500 ft./min (7.5 m/sec), was located in a belt just north of the air advancing from the sea. The belt was a narrow one, only 100–250 yards (or metres) wide but it was possible to climb to about 4000 ft. (1300 m) provided the glider was flown straight along the landward side of the sea breeze front. Circling flight was tactically useless for soaring since downdraught existed immediately to the north (as sketched in Figure 5) and all but a thin slice of the cool sea air was void of lift. The thin, steeply inclined wafer of sea air which did rise was significant not for its weak lift but for its wisps of cloud which, having formed in the cool, moist rising sea air, clearly marked the sea breeze frontal zone. With such a visible guide as this, soaring close to a sea breeze front resembles mountain slope soaring, the wispy curtain of cloud taking the place of the mountain slope.

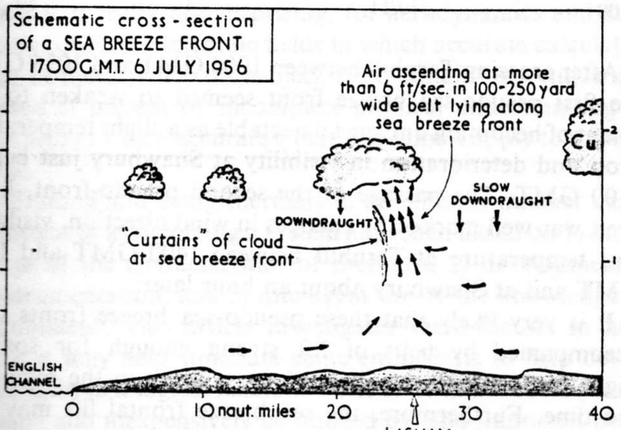

Fig. 5 In this cross-section of a sea breeze front the vertical motion and cloud structure are illustrated schematically and not to the horizontal scale indicated. The structure, which was first sketched by J. K. Mackenzie, is almost identical with that noted by E. A. Moore on 21 May 1958. On this latter occasion, however, sections of the front were marked by a visibility contrast rather than a distinctive cloud pattern

Unlike the mountainside, of course, the cloud is liable to move and may disappear. E.A. Moore soared along an almost cloudless sea breeze front between 1800 and 2000 GMT on 21 May 1958. He was able to maintain heigh at about 3300 ft. (1000 m) in a sea breeze frontal lift over the route Lasham–Winchester–Wisley. Fortunately the pronounced haziness of the moist sea air (which probably included smoke from urban districts on the south coast) contrasted strongly with the cleaner air inland, and the sea breeze wall of haze could be followed even to the extent of discerning some indentations of about half a mile (1 km) or so in the otherwise smooth NNW face of the front. During most of this flight lift was weak, only about 200 ft./min (1 m/sec) and confined to within a belt not more than 150 yards wide, but some pointers to the position of this narrow belt were provided not only by the haze and isolated wisps of cloud (about 200 yards south of the best lift) but also by a few smoke plumes which converged from the WNW in the land air and from WSW in the sea air towards the sea breeze front.

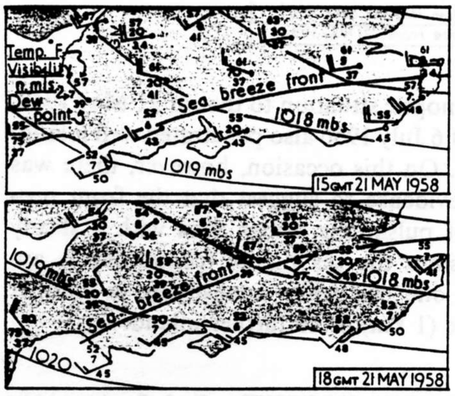

Fig. 6 Two synoptic charts for 21 May 1958

The sea breeze soaring flights by Mackenzie and Moore were both made in airstreams favourable for convection from ground level up to between 7000 and 10,000 ft. (2100 and 3000 m) and it is instructive to examine in detail some of the relevant weather records.

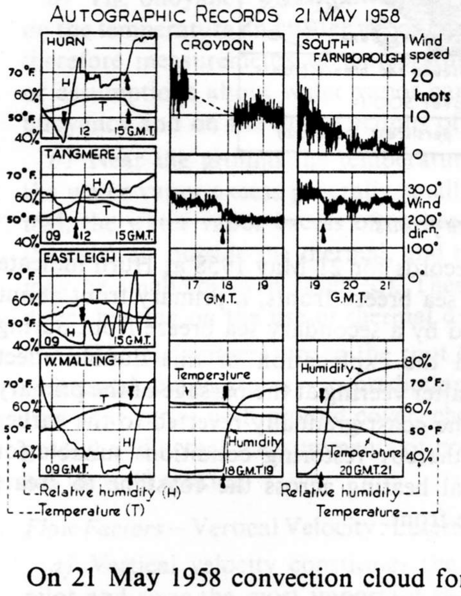

Fig. 7 Large arrows point to sea breeze effects. A second sea breeze appears to have affected Hurn. Showers caused the humidity fluctuations at Eastleigh during the afternoon. The break in the Croydon record is due to an instrumental fault

On 21 May 1958 convection cloud formed over southern England in a fresh westerly airstream bringing showery conditions to much of Britain. The synoptic charts, two of which are shown in Figure 6 and the autographic records shown in Figure 7 show significant wind direction and humidity changes across the sea breeze front. The isochrones drawn in Figure 8 show that the sea breeze front penetrated well inland, especially in the east—in fact the hourly synoptic charts indicate that the sea breeze front may well have moved into the Thames estuary as a paradoxical sea breeze from the land.

It is also feasible that the sea breeze front extended further southwestwards than marked on the map. It is very likely that some soaring flights have been sustained by off-shore sections of a sea breeze front, but when exploring such soaring conditions it is wise to remember that the lift in a well marked sea breeze front has often been observed to occur in a narrow belt sandwiched between broader zones of downdraught.

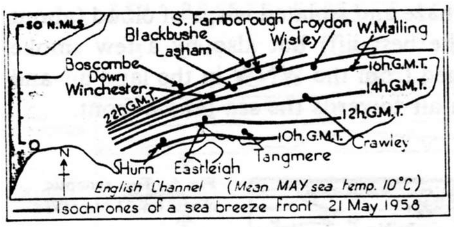

Fig. 8 Sea breeze frontal progress 21 May 1958

In a very similar synoptic situation to that of 21 May 1958, the sea breeze front of 6 July 1956 also penetrated well inland, especially in the east. On this occasion, however, there was some observational evidence to suggest that the front progressed in a series of pulsations rather than with a steady movement; on occasions the sea breeze frontal effects appeared to decline in one belt while intensifying in another belt about half a mile (1 km) or so farther inland.

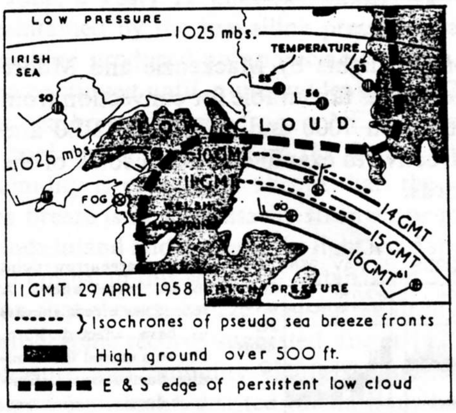

Fig. 9 Pseudo-sea breeze fronts appeared to move southwards from the southern edge of a persistent low cloud cover

Secondary sea breeze fronts

The autograph records for 21 May 1958 at Hurn indicate the passage of two sea breeze fronts, a primary front about 1015 GMT followed by a secondary sea breeze front during the afternoon, and the explanation of this double effect appears to be that, after veering at the passage of the primary front, winds near the coast gradually reverted to the earlier westerly direction thereby restoring conditions suitable for sufficient differential heating across the coastline to create a second sea breeze front.

Pseudo-sea breeze effects

Viewed from above, an extensive layer of low stratus can aptly be described as a sea of cloud and if this "sea" happens to have a clear cut edge over a land mass it may even promote the development of a pseudo sea breeze front. On 29 April 1958 [5] in the situation shown in Figure 9 a westerly airstream across England was moist enough to bring low stratus from over the Irish Sea into the Cheshire Plain and, with the Welsh Mountains blocking the advance of the low cloud immediately to the south, the low cloud over the NW Midlands was bounded by a fairly sharp edge south of which bright sunshine was able to warm the air at low levels sufficiently to produce small cumulus clouds. The low stratus was thick enough to prevent a rise in temperature in the area it covered and so conditions were ripe for a pseudo-sea breeze front to develop and move southwards. In fact there appeared to be a double frontal effect which produced weather changes like those recorded below, and it is quite feasible that the soaring conditions were somewhat similar to those found at genuine sea breeze fronts.

Observations recorded at Ternhill and Shawbury on 29 April 1958

Time GMT	Surface wind	Visibility (nautical miles)	Temperature (°F)
Ternhill			
09 00	280/14	20	59
10 00	250/13	25	59
	First frontal change		
10 35	350/13	3½	—
11 00	010/7	2½	55
12 00	020/4	4	56
13 00	250/6	10	60
14 00	230/9	25	62
	Second frontal change		
15 00	020/12	4	58
16 00	010/6	3½	57
Shawbury			
09 00	270/12	16	58
10 00	260/14	16	61
10 35	—	—	—
	First frontal change		
11 00	270/15	8	60
12 00	250/13	16	62
13 00	—	—	63
14 00	250/14	22	63
15 00	270/16	13	63
	Second frontal change		
16 00	340/11	4	59

After crossing Ternhill between 1000 GMT and 1035 GMT the first pseudo-sea breeze front seemed to weaken to the extent of becoming only just detectable as a slight temperature drop and deterioration in visibility at Shawbury just before 1100 GMT. The passage of the second pseudo-front, however, was well marked by changes in wind direction, visibility and temperature at Ternhill between 1400 GMT and 1500 GMT and at Shawbury about an hour later.

It is very likely that these pseudo-sea breeze fronts were accompanied by belts of lift strong enough for soaring flight, but no gliders happened to be flying in the region at the time. Furthermore, the sea breeze frontal lift may not have been readily recognised or located.

Insufficient experience has yet been accrued in locating a belt of a sea breeze lift without visual aids in the form of cloud, haze or converging smoke plumes. Whether it is feasible to use the temperature, humidity and wind changes across a sea breeze front as signposts to the belt of lift is a matter for further exploration offering ample scope for ingenuity in instrument design and flight technique.

References

[1] Marshall, W.A.L.: "Sea Breeze across London". Meteorological Magazine, June 1950, p. 165.

[2] Koschmieder, H.: "Danziger Seewindstudien". Forsch. Arb. meteor. Inst. Danzig. 8, p. 1–44, 1936, and 10, p. 1–39, 1941.

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