SOME OBSERVATIONS AND COMMENTS ON THE SEABREEZE

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Abstract: A brief review is made of some current sea breeze theories, with a view to answering some questions about sea breezes in Australia. It is concluded that no theory so far advanced is adequate satisfactorily to answer questions about the lateral extent of the circulation.

A brief interim report is presented on some observations made last summer in the Kalgoorlie-Esperance area, which show rather conclusively that, on occasion, the seabreeze circulation extends inland for at least 200 miles in a recognizable, although decadent, form.

I. INTRODUCTION

Seabreezes are of world wide occurrence, and have attracted a good deal of attention, both from professional meteorologists and others. One reason for their attractiveness to the theoretician lies in the fact that they appear to represent the simplest form of the atmospheric energy process: the conversion of radiant into kinetic energy. In Australia, summertime conditions are often highly favourable for seabreeze development and evidence is not lacking to the synoptic meteorologist that the mechanism plays quite an important part in our warm-season synoptic sequences. It has long been felt that some detailed investigation of the seabreeze effect on our daily weather sequences would be interesting both theoretically and to the forecaster. Of the large volume of data on the subject collected by the author, a small selection is presented below.
2. KOSCHMIEDER'S OBSERVATIONS

Of the observational data available from overseas sources, one of the most interesting series is that obtained by Koschmieder (1936-42) in Danzig. As these results are not well known in Australia a brief summary of the conclusions of Koschmieder and Hornickel follows. It is not however implied that these conclusions will apply without change to the very different conditions found in Australia.

The seabreeze at Danzig was divided into two types, depending on whether the gradient wind prevailing was offshore or nil. The case of onshore gradient winds, through lack of sufficient definition, was not studied. It was found that a moderate offshore gradient wind favoured seabreeze development; the breeze broke over the land as a minor cold front about the middle of the day; it propagated with a speed less than that of the normal component of wind; the upward motion in the sea air deduced from continuity considerations was the result of turbulent drag by the rising "land air", which also caused an offshore component of motion in the upper layers of the sea air; mixing was strong at the frontal boundary; the strength of the seabreeze was Beaufort 2, with 4-5 as maximum values; its height averaged 350m, but tended to show a progression upwards until 1500 hrs. and downwards thereafter; on the days studied, it was much more clearly defined than the land breeze; the mean slope of the frontal surface was about one in four over the first kilometer seawards of the leading edge, and one in 100 thereafter; it might be very steeply inclined in the lower levels, and in two cases it overhung, i.e. exhibited negative inclination; the deduced two-dimensional streamline picture at the leading edge of the front was similar to that deduced for cold front dust storms and is shown in figure 1.

![Figure 1: Deduced streamlines near leading edge of seabreeze front (After Koschmieder).](image-url)
The horizontal stream flow parallel to the sea breeze front showed cyclonic shear as demanded by Margules' frontal theory, with the exception of one case, when overhanging of the leading edge was detected and the shear was opposite to that required by the stationary (i.e., Margules) conditions. Before the incursion of sea air the land air had dry adiabatic or slightly super adiabatic lapse rate. Stable air over the land was believed to inhibit sea breeze development. Distinct pressure rises of about 4 mb were observed with the onset of the seabreeze. Tracing trajectories showed that cool sea air was rapidly warmed over the land (at 2 m height), at roughly 1 °C per 6 minutes; at this rate of heating and at a speed of 5 m sec⁻¹, the maximum depth of penetration should not exceed 15 km. Climatically, the seabreeze showed its influence through a distinctly earlier mean time of maximum temperature at coastal stations than inland. The other type of seabreeze with no superimposed gradient wind, set in earlier, was shallower (200 m) and lacked the strong contrasts in temperature, pressure and humidity observed in the first type. A "late" and "high" seabreeze, thought to be controlled by the general regime of the Baltic coast rather than by that of the Danzig Bight, was also noted on especially favourable occasions.

3. SOME SEABREEZE THEORIES

The broad outline of the theory of seabreezes is fairly well known. The sun shines on earth and water; because the latter is a fluid in more or less turbulent motion, the heating is distributed to a considerable depth, so that the surface rise of temperature is slight. On the other hand, owing to relatively small conductivity, the earth's surface heats rapidly and a transfer of heat across the earth-air boundary results in heating of the lower layer of air. This near-surface heating is distributed upwards by turbulent mixing. The rise in air temperature results in expansion, so that, aloft individual particles over land are lifted relative to those over the sea. Level for level, the pressure aloft, but not at the surface, becomes higher over the land than over the sea, and this results in a compensating outflow of air from near coastal areas over the land to those over the sea. The surface pressure thus falls over a coastal strip of land and rises over a coastal strip of sea. The pressure gradient thus set up in the lower layers from sea to land results in a lower level seabreeze. In reality, these factors operate simultaneously rather than consecutively, and if it were not for the effect of friction, which is far greater in low levels, the result would be a circulation accelerating as long as the supply of heat was maintained.
Instead of this, a balance is struck between the thermodynamic acceleration and the frictional retardation, which results in a rather close correspondence, although with some time lag, between maximum temperature over the land and intensity of the circulation. This rough account, does not mention the horizontal or vertical extent of the circulation, and these, especially the former, are precisely the things which no theory appears capable of predicting satisfactorily.

A satisfactory theory might be expected to begin from the known solar radiation, and physical properties of air, earth and water and to derive from known initial and boundary conditions the spatial and temporal distribution of motion, temperature, pressure density and humidity.

If it may be assumed that the rate of heat supply to the air is fully known as a function of space and time co-ordinates (in reality the heat supply is not independent, but is modified by the circulation it produces) then this equation, the gas equation, the continuity equation, and three equations of motion, six equations in all, suffice to define the six variables pressure, temperature, density and motion in terms of space-time co-ordinates. Unfortunately no general analytical solution of these non-linear equations is possible. However, a very recent attempt has been made to solve the problems by numerical computation (Pearce, 1955) and the advantages of this technique over the analytical are seen by the great supericity of the solution obtained.

All general theories so far put forward have necessitated a great many simplifying assumptions. Most have taken the temperature field as given, although it is in reality modified by the wind. We shall note some features of Defant's theory (1950), which is widely quoted:

1. a Fourier series expresses the horizontal distribution of the assumed periodic surface temperature. Time variation of this temperature is everywhere in phase.

2. a Guldberg-Mohn friction law (friction proportional to velocity) is assumed, with the proportionality factor constant at all heights.

3. An incompressible atmosphere is assumed.

4. Adveced velocity is neglected throughout.

5. Horizontal temperature advection is neglected.
One may record some serious objections to the above assumptions. That of equal phase everywhere disagrees with observations in Australia and at Danzig; the assumed friction law is quite unrealistic; the neglect of advective terms has not been justified and this is believed to invalidate the solution everywhere except in a narrow coastal strip; it is not possible to assess the error resulting from the use of a repeating function (Fourier series) for horizontal temperature distribution. In short, the assumptions can only be justified by expediency and one cannot expect the solution to shed any new light on the seabreeze phenomenon.

There certainly are some aspects of seabreezes which are explained by Defant’s theory. One is the turning of the wind "with the sun," so that the locus of the end-points of the wind vector for successive hours of the day is an ellipse with its axis oriented at an angle to the coast; this turning with time is seen to be an effect of including the Coriolis term in the equations of motion. The phase difference between temperature and wind, computed to be about one hour, is in fair agreement with observation in coastal areas and is due partly to frictional and partly to heat transfer terms in Defant’s equations. The strength of the breeze, $1.8 \Delta T$, in sec$^{-1}$, where $T$ is the maximum temperature difference ($\degree$C) between land and sea, is in rough agreement with observations at coastal places. The height of the theoretical seabreeze (500m) which is computed to be independent of $\Delta T$, is also in fair agreement with near-coastal observations.

However, a closer inspection reveals serious deficiencies in the theory. The phase is everywhere the same; only the speed varies at a fixed instant from place to place, being at a maximum over the coast. The land and seabreeze alternate with equal intensity. The observed extension of the circulation upwards and away from the coast during the day, and the frontal character of the seabreeze are entirely unaccounted for.

A study of other theories reveals similar deficiencies. That of Pierson (1950) represents an attempt like Defant’s, to solve the problem near the centre of a coastal strip, and is noteworthy for the use of a more realistic representation of eddy viscosity. As in Defant’s theory, advected velocity is neglected in order to linearize the equations of motion, so that the solution becomes inapplicable towards the edges of the circulation.

It was concluded, then, that observation, not theory, was the appropriate method of studying the finer details of the seabreeze phenomenon.
4. SOME SEABREEZE OBSERVATIONS

Interest in the subject was stimulated by observation of the afternoon easterly at Canberra, which has an altitude of over 1800 feet M.S.L. and is about 50 miles inland. It was established by car and aeroplane observations, that the easterly is a seabreeze and it was deduced that, on occasion, it may penetrate to Wagga, 160 miles from the coast, in a somewhat degenerate form. Answers to questionnaires sent to many places within 100 miles of the coast in New South Wales and Queensland suggested that the phenomenon was widespread, at least in the valleys; large scale seabreezes were common in summer inland from the long, relatively straight coastlines, and were not inhibited by the mountainous terrain. This conclusion appeared to be confirmed by accounts from many parts of the continent, from Batchelor, N.T., to Kalgoorlie, Forrest, Toomual, Renmark and Toowoomba, to mention only a few.

It was decided to make an investigation in an area as free as possible of orographical effects. Since the terrain from Esperance to Kalgoorlie slopes rather regularly and gradually, and since Hounam (1945) claimed that the seabreeze penetrated to Kalgoorlie, this area was chosen for a somewhat detailed on-the-spot examination. The Bureau of Meteorology kindly co-operated by lending instruments, donating hydrogen and balloons, and making available official records. Considerable assistance was also afforded by some volunteers residing in the area, and by Mr. E.R. Clarke, of Renmark, S.A. who accompanied the author. The programme was inevitably limited by available resources; no upper air observations of temperature or humidity were possible apart from the routine daily sounding at Kalgoorlie. Upper wind observations apart from those done at Kalgoorlie at six-hourly intervals, were limited to what could be made by the author and his companion. Surface wind observations were much less complete than desirable, owing to the lack of automatic instruments, except for the Dines Anemograph at Kalgoorlie. Automatic records of pressure, temperature and humidity were obtained at three places for three weeks, which, combined with official records, yielded a line of five stations, (see Figure 2) namely, Esperance (on the coast), Gibson (16 n. miles inland), Salmon Gums (53 n. m.), Norseman (100 n. m.) and Kalgoorlie (186 n. m.). A week's records were also obtained from Widgiemooltha (142 n. m.). In addition, a number of cross-sections of temperature, humidity and surface wind were obtained from observations made during traverses over the route in the author's car.
FIG. 2 - Map showing the lines of Stations used in the investigation. Altitude in feet and distance inland in nautical miles are shown. Forrest in Station number 646.

FIG. 3 - M.S.L. isobars at 1500 hrs. W.S.T. 30/1/55.
FIG. 4 - M.S.L. isobars at 1500 hrs. W.S.T. 18/1/55.

FIG. 5 - M.S.L. isobars at 1500 hrs. W.S.T. 19/1/55.
FIG. 6 - M.S.L. isobars at 1500 hrs. W.S.T. 20/1/55.

FIG. 7 - M.S.L. isobars at 1500 hrs. W.S.T. 21/1/55.
FIG. 8 - Time graph of vapour pressure for four days at the Stations indicated. The sloping broken lines show the inland propagation of a wind change.

FIG. 9 - Time graph of temperature differences between adjacent Stations for four days.
FIG. 10 - Photograph of smoke from a coastal fire, showing the sea breeze in the lower levels, with an offshore component above it.
FIG. 11 - Time graph of pressure differences between adjacent stations for four days.

FIG. 12 - Distance inland plotted against time of day, for a number of wind changes.
FIG. 13 - On shore components of upper winds at indicated times and places.

FIG. 14 - Typical hygrograph and thermograph traces, showing the effect of the sea breeze at Forrest.
FIG. 15 - Anemograph traces at Kalgoorlie, showing some nocturnal wind changes.

FIGURE 16. Sea breezes at FORREST for January–March 1955. For details see text.
During the period of the investigation somewhat disturbed weather conditions prevailed, including the passage of a tropical cyclone, so that the number of days favourable for clear seabreeze development was smaller than had been hoped for.

Since Hounam based his claim that the seabreeze reached Kalgoorlie in the early evening on accounts of local residents, it may be of interest to record the impressions elicited from residents in the area by the author. Those resident from Norseman southwards were definite in maintaining that the "Esperance doctor" did reach them and was an important modifying influence on their summer climate. Further north, the accounts were rather confused, and diverse, some at least clearly identifying the "doctor" with cold frontal passages.

No attempt at a complete presentation of the data obtained is made here, and no final conclusions are stated. Certain interesting features are noted below.

**The seabreeze of 30/1/55**

The surface synoptic situation at 1500 hours W.S.T. is shown in figure 3. The author and his companion were stationed at Gibson and observed what was taken to be a diffuse seabreeze passage at 1300 hours W.S.T. It was decided to follow its progress inland. No difficulty was experienced in distinguishing the boundary of the cooler air as it moved inland, as far as Norseman, which was reached about 1845 hours. The temperature contrast across the boundary became negligible about this time.

Vapour pressure in the cooler air was markedly higher in the earlier stages, but the difference became smaller with time, until at Norseman it was quite slight. The spectacular feature was the surface wind, which rose quite suddenly with the passage of the "front" from almost nil to a moderate wind, average about 15 knots, from south-south-east. By the wind change alone the progression of the "front" was traced inland from Norseman to Kalgoorlie, which was reached at 2345 W.S.T. The effect of the "front" at Kalgoorlie was barely perceptible with regard to temperature, a temporary very slight increase was observed in the rate of pressure rise, and the dew point rose temporarily from 40 to 49°F. There can be doubt that on this occasion a wind surge line originating at or near the coast penetrated inland to Kalgoorlie.
Its speed of propagation apparently increased from about 8 knots in the early stages to 17 knots at night, 100 to 200 miles inland (Figure 12). This speed of propagation, comparable with the velocity of the cooler air, suggested that the surge was frontal in character, and this conclusion appears to be borne out by the slight, although definite, changes observed on its arrival at Norseman and Kalgoorlie. There is some reason, therefore, to apply the name "seabreeze" to what was observed. This title is sanctioned by usage abroad (e.g. Kimble 1946; Pearce 1955) up to a limit of 100 km inland, and no valid argument has been raised against its extension to the phenomenon observed on this day further inland.

The series 18-21 Jan. 1955

This was chosen to illustrate what appears to be a rather typical sequence. The synoptic situations are represented by figures 4-7. On 17/1/55, the stream was directed onshore in the Esperance area. On 18/1/55 a new anticyclone has pushed well over into the Bight from the west. On 19/1/55 the anticyclone continues on its eastward course, and a new depression begins to form about the west coast. On 20/1/55 the depression moves rapidly southwards, and a northerly stream flows over Esperance area. On 21/1/55 the depression moves rapidly to the south east and the front which has developed in association with it moves over Esperance from the south.

In figure 8 is shown the vapour pressure plotted against time for the four days at the five stations. The surface wind speed (knots) and direction are plotted where available. The dotted line marks the inland progression of a sudden increase in vapour pressure as far as Norseman, and the large figure on it represents its speed of propagation.

On 18/1/55 a seabreeze has certainly penetrated as far as Norseman, and possibly to Kalgoorlie, where the vapour pressure fell on its arrival. The humidity at Kalgoorlie was considerably higher that it was nearer the coast, perhaps due to the influence of inland rain from the previous depression. The moist air was replaced by drier air of more southern origin. The Kalgoorlie wind trace (figure 13) certainly suggests the possibility of a seabreeze there.
On 19/1/55 the sea breeze can be traced to Norseman, but no continuity can be claimed from Norseman to Kalgoorlie. The 25 knot movement required certainly does not seem possible from the wind trace at Kalgoorlie. The substantial rise in vapour pressure there must also remain unexplained, but one is tempted to postulate the arrival of a seabreeze surge from Forrest (approximately 350 n.m. to the east of Kalgoorlie and 60 n.m. inland). Available data suggest the possibility of this but it cannot be confirmed. It certainly cannot be claimed that the frequently observed freshening of the easterlies at Kalgoorlie commencing between 2000 and 2400 hours can be explained as a seabreeze, at this stage.

The weak land breeze at 0600 hours at Esperance is noteworthy. No convincing land breezes were observed at any time except within a few hundred yards of the beach, but it is not intended to claim that this statement is valid generally.

On 20/1/55, with prevailing hot north east winds, the seabreeze penetrated only to Gibson, and not more than 4 miles further, as observed by travelling through it. It moved very slowly against the "gradient" wind, about 2 kt. mean speed, and observations taken at Gibson and Esperance suggest that it was gradually destroyed by mixing with the warmer, drier air above rather than that it retreated as a "warm front". A fire near the coast on this day provided a means of depicting the seabreeze (figure 10). The photograph was taken 4 miles north of the coast, looking towards southwest, at 1540 hours and shows the smoke carried inland in a shallow layer, and seaward aloft, where the smoke had penetrated the inversion. The onshore wind component at the coast and just inland of the seabreeze at 18 miles from the coast is shown in figure 15, which indicates that the seabreeze was 300 m. deep at the coast.

On 21/1/55 the front moves inland from the south, in much the same manner as the seabreeze, but more pronounced in its effects on all elements. The similarity between frontal passages and seabreezes around the Australian continent in summer is remarkable, and is thought to be a significant reflection of the effect of diurnal heating on frontal behaviour. The same acceleration inland is noted as in the case of the seabreezes, from 10 knots near the coast, to 17 knots from Norseman to Kalgoorlie.
Figure 9 graphs time against temperature differences between adjacent stations. The curves are the result of subtracting one trace from another, both of large diurnal amplitude. It is observed that the north-south temperature gradient expected by Hounam (1945) and Cassidy (1945) did not exist; in fact, apart from the seabreeze influence, which materially reduced Norseman's temperature compared with Kalgoorlie's in the evenings, Norseman experienced slightly higher day temperatures than Kalgoorlie, perhaps owing to the effect of elevation. On the evening (20/1/55) of no seabreeze at Norseman, the evening temperature there remained slightly higher than at Kalgoorlie. On 19th and 20th, the temperature at Kalgoorlie fell more rapidly than at Norseman after midnight, but remained higher throughout the night, indicating that the advective temperature effect due to the seabreeze at Kalgoorlie was very slight, if present at all. The surprisingly small temperature excess at Gibson compared with Esperance in the midday hours (2-3°F) on 18th and 19th and the large excess (13-15°F) at Salmon Gums over Gibson in the afternoon are noteworthy features, since these two days may be regarded as typical days of deep inland seabreeze penetration. By contrast we may note the large temperature excess (12°F) of Gibson over Esperance on the afternoon of 20th, a day of offshore wind combined with seabreeze of the type investigated by Roschmeider. Also noteworthy is the temperature excess at Esperance compared with Gibson at midnight on 18th and 19th, when land breezes were observed at Esperance.

Figure 11 shows the pressure differences between adjacent stations for the same four days. The diurnal oscillation in the pressure gradients is clearly marked, the maximum occurring about the time of maximum temperature, inland as far as Norseman, but being delayed until much later in the section Norseman to Kalgoorlie. This feature lends observational support to Pearce's calculations of the "tidal effect" of heating on the surface pressure, which, apart from the pressure effect of the seabreeze should produce, at the time of maximum heating a pressure minimum on the inland side of the coast, with pressure rising slowly further inland. The change in the mean gradients involved may be obtained by dividing the pressure differences by the distance between the adjacent stations, and this suggests that the oscillations in the gradient are greatest near the coast, of the order of ½ to 1 mb. in 16 miles, which agrees well with unpublished figures obtained by the author for Sydney, Canberra, Brisbane and Melbourne areas, by Hounam for Perth, and by Pearce in his theoretical calculations. Absolute values of the gradients are not presented because of the altitude correction difficulty, the exact altitudes of some of the stations being unknown.
It may be noted that near the coast, the pressure rises well after the onset of the seabreeze; 50-100 miles inland it frequently rises at the onset of the breeze, while at Kalgoorlie it rises well before the nocturnal freshening of the wind. This emphasises the connection between the diurnal pressure wave and the seabreeze, which appears to be remarkably consistent both in time of arrival and strength 50-100 miles inland. Wagner's (1938) expression "the breathing of the continent" comes to mind. A curious feature of figure 11 is the behaviour of the gradients on 20th when the seabreeze did not penetrate north of Gibson. Kalgoorlie experienced a freshening of the easterly wind on this day, about 2100 hours, roughly in phase with the pressure gradient maximum.

Figure 12 plots distance inland of the wind change against time of day for 18th, 19th, 21st and 30th January. The strong curvature (acceleration) over the last stage on 19th has already been commented upon. The large figures represent presumed speed of propagation northward in knots, except on 19th, when no claim is made that the change at Norseman was identifiable with that at Kalgoorlie.

Figure 13 reproduces the autographic wind records at Kalgoorlie on the nights of 18th, 19th, 21st and 30th. Here we have in order a presumed seabreeze, a "freshening of the easterlies" for which no adequate explanation has been found, a genuine cold front, and a proven seabreeze.

Figure 15 illustrates the southerly component of upper winds observed by means of balloons with "tails". The scale on the abscissa and ordinate is indicated on the diagram. The later flight of each pair is represented by a dashed line.

On 18/1/55, both releases were at a different time and place in the sea air. A rather sharp south wind maximum was found in both, at 200m, with speed slightly greater than that of propagation of the front.

On 19/1/55, both at Salmon Gums, the first balloon was released 1½ hours before the onset of the breeze, the second, 1½ hour after. If the observation is representative, a jet of 30 kt. from the south existed at 360m although the speed of the front was 12 kt. roughly that of the lowest 200m.

On 20/1/55, the first balloon was released at the coast, and indicated a seabreeze of depth 280m, while the second was released in the hot northeast wind to the north of the seabreeze. The inland component of 13 kt. compares with 2 kt. as the rate of propagation of the front.
On 26/1/55, the first balloon was released as the wind began to change from north west to south, and the second, 35 minutes later, when the southerlies had increased in depth from 350 m to 840 m and reached a speed of about 20 kt, compared with a frontal propagation speed of 12-13 kt. Some sign of an upper counter current is to be seen above 2 km in this pair of flights, and above 1400 m on 19th. It may be of interest to note that mean one-dimensional convergence on 26th over the 35 minute interval between the flights had a maximum value of $6 \times 10^{-5}$ sec$^{-1}$ at 100 m altitude, and that integrated convergence yielded an average ascending velocity increasing from 0 at the ground to 50 cm sec$^{-1}$ at 1700 m thence decreasing. This may be compared with the ascending motion as detected by the rate of ascent of the balloons. Strong upward air motion was indicated in the earlier release, of the order of 6 m sec$^{-1}$, centred at 400 m, while from the second release, upward motion could only be inferred above about 1200 m, perhaps of the order of 30 cm sec$^{-1}$. These figures are not incompatible with the 35 minute mean, as calculated from the convergence. Experience of glider pilots and airline pilots at Canberra showed that strong upward currents are commonly found over the leading edge of the seabreeze, and it is thought that the maximum value of 6 m sec$^{-1}$, although open to criticism, may not be grossly in error. It may also be of interest to deduce the slope of the front from the two flights. From the increase in depth of the southerlies and distance moved by the front in 35 minutes the mean slope is deduced to have been 1:27 over approximately the first 7 miles. If the ascending motion deduced from the ascent rate of the first balloon is accepted and streamlines in the warm air are assumed to be parallel to the frontal surface, the instantaneous slope of the latter may be calculated. For it can easily be shown that $\tan \alpha = \frac{w}{u}$ where $\alpha$ is the slope of the front, $w$ the vertical component and $u$ the horizontal components of motion (the component parallel to the front is of no consequence in this consideration) and $c$ the speed of the front. The data at 400 m then yield $\alpha \approx 45^\circ$ as the slope of the front. This steep slope agrees qualitatively with the Danzig observations, and also with an observation made by the author at Canberra on 20/12/48, where a forest fire near the coast strongly coloured the incoming seabreeze. The slope of the wall of smoke at the moment of engulfing the observer on that occasion appeared to be 30-40$^\circ$.

Although the components of motion parallel to the coast are not shown it may be of interest to note that in all cases the onset of the seabreeze was accompanied by an increased easterly component. This indicates "cyconic shear", so that qualitatively the seabreeze front obeys the longues frontal criterion.
Figure 14 illustrates typical behaviour of temperature and humidity on the arrival of the seabreeze at Forrest, W.A., about 60 miles inland, on daily hygrograph and thermograph charts. The distinctive appearance of the hygrograph trace can be matched by traces from many parts of Australia at about the same distance inland. A similar trace frequently accompanies genuine frontal passages, as opposed to seabreeses. The latter can usually be distinguished from the former, however, on the autographic records, by the fact that the temperature is usually markedly lower on the succeeding day in the case of a front, but not in the case of a seabreeze. A brief investigation, using data from Forrest, was made in an attempt to define the conditions under which hygrograph traces like that in figure 14 may be expected.

In figure 16 the abscissa is 1500 W.S.T., temperature at Forrest and the ordinate is the onshore (southerly) component of 1100 W.S.T., 1000 ft. wind at Forrest. On the diagram are plotted circles, which represent no hygrograph discontinuity during the afternoon, the letter F, which means a hygrograph discontinuity occurred, but that the maximum temperature on the next day was substantially lower, and the figures 6, 7 and 8, which mean respectively hygrograph discontinuity from 1600-1655, 1700-1755 and 1800-1855 with no substantially lower maximum temperature on the next day. The data used was for the period 1 January to 31 March 1955. The letter M beside a figure indicates that the observation belonged to March, when seabreeses with lower temperatures would be expected, owing to the decreased sea water temperature. The broken line encloses all discontinuities which could be called seabreezes, occurring in January and February. It would appear that the two parameters chosen are highly significant in determining seabreeze occurrence at Forrest, and that the phenomenon occurs within a 1500 hour temperature range of about 85-95°F and within an 1100 hour 1000 ft. southerly wind component range of -6 to 6 knots. A suggested explanation of the upper limit to the temperature for seabreeze occurrence is that higher temperatures only occur with strongly disturbed conditions. If the onshore wind is too strong, evidently the seabreeze, if it occurs, is too diffuse to produce a hygrograph discontinuity.

5. CONCLUSIONS

The seabreeze is seen to be a frequently occurring summer phenomenon in southern Western Australia, and is probably of considerable climatic significance in a one hundred mile wide strip around the coast. Evidence that the seabreeze may move much further inland in a weakening form is fairly conclusive, but a study of temperature, pressure, humidity and wind distribution indicates that there may be other phenomena which require explanation.
The sudden 2000-2400 hour freshening of winds at Kalgoorlie has not been sufficiently studied. Further investigations with a better instrumental network, especially of radiosondes and anemographs, are required fully to describe the summer diurnal phenomena encountered.

The seabreeze problem is only a portion of the problem of the complete effects of solar heating of the continent, and, in principle at least, its solution is bound up with that of the larger problem, which is of great importance in forecasting for the Australian area.

Compared with those investigated abroad, it appears that seabreezes in at least some parts of Australia have considerably greater lateral extent.

References:


