Sea-breezes in the Latrobe Valley

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Examination of surface wind data in the Latrobe Valley region of Victoria reveals the existence of sea-breezes penetrating as far as 100 km inland from the southeastern coast of Australia. The sea-breeze enters the valley near this coast by one of two routes. It either flows over the hills running parallel to the coast on the southeast side of the valley or is diverted around them and enters from a northeasterly direction. The former path is preferred about three times more than the latter, the actual route chosen depending on the synoptic wind.

On a number of days the sea-breeze was tracked by a vehicle equipped with wind, temperature and humidity measuring instruments. The above conclusions were confirmed and on one occasion a further sea-breeze was detected. This came over a saddle in the Strzelecki Range to the south and moved northeast down the valley, meeting the usual sea-breeze from the opposite direction near Morwell (about 80 km up the valley). A surprising phenomenon encountered on this day was the advection of drier air into the valley by the sea-breezes. Interesting small-scale features associated with sea-breeze fronts were also recorded during these excursions.

Introduction

Many field experiments in the last two decades have significantly increased our understanding of the sea/lake breeze. However, the vast majority of these have taken place in regions of negligible orography. Exceptions include the Californian sea-breeze work of Fosberg and Schroeder (1966) and a study by Sumner (1977) of the penetration of marine air up the Teifi Valley in Wales. An interesting finding from the latter study was the existence of two different routes for the sea-breeze from the coast to the town of Lampeter, situated 40 km up the valley from its mouth. The majority of sea-breezes travelled up the Teifi Valley, but occasionally one would take the direct route over the hills, the valley lying roughly parallel to the coastline.

The Latrobe Valley, about 120 km southeast of Melbourne, is similarly aligned with respect to the coastline of southeast Australia (Fig. 1). It is typically 15 km wide and oriented east-northeast/west-southwest from Yallourn to Rosedale before widening to its mouth near the coastline. The western section between Warragul and Yallourn lies east-west and is narrower (about 8 km). At Yallourn, the valley sides converge to within 1 km. The Great Dividing Range north of the valley rises slowly to 2000 m above sea level, while the height of the Strzelecki Range to the south is about 500 m.

While examining the general behaviour of sea-breezes in orographic regions, a study of the Latrobe Valley sea-breezes would also provide input to air quality studies of the region. Large brown coal deposits in the area are used by the State Electricity Commission of Victoria (SECV) to fuel power stations at Hazelwood and Yallourn. Gaseous emissions from these stations can cause pollution of the atmosphere if they are not dispersed sufficiently by the prevailing winds. As the sea-breeze is essentially an inflow of relatively clean maritime air, it could be considered an ideal flushing mechanism for a contained area such as a valley. However, the cool air undercutting the warm land air creates a low level inversion (and thus the potential for trapping pollutants), and the circulation associated with the sea-breeze system can merely recirculate any of these trapped pollutants. Lyons and Olsson (1973) found such occurrences with the Chicago lake breeze. The sea-breeze is likely to be one of the wind regimes frequently observed in the valley in the warmer months and thus could play a significant role in the dispersal or otherwise of pollutants. Although not endeavouring to address this problem directly, this paper attempts to define the Latrobe Valley sea-breeze in terms of frequency of occurrence, distance penetrated, arrival times at certain places, and various other relevant characteristics. These are evaluated in the next section using data obtained from an SECV anemometer network in the valley.

In further sections results obtained from tracking the sea-breeze up the valley by vehicle are presented. Carrying equipment to continuously monitor wind speed and direction and wet and dry bulb temperature, this mobile platform enabled a number of traces to be made through the sea-breeze front as it advanced up the valley. Particularly interesting results were obtained on 16 February 1980, and these and other traces illustrating various facets of
the 1980 summer sea-breezes are presented in the following sections.

Sea-breeze climatology

As part of the study of the local wind circulations in the valley and their direct effect on the dispersal of pollutants from power stations at Yallourn and Hazelwood, the SECV is presently installing an extensive air quality and meteorological monitoring network (Hoy and Howard 1979). However, a less comprehensive surface network has been in operation for about eight years. Tapp and Hoy (1980) used data from this network in their study of surface wind fields in the Latrobe Valley. They analysed wind roses and frequency of winds from certain directions as a function of time of day to infer such information as distance penetrated and frequency of occurrence of sea-breezes at various locations. In this section, a more accurate assessment of these statistics is made by examining all individual cases of sea-breezes over a total of 12 months.

Wind speed and direction traces from Woollfle anemometers at Giffard (anemometer mounted at 2 m), Rosedale (2 m) and Hazelwood (2 m) were examined for two summers. This data periods spanned October 1977 to March 1978 and October 1979 to March 1980. Wind data from Yarragon North (6 m) were also available between December 1977 and March 1978. These stations are marked on Fig. 1 and were chosen for analysis due to their location with respect to sea-breeze arrival time, viz. morning, afternoon, late afternoon and evening.

For each day of the study period, the Giffard wind record was examined for mid-morning light onshore winds strengthening later and persisting through the day. For these days, the synoptic situation was checked for relatively light gradient winds with little direction change during the day. Days which satisfied these criteria were deemed sea-breeze days. A total of 54 such days were found in the 12 analysed months, and various statistics for each station are shown in Table 1. The number of sea-breezes is denoted by n, the mean arrival time by \( t \), and preferred direction by \( \theta \). Unfortunately, data at Rosedale were available for only three of the seven sea-breeze days in October. In the statistics for Yarragon North, an expression such as ‘3 of 4’ means the sea-breeze reached there on three of the four days on which there was a sea-breeze at Rosedale. The two preferred arrival directions at Rosedale indicate two different paths and this will be discussed later. The mean arrival time shown encompasses sea-breezes from both directions.

In a number of aspects the statistics for October, November and December (OND) are similar, as are those for January, February and March (JFM). For instance, at each station the mean arrival time for the former group is considerably earlier than for the latter (between 40 and 60 minutes). Also, at Giffard the sea-breeze has a more southerly component in JFM than in OND. This fact, and the tendency to
Table 1. Mean arrival time and preferred direction of the sea-breeze at various locations. Note that the sample size n denotes everywhere the total number of sea-breezes observed in two years.

<table>
<thead>
<tr>
<th></th>
<th>Giffard</th>
<th>Rosedale</th>
<th>Hazelwood</th>
<th>Yarragon North</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>t</td>
<td>θ</td>
<td>n</td>
</tr>
<tr>
<td>October</td>
<td>7</td>
<td>0940</td>
<td>ESE</td>
<td>2</td>
</tr>
<tr>
<td>November</td>
<td>5</td>
<td>0930</td>
<td>E</td>
<td>2</td>
</tr>
<tr>
<td>December</td>
<td>7</td>
<td>0925</td>
<td>ESE</td>
<td>4</td>
</tr>
<tr>
<td>Oct., Nov., Dec.</td>
<td>19</td>
<td>0930</td>
<td>15</td>
<td>1430</td>
</tr>
<tr>
<td>January</td>
<td>8</td>
<td>1050</td>
<td>SE</td>
<td>6</td>
</tr>
<tr>
<td>February</td>
<td>17</td>
<td>1010</td>
<td>SE</td>
<td>15</td>
</tr>
<tr>
<td>March</td>
<td>10</td>
<td>1045</td>
<td>SSE</td>
<td>9</td>
</tr>
<tr>
<td>Jan., Feb., Mar.</td>
<td>35</td>
<td>1030</td>
<td>35</td>
<td>1520</td>
</tr>
</tbody>
</table>

arrive later in JFM, is a direct result of the dominance of a particular synoptic situation during OND. In these months, 17 of the 19 sea-breeze days occurred with an anticyclone in the Tasman Sea. For the Latrobe Valley region, this implies a synoptic wind with a northerly (often northeasterly) component, which should aid the progress of the sea-breeze up the valley. However, during JFM this situation occurred on only 15 of the sea-breeze days and quite often the large-scale prevailing wind had a westerly component which tended to hinder the progress of the sea-breeze.

The number of sea-breezes which reached Giffard and Rosedale but not Hazelwood is greater in JFM (Table 1) and can also be attributed to the synoptic situation, although the shorter day length in March is also a factor. The lack of sea-breezes at Yarragon North in March is also probably due to the length of day and for the same reason October sea-breezes are unlikely to reach there either. An interesting anomaly in Table 1 is the mean arrival time at Hazelwood in December. It is considerably earlier than for other months and the reason is not apparent when individual cases are inspected. However, the longer days in December, as opposed to October and November, and the greater number of synoptic situations with an up-valley wind component in OND than in JFM, are probably the main factors.

The two preferred arrival directions at Rosedale indicate two quite different paths. When the sea-breeze arrives from the northeast, it has come up the valley, i.e. around the northeastern end of the Strzelecki Range. However, the arrival direction of east-southeast indicates that the sea-breeze has travelled over the hills from the coastline a few kilometres northeast of Giffard. The latter path is preferred in the ratio of about three to one in the analysed sample of 50 cases. This finding is opposite to that of Sumner (1977) who found that the longer route up the valley, rather than directly over a ridge, was preferred by the sea-breeze of the Teifi Valley region in Wales. It appears that the direction of the prevailing gradient wind is the prime factor in determining the sea-breeze path into the valley. Synoptic winds from the northwest quadrant have a component opposing the sea-breeze coming over the Strzelecki Range, and it is under this large-scale situation that the pathway from the northeast is chosen. The east-southeast direction is favoured for gradient winds from the other quadrants. Northwesterlies most commonly occur when a high pressure system is situated over the Tasman Sea. From previous discussion, it should follow that the route around the Strzelecki Range should be more prevalent in OND than in JFM. This is borne out by the respective ratios (over route to around route) of 8:7 and 30:5 for these two periods. On average, the sea-breeze arrives 35 minutes later at Rosedale when it travels around the hills. At Hazelwood and a number of other stations west of Rosedale (the
nearest station, Minnedale Road, is 17 km to the west), the arrival direction always lies in the northeast quadrant, indicating that the sea-breeze is unable to get over the Range immediately southwest of Rosedale. Elevations in this area are typically 500 m, with peaks over 600 m. Southeast of Rosedale, the maximum height above sea level is about 220 m.

The conclusions of this study and that of Tapp and Hoy (1980) (TH) are generally similar. However, the analysis methods of TH (wind roses and frequency of easterlies) give an overestimate of the number of sea-breezes in a season as onshore gradient winds cannot be distinguished from sea-breezes. This was acknowledged by those authors. It also give the impression that sea-breezes passing through Giffard reach Rosedale only about 70 per cent of the time. A figure of 100 per cent was found in this study. A higher percentage reaching Hazelwood (78 per cent) was also found here than was inferred by TH (about 33 per cent).

The analysis of TH indicated an afternoon peak in the frequency of southwesterlies at Hazelwood and Morwell for the month of February. Winds from that direction were also quite common prior to the onset of the east coast sea-breeze on the days examined in this study. TH felt that this indicated a south coast sea-breeze originating in the vicinity of Wonthaggi. This is quite likely the case on some occasions and a specific occurrence is detailed in the next section. However, the wide range of onset times of the southwesterlies at Hazelwood and the lack of a typical sea-breeze signature in many of the wind traces examined in this study suggest there is at least one other reason for these winds. The channelling of the prevailing gradient wind down the Morwell River valley, as suggested by TH, is certainly one mechanism, while a very local pond breeze from the Hazelwood cooling pond could also be responsible on some occasions. Analysis of Hazelwood wind data in conjunction with wind, temperature and humidity data from the more recently installed air quality monitoring stations at Boolarra and Hazelwood Estate would certainly provide a more accurate assessment of the frequency of south coast sea-breezes reaching Hazelwood.

Further measurements
On selected days from January to March 1980, the sea-breeze was tracked by vehicle up the Latrobe Valley from the coastline east of Sale. At the surface (1.5 m), traces of wind speed and direction and wet and dry bulb temperature were made in the land air ahead of the front, and then for about 30 minutes after the front had passed. Temperature equipment consisted of an aspirated psychrometer using platinum resistance thermometers outputting to a chart recorder, while wind data were obtained from a vector wind set (6 cup with separate vane) electrically damped to a 2-minute time constant. The vehicle then overtook the sea-breeze and the procedure was repeated. In this way, the small-scale (longitudinal) thermal and dynamic structure, at the surface at least, of the same sea-breeze front was obtained at an average of seven different times and locations. In conjunction with SEC instrumentations, penetration rates could be calculated and initially it was hoped to relate these to the temperature drop across the front. However, the effect of the complex terrain on both the synoptic wind and the sea-breeze itself prevented any accurate comparison with empirical relations derived from tank models of gravity currents (e.g. Simpson and Bitter 1980). In this section data from 16 February 1980 are discussed, as several unusual features of interest to both modellers and theoreticians were evident on this day. Then, in the following section, a collection of traces from various other days illustrating a number of known and not so well known facets of sea-breezes is presented.

The sea-breeze of 16 February 1980

Figure 2 shows the synoptic situation at 0900 Eastern Standard Time (EST) 16 February 1980, with a slack gradient over Victoria producing very light southeasterly flow in the Latrobe Valley region. Conditions were such that fog remained in the valley most of the morning, eventually beginning to clear about 1100 EST, initially at the coastline and then progressively inland. Skies were cloudless for the rest of the day with the temperature reaching a maximum of 28°C near Rosedale.

Fig. 2 Mean sea level pressure at 0900 EST on 16 February 1980.
Table 2. Sea-breeze statistics at data stations on 16 February 1980. ‘Before’ and ‘after’ refer to passage of sea-breeze front. ‘After’ values are typical of steady flow behind the mixed frontal zone. East Sale and Boolarra anemometer heights are 10 m.

<table>
<thead>
<tr>
<th>Location</th>
<th>Arrival time</th>
<th>Temperature (°C)</th>
<th>Humidity (g kg⁻¹)</th>
<th>Wind (m s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>Station 1</td>
<td>1300</td>
<td>24.3</td>
<td>23.5</td>
<td>8.3</td>
</tr>
<tr>
<td>East Sale</td>
<td>1320</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Station 2</td>
<td>1441</td>
<td>28.2</td>
<td>26.6</td>
<td>10.6</td>
</tr>
<tr>
<td>Rosedale</td>
<td>1511</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Station 3</td>
<td>1602</td>
<td>27.5</td>
<td>26.5</td>
<td>10.2</td>
</tr>
<tr>
<td>Station 4</td>
<td>1650</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Station 5</td>
<td>1743</td>
<td>26.3</td>
<td>24.5</td>
<td>7.7</td>
</tr>
<tr>
<td>Hazelwood</td>
<td>1828</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Boolarra</td>
<td>1506</td>
<td>—</td>
<td>—</td>
<td>10.7</td>
</tr>
<tr>
<td>Hazelwood</td>
<td>1543</td>
<td>—</td>
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</tr>
</tbody>
</table>

The locations of the data stations for this day can be seen in Fig. 3 and the sea-breeze arrival times and various wind, temperature and humidity data are shown in Table 2. The arrival of the sea-breeze at Station 1 at 1300 EST produced negligible effect in the temperature and wind direction traces. An increase in wind speed of about 1 m s⁻¹ was detected for about seven minutes and in that time specific humidity gradually fell by 1.3 kg⁻¹. The lack of strong frontal definition associated with the sea-breeze near the coastline, especially with an onshore synoptic wind, has been commented on by other observers (Clarke 1955; Simpson et al. 1977) and modellers (Clarke 1973). Drier air behind the front was found at all stations and is a most unusual feature of this day’s sea-breeze. The transport of moist air over land is regarded as a typical characteristic of the sea-breeze although, as is evidenced here, it is by no means definitive. A study of the synoptic situation over this period explains the anomaly. For two days prior to 16 February, air reaching the Latrobe Valley region had been passing over the warm subtropical waters east of Australia. This was brought about by a ridge extending up the eastern Australian coast from an anticyclone centred southeast of New Zealand. On 15 February a depression and associated cold front passed just to the south of Victoria and another high pressure system began to ridge in to western Victoria from the Great Australian Bight. At the same time a trough was developing over northern Victoria and as a result the 2100 EST surface chart showed a col situation centred in Bass Strait. Although of course flow in the region was extremely light, air reaching Bass Strait had travelled over the cool Southern Ocean and thus contained less moisture than the subtropical air in the Latrobe Valley. Hence the advection of drier air into the valley by the sea-breeze next day. It is also possible to interpret this situation as a meso-scale mechanism (differential heating across a coastline) being responsible for the movement onshore of a front formed by synoptic-scale processes. However, the day’s events are still classified as a sea-breeze.

The sea-breeze arrived at East Sale Meteorological Station at 1320 EST from east of southeast. By assuming the sea-breeze at this stage is advancing inland in a direction normal to the coastline, we calculate its speed of movement from Station 1 to be about 13.5 km h⁻¹. At Station 2 the arrival direction and time are east and 1441 EST. The easterly direction indicates that the sea-breeze has already begun to back in response to the orography. It is difficult to estimate any penetration speed for the sea-breeze to this station as its exact trajectory cannot be determined. However, if it had travelled inland on a line normal to the coast, its speed from the vicinity of Station 1 to Station 2 would have been 11.7 km h⁻¹.

According to the SECV anemometer at Rosedale, 12 km to the southwest of Station 2, the sea-breeze arrived at 1511 EST from an east-southeast direction. This means it travelled over the Strzelecki Range on its journey from the coastline. Its penetration speed to Rosedale from its position on the 1300 EST isochrone was 9.5 km h⁻¹, a considerable slowing from its earlier speed of 13.5 km h⁻¹. This is almost certainly an orographic effect. At all data stations west of Rosedale the sea-breeze arrived from the northeast quadrant indicating that
in this part of the valley it was being channelled by the orography. However, in the Rosedale region (and to the east) the data considered thus far indicate the flow could be quite complex.

At Station 3 (only 5 km west-northwest of Rosedale) the steady flow behind the frontal zone was from the east but, in the turbulent flow near the front, winds with a significant northerly component were experienced. Wind, temperature and humidity traces for this station are shown in Fig. 4 and illustrate well the unsteady transition zone between land and sea air. Very light and variable winds are interrupted by a strengthening of the wind from the north at 1602 with an accompanying temperature drop. At 1605 there is a lull in the wind for about 30 seconds, but this is masked in Fig. 4 by the 2-minute averaging process. The speed and direction remain constant after 1622. It should be noted that the temperature trace is dominated by convective turbulence.

The arrival of the sea-breeze from north of northeast was surprising, especially as the following flow after about 20 minutes came from almost due east. Adjustment to the valley topography may have been responsible, although a similar deviation of the flow in the head region was observed at Station 5 (27 km further into the valley). Greater friction, both at the ground and at the top of the sea air, in the head than further back in the steady flow of stable air may also be a factor. The lack of wind at Station 3 prior to the sea-breeze arrival enables comparison of the traces with laboratory models of a gravity flow into a fluid at rest. These latter experiments have shown that density currents move forward in a pulsating manner by advancing a series of lobes and clefts of constantly changing form (q.v. Simpson 1969). It appears to be in this region of the Latrobe Valley sea-breeze that the gusts and lulls were found. An arrival time of 1650 at Station 4 gives a penetration speed of 16.3 km h⁻¹ along the line joining 3 and 4 (oriented 80°/260°). At Station 3 the wind speed, direction and humidity settled down to a constant value associated with the following maritime air after about 20 minutes. Assuming a frontal speed of 16.3 km h⁻¹, the horizontal scale of the mixing zone is thus about 5.4 km. A value of about 5 km was found by Simpson et al. (1977) using an instrumented motor glider.

The sea-breeze then advanced to Station 5 at Morwell, 14 km further up the valley, at a speed of 15.8 km h⁻¹. Prior to its arrival, the wind at Morwell was blowing steadily from the southwest at about 1.5 m s⁻¹. The humidity of this air was 7.7 g kg⁻¹, a value comparable with that of the advancing east coast sea air measured further down the valley. Inspection of the anemometer trace for nearby Hazelwood shows a wind change from light and variable about northwest to stronger and steady from the southwest, at 1543. These facts suggest that a sea-breeze from the south coast may have advanced to Hazelwood (and Morwell) down the Morwell River valley. Data from Boolarra, atop the Strzelecki Range to the south, strengthen this hypothesis. At 1506, a steady moderate breeze from the south-southwest sprang up at Boolarra bringing about a humidity drop from 10.7 g kg⁻¹ to 8.5 g kg⁻¹. The orography in this area is about 250 m above mean sea level. On a large number of sea-breeze days in the Latrobe Valley, the synoptic wind has a northerly component, opposing sea-breezes from the south coast. Inspection of wind data from Hazelwood and Boolarra on such days reveals no evidence of southern sea-breezes, indicating that the southerly onshore component in the synoptic wind was largely responsible for the crossing of the Range on this day. The penetration rate between Boolarra and Hazelwood was 25.9 km h⁻¹. This value was higher than for the sea-breeze from the east, but the elevation drop from Boolarra to Hazelwood and the onshore gradient wind would tend to reinforce this sea-breeze.

Edinger and Helvey (1961) have examined the vertical structure of a zone of converging winds in the San Fernando Valley (USA) using pitot observations and a network of continuously recording surface wind stations. This zone of convergence marks the location where two sea-breezes of different points of origin along the southern California coast meet, and produces rising motions stronger than those of either sea-breeze. The associated flow pattern prescribes a redistribution of a ground-based layer of pollution on the Los Angeles side of the zone of convergence, thus implying that this convergence zone functions
as a generator of an upper layer of pollution. Although the results of this study cannot be applied directly to the Latrobe Valley, they do suggest that the zone of convergence where the south and east coast sea-breezes meet may be an important redistributor of pollutants within the valley.

Some small-scale features of sea-breeze fronts

Wind, temperature and humidity traces on a daily chart, while displaying meso-scale events adequately, are unable to resolve the smaller-scale effects associated with these events. The greater resolution of data from the field work described in the previous section has enabled some small-scale (time and space) phenomena to be observed. These are associated with the frontal region of the sea-breeze where the intense mixing of land and sea air occurs, and should be reproducible in tank models of gravity currents. Some specific examples of these phenomena are presented.

25 March 1980

Figure 5 shows dry bulb (T) and dry bulb minus wet bulb (T–T_w) temperature traces obtained at a site between Rosedale and Traralgon. The synoptic wind was light and variable about the northwest direction. Skies were clear and the lapse rate in the surface layer was unstable, as evidenced by the turbulence in both traces. The sea-breeze arrived at 1626 EST and dropped the temperature by 1.2 degrees over 10 minutes. However, the T–T_w trace shows a sharper steadier drop coinciding with the wind change. This behaviour was found to be fairly common in unstable conditions and implies that a variable involving moisture is a better indicator of sea-breeze arrival than is a temperature variable.

22 January 1980

The late afternoon trace (Fig. 6) on this day was taken during a 5-minute shower of rain which began at 1659 EST. This was preceded by light rain from 1652 EST. The temperature fell and humidity rose as evaporation of falling raindrops took place, but then both tended to return towards their pre-shower values, indicating a lack of rain upwind of the measuring site. The sea-breeze arrived at 1712 and dropped the temperature by over 3 degrees. It was also detected further inland at 1836 EST, although there had been a complete cover of cirrus cloud since noon. However, the morning direct and afternoon diffuse radiation were able to heat the land air to the mid-twenties; sufficiently warmer than the sea air to maintain the incoming sea-breeze. This example illustrates the ability of the sea-breeze to survive through rain and total cloud cover. Also evident is the effect of the rain-induced cooling on the sea-breeze penetration rate. Prior to the rain the rate was 11.1 m s^{-1} (between 1528 and 1625 EST) and afterwards it was 15.6 m s^{-1} (1712 to 1737 EST). However during the rain period it slowed to 9.3 m s^{-1} (1625 to 1712 EST).

31 January 1980

The traces in Fig. 7 were taken during the final stages of the sea-breeze before it died out. They were obtained at Yarrawon 110 km up the Latrobe Valley from the coast. At 1831 EST, the wind rose quickly from calm conditions to 4 m s^{-1} with an accompanying rise in T and T–T_w. This temperature anomaly was due to strong radiational cooling in the near surface layer of the still land air.
Fig. 7 Early evening $T$ (below) and $T - T_w$ (above) traces taken in calm stable conditions when the sea-breeze temporarily brings warmer drier air at the surface.

![Graph showing temperature and $T - T_w$ over time.]

Fig. 8 These traces illustrate the surging manner in which the sea breeze is sometimes observed to move inland. (a) $T$ (below) and $T - T_w$ (above), (b) wind speed (full curve) and direction (dashed curve).

![Graph showing wind speed and direction over time.]

bringing about a temperature lower than that of the advancing sea air, which was turbulently mixed in the vertical to perhaps 200 m. The temperature rose for about 1.5 minutes by almost 1 degree and then continued to fall. (At levels higher than a few metres above the ground, the sea-breeze air would of course have been cooler than the land air.) In general as the radiational cooling extends to higher levels and a strong nocturnal inversion develops, the pressure gradient across the front slowly reduces the zero and causes the sea-breeze to die out. However, the influence of the sea-breeze may continue after its demise as recent work by Christie et al. (1977) and Clarke et al. (1981) has postulated that sea-breezes interacting with the nocturnal inversion may be responsible for solitary waves observed by those authors.

17 January 1980

A westerly synoptic wind of almost 2 m s$^{-1}$ at the surface on this day provided an opportunity to study the sea-breeze under conditions of a steady opposing wind. The wind, temperature and $T - T_w$ traces (Fig. 8) show that the wind switched to the north for about 3 minutes with a sharp drop in temperature and $T - T_w$. Then it switched back to northwest with a rise in temperature and $T - T_w$ although not to their previous values. After a couple of minutes, the wind again veered through north and was steady from about 70° within 5 minutes. These traces are interpreted as the front advancing, then retreating and finally advancing again in a surging rather than steady manner. This type of behaviour was rarely observed in such a clear-cut way in this series of field trips, but Wallington (1969) reports that gliding experience suggests the sea-breeze progresses inland in a series of pulsations rather than with a steady movement. These observations may also be a manifestation of the lobe and cleft behaviour associated with tank models of density currents (Simpson 1969). These data, and those of 16 February concerning the flow in the transition zone between sea and land air, raise questions on the validity of two-dimensional sea-breeze models. Currently these models, with grid-lengths around 10 km, are mainly used to further our understanding of dynamics on a larger scale than that observed here, but it does appear that the effects of transverse flow regimes near the front will have to be taken into account as our scale of investigation decreases.
Summary

Analysis of surface wind data for the Latrobe Valley has revealed the existence of sea-breezes which regularly penetrate to Hazelwood, 85 km up the valley from the east coast. Nor is it uncommon for the sea-breeze to advance further to Yarragon North, 110 km inland. Although always arriving at Hazelwood from an east-northeast direction, the sea-breeze enters the valley nearer the coast by one of two routes. It either spills over the hills southeast of Rosedale and is then channelled to an east-northeast direction further in, or it is diverted around the hills and enters the lower reaches of the valley west of Sale from a northeast direction. The latter route is usually chosen when the synoptic winds are from the northwest quadrant.

On selected days, the sea-breeze was tracked up the valley by a vehicle carrying wind, temperature and humidity equipment. Besides confirming the above conclusions, this series of field trips discovered a sea-breeze reaching Hazelwood from a southwest direction and later meeting the east coast sea-breeze near Morwell. This was deemed to be a rather infrequent event. On the same day the sea-breeze from both coasts brought drier air into the valley, a most unusual phenomenon. A number of small-scale features associated with the sea-breeze front were observed and recorded. These included a significant deviation of the wind in the transition zone between sea and land air (from the direction of the following flow), the inland progression of the sea-breeze by a series of advances and retreats (pulsing), and a temporary temperature rise as the sea-breeze arrived at inland stations in the early evening.

As only surface data have been analysed in this paper, we do not intend to speculate on the role of the sea-breeze in pollutant transport in the Latrobe Valley. However, it has been established that it is a major component of the summer wind regime within the valley and must certainly be taken into account when designing stack heights, emission times and sites for future power stations.

References

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