

# THE DIURNAL VARIATION IN THE DEPTH OF THE CONVECTION LAYER

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## Abstract

Estimates of the depth of the convection layer made on the basis of early morning aircraft sounding on cloudless days or days with shallow cumulus are compared with the results of afternoon soundings and with the heights reached by sailplanes, and the agreement is generally good. The energy increment of the air column in the convection layer is shown to be about 80 per cent of the available net radiation.

## 1. Introduction

The behaviour of the convection layer in the dry interior of Australia is at present relatively unexplored. Of the 20 radiosonde stations on the mainland, only 6 can be classified as inland stations, and all but 4 make only one sounding each day, around 09.00 local time. Ball (1960) has used the twice-daily ascents at Giles in Central Australia to show a daily variation in inversion height, and some aircraft soundings at frequent intervals, as yet unpublished, have been made by Telford and Warner. In addition a good deal of potentially relevant material has been collected over the years in connection with soaring activities, especially during competitions, e. g. Radok (1948). An opportunity of this kind arose with the Australian championships of 1964/65 at Benalla. The measurements on this occasion consisted of temperature soundings which were made daily at 06.00 and 18.00 hours with an Auster aircraft carrying a Friez meteorograph on the starboard wing struts to an average height of 10,000 feet (3,000 m). A pilot balloon flight was made each morning while the aircraft ascent was in progress. In addition, 25 records from the barographs carried in the sailplanes have been made available by the pilots, permitting the heights attained during the course of each day to be evaluated.

The changes brought about by surface heating on the vertical temperature distribution of an air mass are but briefly described in most text-books; a treatment apposite to the soaring forecast problem being that of Wallington (1961), especially pp. 140-148. In this paper we shall compare the available heat energy, integrated from sunrise, with the heat required to change the air temperature distribution in the vertical from that shown by the morning sounding to dry adiabats from the surface temperatures at specified times of day.

## 2. Topography and broad weather history

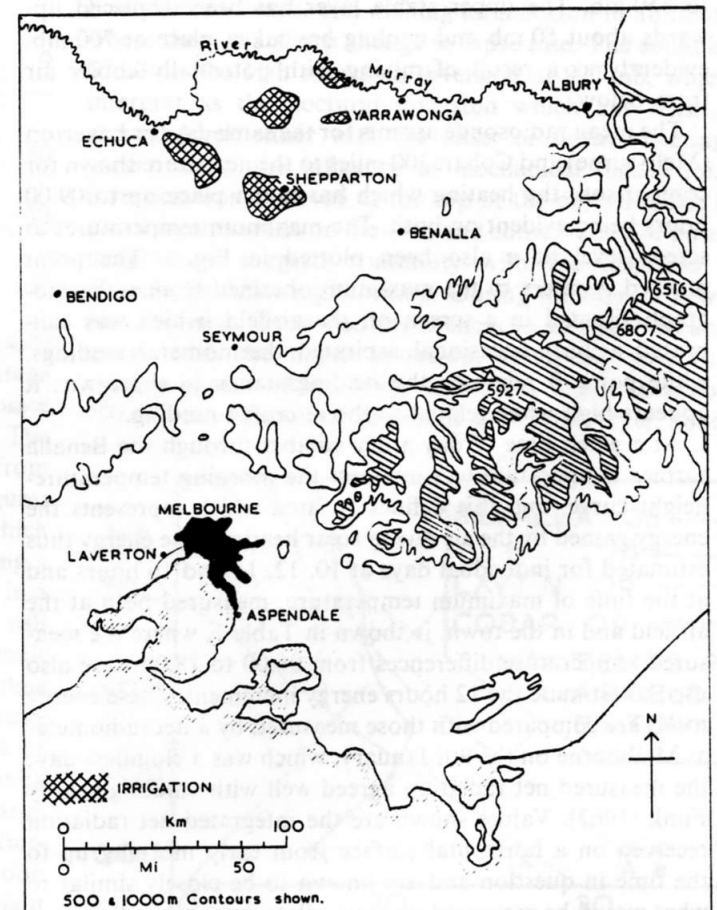
Ideally it would be desirable to study convection in a region having a flat uniform surface of such extent that advective effects are negligible and in the absence of marked synoptic and mesoscale disturbances and in this section we describe some of the departures from the ideal.

Benalla is situated some 15 miles north of the foothills of the Great Dividing Range (Fig. 1). To the north and west of Benalla the country is almost everywhere flat, about 300 feet

above sea level, having a variety of surfaces. It is for the most part open grassland (the grass being quite dry in summer), used for sheep grazing or wheat farming, and in January there are many stubble fields and ploughed paddocks. There are some patches of woodland, especially along the River Murray, which follows a meandering course of variable width, up to several miles, and there are extensive areas of irrigation for fruit growing, market gardening and pasturage.

The period of the contest, from the 27th December to the 9th January, commenced with strong advective changes, first of warm air from the north, and then a cold front on the 28th was followed by a fresh SW'ly airstream, and there was widespread, though shallow cumulus development on the 29th and 30th. By the 31st a ridge had developed in Bass Strait linking anticyclones in the Bight and the Tasman Sea. This persistent situation maintained a cool E-SE airflow over Victoria, and temperatures over the State were well below normal, especially south of the Ranges, where extensive low

Fig. 1. — Topography of Central Victoria. The location of this map is shown in Fig. 3



stratus was frequent. Even at Benalla the highest temperature during the period was 33° C, at a time of year when 40° C is not uncommon there. Fig. 2, the chart for 15.00 hours on the 4th January is typical of the middle period of the contest. The noteworthy features are the concentration of the isotherms, here highly generalised, along the Dividing Range, and the widespread cross-isobaric flow, which was of common occurrence in the afternoons. Weak cold fronts on the 2nd and 6th passed the area with no appreciable cloud formation, but strong advective effects were apparent in the soundings, and the second front was followed by an intensification of the anticyclone off the east coast. The chart for the 8th (Fig. 3) shows the consequent NNE'ly pressure gradient, which was associated with rising temperatures and deepening convection. The broad-scale synoptic situation was thus unusually steady and favourable for the study of convection, especially as cloudiness was also low.

### 3. The temperature soundings and their relation to heat input

A typical morning sounding at Benalla in fine weather shows a nocturnal inversion in the lowest 3,000 feet, with one or more inversions above, interspersed with regions of steep lapse rate. By late afternoon a dry adiabatic layer is established up to 6,000 to 10,000 feet. These features are so regular that they are evident in Fig. 4, which shows the composite sounding obtained by taking mean temperatures at 50 mb intervals for eight days in which the weather situation changed little and there was little or no cloud. The upper inversions of the individual soundings are represented in this figure by the layer of increased stability between 700 and 750 mb. The afternoon sounding shows that the heating was sufficient to enable the convection to surpass the stable layer below 850 mb and the lapse rate was essentially dry adiabatic up to 850 mb. The upper stable layer has been displaced upwards about 50 mb and cooling has taken place at 700 mb, evidently as a result of mixing with potentially cooler air from below.

The mean radiosonde ascents for the same days at Laverton (Melbourne) and Cobarr, 300 miles to the north, are shown for comparison, the heating which has taken place up to 09.00 hours being evident on both. The maximum temperatures at screen level have also been plotted in Fig. 4. The point marked A refers to the maximum obtained from a thermometer situated in a screen on the airfield, which was calibrated against occasional aspirated thermometer readings, while point B refers to the readings taken in the town; it appears high when related to the aircraft sounding.

At a given time of day a dry adiabat through the Benalla surface temperature will intersect the morning temperature-height curve, and this defines an area which represents the energy gained by the air due to solar heating. The energy thus estimated for individual days at 10, 12, 14 and 16 hours and at the time of maximum temperature, measured both at the airfield and in the town, is shown in Table 1, where the measured temperature differences from 06.00 to 18.00 were also used to estimate the 12 hours energy increment. These energy totals are compared with those measured by a net radiometer at Melbourne on the 9th January, which was a cloudless day; the measured net radiation agreed well with values given by Funk (1963). Values shown are the integrated net radiation received on a horizontal surface from early morning up to the time in question and are known to be closely similar to what would be measured on a cloudless day at Benalla.

TABLE 1. Comparison of energy ( $mWhr\ cm^{-2}$ ) estimated from aircraft soundings and surface temperatures with measured net radiation.

Date	1000 hrs.	1200 hrs.	1400 hrs.	1600 hrs.	Maximum Temperature		1800 hrs.
					Airfield	Town	
28	Cold front						
29	260	425	540	633	633	—	606
30	132	306	341	380	424	477	345
31	126	250	335	368	439	496	241
1	129	237	330	330	416	655	339
2	Cold front						
3	114	223	338	338	338	455	460
4	96	174	273	273	297	385	335
5	122	215	325	326	340	363	237
6	Cold front						
7	124	236	315	387	410	482	580
8	142	206	358	483	500	588	592
9	87	198	288	288	340	416	No obs.
Mean <sup>1</sup>	129	232	345	365	400	477	372
Integrated net radiation	107	215	330	420	—	—	467

<sup>1</sup> (29th and 9th omitted).

The only measured temperatures aloft are those at 06.00 and 18.00 hours and if the effect of large scale motions do not intrude too strongly, we should expect these to provide a good estimate of sensible heat input. In fact there is evidence that on some days advection or vertical motion has strongly affected the profiles, for example, so that there is no intersection of the dry adiabatic portion of the 18.00 sounding with the 06.00 sounding. This is particularly so on days following cold frontal passages, when one would expect warming through subsidence. The mean of the 06.00 to 18.00 hour energy estimates, however, is thought to give a fairly reliable indication of the effects of sensible heating, and this shows that 80 per cent of the integrated net radiation has been used for this purpose. The remaining 20 per cent has either escaped into the ground or is used in evapotranspiration, and this proportion is consistent with what is known of energy partition in a rather arid region.

The estimates of energy increment based on surface temperatures all appear too high. Two contributing factors may account for this. The more important is the existence of a superadiabatic lapse rate near the ground, which means that, under conditions of strong heating the surface temperature gives an overestimate by up to several degrees of the effective free air temperature. The other factor is the downward transfer of heat from the warm air initially above the inversion (Ball, 1960), which requires that the upper part of the convectively mixed layer should be cooled by the mixing process. This is not taken into account in the procedure used for estimating energy gain in Table 1.

### 4. The depth of the convection layer

The evening sounding gives a direct measure of the height to which the convection has extended, the dry adiabatic layer being usually well-defined, and sometimes confirmed by the observation of a haze top. The heights estimated from the morning sounding and the maximum temperature observed

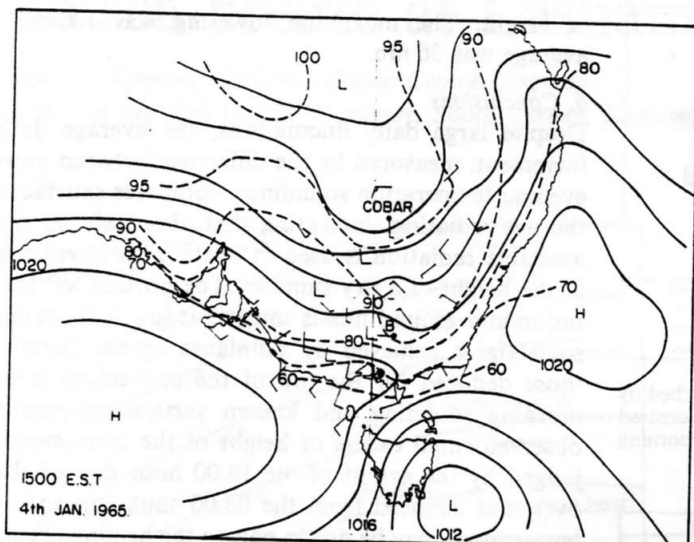


Fig. 2. — Synoptic chart for 15.00 Eastern Standard Time, 4th January, 1965

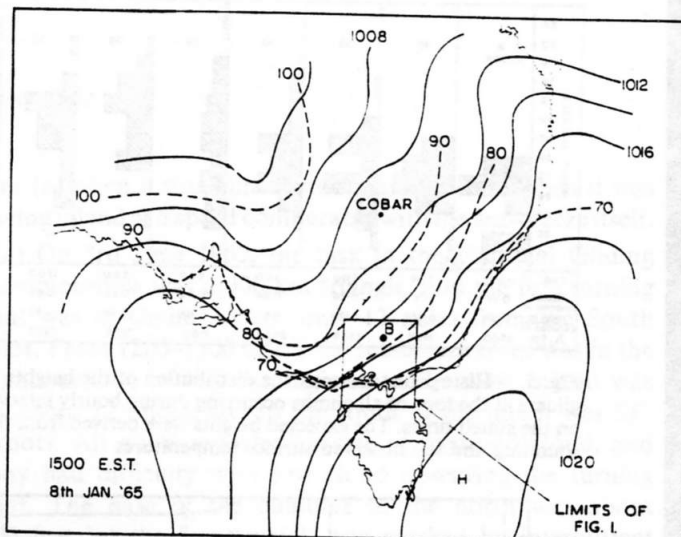


Fig. 3. — Synoptic chart for 15.00 Eastern Standard Time, 8th January, 1965

either at the airfield or in the town were usually lower than this height, as shown in Table 2. The maximum heights reached by gliders were usually in good agreement, but slightly lower than the heights estimated using the airfield maximum temperatures. The greater heights observed at 18.00 than those estimated from maximum temperatures can be accounted for by the deepening which would take place between 15.00, approximately the time of maximum temperature, and the evening sounding.

TABLE 2. Comparison of estimates of the maximum depth of the convection layer. (Unit-hundreds of feet.)

Date	30	31	1	3	4	5	7	8	9
(a) 18.00 Ascent	65	100	108	86	66	70	80	76	—
(b) 06.00 Ascent									
Airfield Max.	74	85	86	60	63	66	74	76	80
(c) 06.00 Ascent									
Town Max.	75	96	105	66	66	69	76	82	83
(d) Highest									
Sailplane	65	81	87	—	57	60	—	66	79

For one day, the 8th January, the barograms of six sailplanes are available, and in Fig. 5 are shown the percentage frequency distributions of the tops of all climbs taking place in periods of one hour, centred on the stated times. The expected maximum heights at those times, estimated from the temperature data, are shown at the bottom of the figure; the agreement is good for the first three hours, after which the sailplanes fall well below the expected heights. During a cross-country race, a sailplane is either circling upwards in a thermal or flying on course, losing height, and pilots will endeavour to select the height range over which the thermals are strongest, and may not necessarily climb as high as they could. Thus the high percentage of climbs almost reaching the expected height in the first three hours could well be attributed to caution, and the later levelling off to selectivity by pilots, or alternatively to a real inability of the sailplanes to utilise to the full the weakening thermals of the late afternoon. The route that day carried some aircraft over irrigation areas, and this could also have been a factor reducing height reached. Another interesting feature of the histograms is the

apparent tendency for double maxima, especially between 13.00 and 15.00 hours, when there are peaks around 3,000 and 3,800 feet.

#### 5. Serial ascents and the construction of time cross-sections

So far we have dealt with the morning and afternoon soundings and have considered the evolution of the latter from the former. A series of aircraft soundings made at a gliding camp in 1950 at Parkes in inland New South Wales provides material evidence of the progressive rising of the inversion during the day. Fig. 6 has been drawn by noting the base and top of every inversion or isothermal layer, drawing the boundaries of each, and making an inflexion in an isentrope where there is a sharp change in lapse rate. The sounding at 07.00 on the 11th shows an inversion at 927 mb, which we interpret as the nocturnal inversion which has risen from ground level, either with the onset of surface heating, or earlier under the influence of mechanical turbulence. An inversion was observed at the top of the dry adiabatic layer on all ascents made on the 11th and conservation of potential temperature suggests continuity with the inversion near 700 mb the following morning. During the night a new surface inversion forms and commences to ascend, probably to merge with the upper inversion. Reverting now to the evening ascent of the 10th, there is a sharp inversion at 790–750 mb which can be traced as a stable layer, not quite

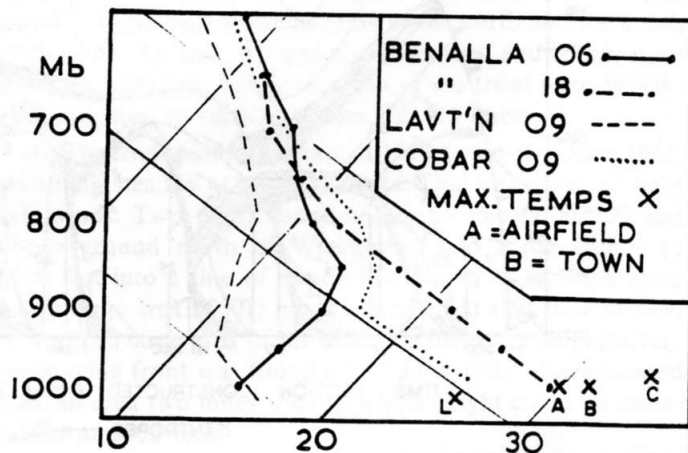


Fig. 4. — Mean soundings for eight fine days in January, 1965

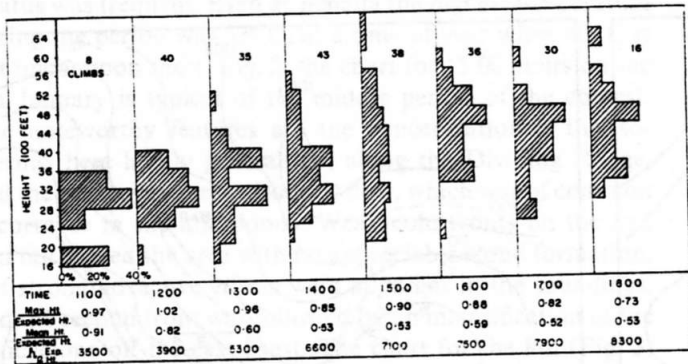


Fig. 5. — Histograms showing the distribution of the heights reached by gliders at the tops of all climbs occurring during hourly intervals centred on the stated times. The expected heights were derived from the morning sounding and the observed surface temperatures

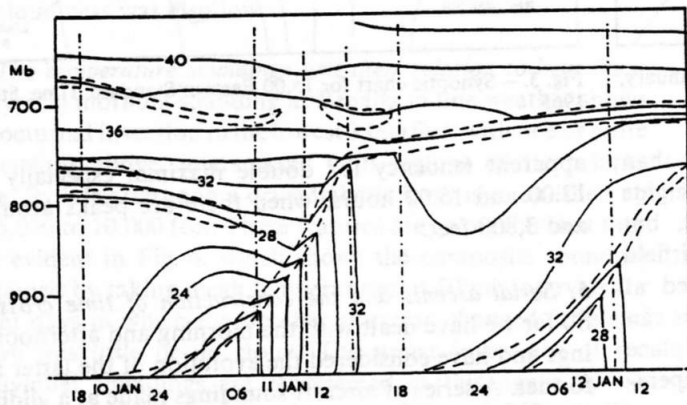
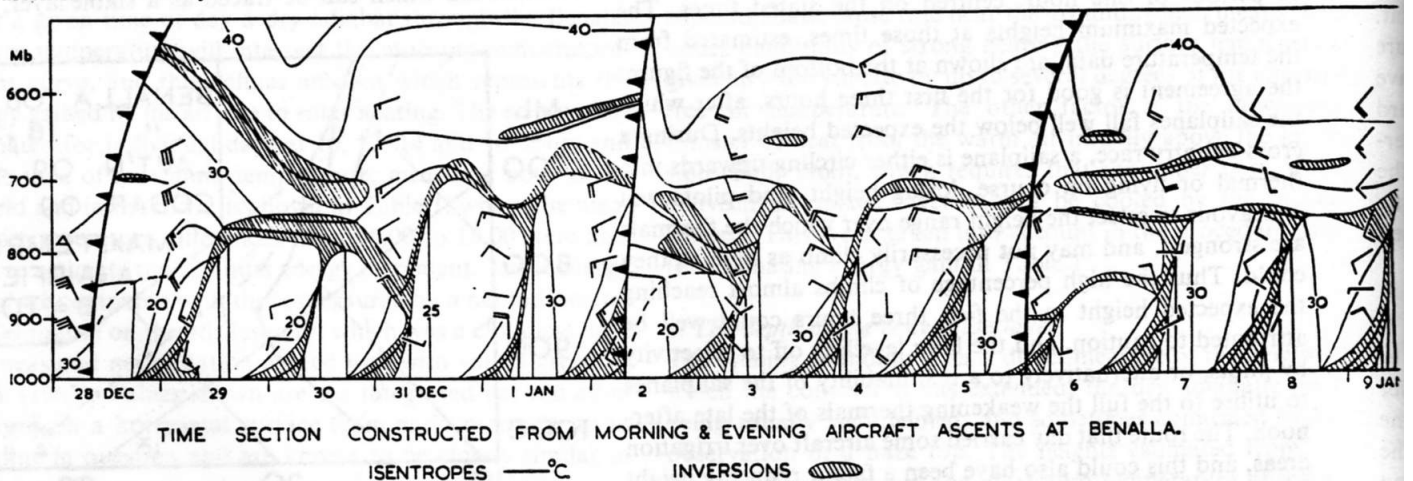


Fig. 6. — Time section constructed from aircraft soundings at Parkes on 10th-12th January, 1950, showing the development of the convection layer. The soundings are indicated by vertical dash-dot lines, and the boundaries of inversion layers by dashed lines. The solid lines are isentropes

isothermal, between 870 and 810 mb the following morning.

Fig. 7 has been drawn using the foregoing as a model, from the twice-daily ascents at Benalla. In undisturbed weather the sequence can be estimated with little difficulty, but there is considerable uncertainty in the period following a cold front and in the region above the convection layer, where there are often evanescent inversions. On the nine occasions when the remnants of the convection inversion of the previous day can be traced on the morning sounding, it was lower on all occasions save one, when it was unchanged

Fig. 7. — Time section for the period 28th December, 1964, to 9th January, 1965, at Benalla constructed from morning and evening aircraft ascents. Inversion layers are shaded and the solid lines are isentropes



(Swiss Aero-Revue 10 and 11/1965)

in height. The maximum lowering was 100 mb and the average was 36 mb.

## 6. Conclusions

Despite large daily fluctuations, the average daily energy increment, measured by the difference between morning and evening temperature soundings, compares satisfactorily with the net radiation, indicating that about 80 per cent of the available radiation is used in heating the lower troposphere at the height of a dry summer. The portion left for transpiration and ground flux is somewhat low, but not improbably so. Heights achieved by sailplanes agreed fairly well with those deduced for the top of the convection layer from a morning sounding and known surface temperatures. The observed small excess of height of the convection layer, as judged by the extent of the 18.00 hour dry adiabatic layer over that deduced from the 06.00 sounding and maximum temperature may be due in part to the heating occurring after the time of maximum temperature and in part to the cooling which occurs in the upper part of the convection layer.

It would be desirable to obtain confirmation of the interpretation which has been put upon the serial soundings at Parkes concerning the continuity and detailed behaviour of the inversions. Finally, we emphasise the need to consider convection in a broad framework embracing local wind systems and the local geography.

## Acknowledgements

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