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FORECASTING THERMALS FOR GLIDING

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The following notes have been compiled by Dr S.J. Reid.

They are reproduced for the use of meteorologists concerned with gliding operations.

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1. Introduction

A growing number of enquiries from glider pilots is reaching forecasting offices for forecasts of thermal strengths. These are not easy to make because the formation of thermals depends on many factors, ranging from the nature of the ground to the stability of the upper air. Nevertheless, a useful short-range forecast can often be made for a limited area and attention to details such as the amount of cloud cover, sea breezes, and mountain winds needed to forecast the occurrence and strength of thermals can help refine more general forecasts.

2. The characteristics of thermals

The term "thermal" is used to represent a buoyant, unsaturated volume of air rising under conditions of surface heating. In the first 300 m of the atmosphere the lapse rate on a sunny summer day is typically super-adiabatic. The Christchurch and Auckland 1100 NZST temperature soundings show that on days with strong heating the potential temperature decreases by about 2°C between the screen and 300 m. Below screen-level the stratification may be more strongly super-adiabatic. In the first 300 m the rising air currents tend to be narrow and irregular. Above this layer the thermals are more regular and tend to form discrete rising masses of air, although some observations suggest that they are continuing plumes (Warner and Telford, 1967). The thermals will at first have a temperature excess over their surroundings of about 2°C if the air has risen from within a few metres of the ground (Grant (1965)). Above about 300 m the lapse rate is nearly dry-adiabatic and the thermals mix with the environmental air progressively reducing their buoyancy, but increasing their diameter. Below cloud base the thermal may be negligibly warmer than its surroundings and in this region aircraft observations (Grant, 1965) have shown that thermals derive much of their buoyancy from the larger amount of water vapour they contain.

Telford (1966) has shown that after an initial acceleration thermals tend to rise with an approximately constant velocity. This velocity depends on initial conditions, but a rough calculation using similarity theory and the observations of glider pilots suggests that well-formed thermals above 600 m may contain vertical velocities of 4-6 m/s; these are strong thermals. More commonly thermals are somewhat eroded and vertical velocities of 2-4 m/s occur; these are moderate thermals. Weak thermals have vertical velocities of 2-3 m/s and are often poorly distributed. Thermals weaker than 1 m/s are insufficient to keep a glider in the air.

Ideal gliding conditions are found when well spaced cumulus clouds of large diameter are above 900 m, have firm edges and limited vertical extent. Although these conditions do sometimes occur in a period of slack pressure gradient following the passage of a cold front, the exceptions are more frequent and cumulus is more typically ragged and patchy.

Moderate or strong thermals will occur in the ideal conditions but consistently strong thermals are not very common and are found mostly in favoured localities. On many occasions when glider pilots find strong lift, more than one process may be present: thermals may be reinforced with hill-lift, lee waves may be present, or a sea breeze front may be producing strong lift in a limited area.

3. Considerations in forecasts of thermals

When preparing forecasts of the occurrence and strength of thermals for gliding purposes the following factors should be considered:

(a) Atmospheric stability

Favourable conditions for thermals occur after the passage of a cold front when the air in the lower troposphere has become cooler. Although unstable lapse rates are most unlikely a significant depth with a dry adiabatic lapse rate is probable. When solar heating reaches the ground thermals will readily develop.

A stable layer just above the height at which cumulus forms is also favourable because this prevents the clouds getting too deep and cutting off the insolation. If cumulus clouds exceed a depth of about 1800 m showers may also occur (Ludlam, 1951) and cause a lowering of the cloud base and a disruption to the formation of thermals. On the other hand, atmospheric stability inhibits the formation of thermals during an intense anticyclone even when little cloud is present. A subsidence inversion may gradually lower to about 600 m above the ground and although thermals tend to deepen the convection layer the subsiding air above seems to be able to counteract this to a great extent. This situation is often most marked on the lee side of a mountain range where descending air intensifies the inversion above a sea breeze or stagnant layer.

(b) Moisture

The decrease in moisture content about inversion level following a cold front also seems to favour thermal development: this is probably because it keeps the cumulus isolated from one another and the insolation is negligibly depleted.

The moisture near the ground from rain during frontal passage also probably contributes to the buoyancy of the thermals by increasing the amount of water vapour in the thermal once the surface warms enough to produce convection.

The dew-point at the ground can be used to determine the height of the convection cloud base (see appendix 1). This sometimes is inaccurate because the rising thermal mixes in environmental air which is usually dryer than surface air and the cloud base is correspondingly higher. At inland sites the cumulus base is typically 1200 m on favourable gliding days. In the MacKenzie Basin, however, dew-points are typically so low that cumulus bases about 2400 m are common and the inversion level often reaches 3000 m.

On some good gliding days the dew-point is low enough for a rising thermal to reach the inversion before condensation occurs. This is called a "blue thermal". Sometimes cumulus cloud occurs early in the day but the thermals become "blue" again when the convection condensation level rises above the inversion. These occurrences can be forecast if the temperature and humidity do not change except by solar heating; they are not infrequent.

Sometimes a day may start cloudless and cumulus develop early. The cumulus layer, however, instead of having well-spaced clouds rapidly develops and becomes sufficiently dense to cut off most of the direct solar radiation. This condition usually persists for the rest of the day and only weak thermals occur; it is called "over-development". Cumulus clouds usually develop exceptionally early on these days and a high relative humidity (say 80%) in the cloud layer is a necessary but not sufficient condition for over-development. It seems that the wind should be blowing onshore towards a mountain range as well. The reason appears to be that the bulk of the air approaching a mountain range is rising so that the downward convection currents are not sufficiently intense to produce more than small gaps between the cumulus.

In light wind conditions a layer of stratus or fog commonly forms over land at night due to radiation cooling. The cloud layer tends to dissipate during the day as convection affects a progressively deeper layer of the atmosphere. This is called a "burning off" and is the opposite effect of over-development.

(c) Winds

Well-formed thermals tend to occur when the layer of air contacting the ground has warmed to a depth of a few metres. Clearly a strong surface wind stirs the air so that it does not form a large discrete parcel of warm air and so inhibit the formation of thermals. On the other hand a gentle breeze has been observed to assist the lifting-off of an incipient thermal and does not seem to hinder the warming of the air. Over open pastures wind speeds of more than 5 m/s seem to inhibit the formation of thermals. Wind shear greater than 1-1.5 m/s per 300 m tends to distort thermals and although they may not be weakened they are more difficult for gliders to use.

(d) Mountains

The proximity of mountain ranges to most gliding areas has many effects the most beneficial of which is to break up low-level cloud. In some situations lee waves and thermals occur together to give good gliding conditions. On the other hand, winds can be strong and turbulent on the lee side of mountain ranges breaking up thermals or enhancing the stability at low levels. The development of this situation is often associated with a tendency of the thermals to become "blue".

When an inversion is present at or above the top of a mountain range, convection from the summit is suppressed but can continue on the adjacent plains. However, if there is little or no depth of stable layer or if the inversion is below the mountain top and the air above is reasonably moist and not too stable, the mountain ranges are a favoured site for convection. This will often take place when there is no convection over the plains. Large clouds may rapidly form and then drift over the plains with showers and possibly thunder.

(e) Upper Cloud

Cloud above the convection layer is not subject to "burning off" during the day (although there may be some small effect due to direct absorption of solar radiation by the cloud) and changes during the day are largely due to advection.

Solar heating reaches the ground when upper cloud is present (appendix 1) but even a thin layer of cirrus usually reduces the thermal strength one category because the super-adiabatic layer is weakened. A thicker layer of upper cloud will prevent any thermal development.

(f) Sea breezes

The arrival of a sea breeze usually leads to a reduction of the cumulus cover and a weakening and poor dispersal of the thermals. This is partly due to the cooler air in the sea breeze but is also partly due to the strength of a sea breeze which is usually more than 5 m/s.

The empirical rules for forecasting sea breezes given by Wallington (1961) seem of little value in New Zealand. In slack pressure gradients the sea breeze often appears as a freshening of the wind at the coast about 1000 NZST. With a moderate off-shore wind the sea breeze may appear as a front, sometimes squally, and usually with a suppression of thermals in the surrounding air. The sea breeze front is a source of strong lift within a very limited area and is sometimes strong enough to break through quite a strong inversion. If it advances over the plain to the mountain range it can produce marked cumulus development over the mountains.

4. Scheme for forecasting strengths of thermals

A means of predicting thermal strengths within three categories is contained in Fig. 1. In some cases, because of considerations discussed in Section 3 above, the number of unfavourable aspects may be such that the thermal strength should be forecast as nil. Further, the stability of the air may in some cases weaken the thermals more than indicated, particularly when descending air in the lee of mountain ranges is also present. Because of the interaction of many factors affecting thermals the reasoning used to arrive at a forecast is in many cases of more use to glider pilots than the resulting forecast.

References

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APPENDIX 1

PREDICTION OF CUMULUS

The temperature and dew-point are plotted on a tephigram; an appropriate midnight sounding or preferably a local temperature flight is used. The height of a stratocumulus layer overnight is often a useful guide to the height of the inversion.

As the sun heats the ground the air contacting it is warmed and mixes into a progressively deeper layer so that the temperature lies along a dry adiabat. The dew-point during this process remains constant. The heat from the sun available for this may be calculated and is proportional to an area on a tephigram (Gold, 1933). This area on the tephigram is shown as a function of time of day in Table 1 for a day on which the sunlight is not significantly diminished by cloud. The calculation has been made using the radiation formula of Monteith and Szeicz (1961). A thick layer of cloud may diminish the heating by 50% but a thin layer such as cirrus will only diminish it by about 30%.

Table 1

Area on a Met 906 tephigram (proportional to heating by insolation) as a function of time of day (summer values)

Time (NZST)	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700
Area (sq cm)	0.2	0.4	0.7	1.1	1.6	2.0	2.3	2.6	2.7	2.7

Once parcels of air rise above a nocturnal inversion so that the convection layer is more than 600 m weak thermals will form. However, thermals only reach their maximum strength when the heating at the ground is strong enough to form a significant super-adiabatic layer. Cumulus will form when the thermals reach saturation i.e. when they exceed the height at which the saturation mixing ratio line through the surface dew-point and the dry adiabat through the dry-bulb temperature meet. As the air warms further the height of the cumulus base will rise.

Fig. 1

A GUIDE TO FORECASTING THE STRENGTH OF THERMALS

On a summer day with little or no middle and high-level cloud over flat or rolling pastoral land thermals may be estimated using the following guide.