WORLD METEOROLOGICAL ORGANIZATION

TECHNICAL NOTE No. 158

HANDBOOK OF METEOROLOGICAL FORECASTING FOR SOARING FLIGHT

2nd Edition

Organization Scientifique et Technique International du Vol à Voile

prepared by OSTTV-Secretariat
c/o Institut für Physik der Atmosphäre
DLR, 8031 Oberpfaffenhofen, Germany

WMO-No. 495

Secretariat of the World Meteorological Organization – Geneva – Switzerland

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NOTE

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the World Meteorological Organization concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

FOREWORD

The original WMO Handbook on this subject was published after two decades of substantial discovery and understanding of mesoscale features particularly relevant to soaring flight. Since then, new mesoscale analysis and forecasting techniques have been developed for these features. This second edition of WMO Technical Note 158 reflects these developments.

The International Scientific and Technical Soaring Organization OSTIV, has again been instrumental in preparing the material through its Meteorological Panel, organizing workshops, and meetings involving meteorologists and skilled forecasters to collect, exchange and formulate new knowledge of atmospheric structures and dynamics to improve forecasting techniques in air sports.

Since the publication of the first edition, the range of air sports has broadened considerably. As well as more than 100 000 sailplane pilots (using about 20 000 aircraft), there are at least as many again flying hang gliders, paragliders, hot-air balloon and microlights. The new edition of the Handbook has been expanded to cater for their special needs.

Irrespective of the aircraft type or the type of flight planned (record, competition, or otherwise) adequate forecasting contributes substantially to the results and to safety.

The following meteorologists and experts have substantially contributed their knowledge, experience and time to this second edition of the handbook:

T.A.A Bradbury	United Kingdom	C. Lindemann	Germany
J.M. Hacker	Australia	C.V. Lindsay	USA
Th. Hafner	Germany	E. Lorenzen	Germany
M. Hagen	Germany	B. Olofsson	Sweden
D. Heimann	Germany	P. Poeschl	Austria
R. Heinrich	Germany	M.E. Reinhardt	Germany
W. Janata	Germany	H.J. Tanck	Germany
M. Kreipl	Germany	H. Trimmel	Austria
J.P. Kuettner	USA	C.E. Wallington	Australia (Chairman)
H. Leykauf	Germany	W. Wehry	Germany

Special financial support by OSTIV led to the organization of three workshops at St. Auban, France, for setting up and testing revised forecasting methods and texts in theory and practice. The Institute of Atmospheric Physics of the German Aerospace Research Establishment (DLR) at Oberpfaffenhofen, Germany, acted as the focal point for this activity with OSTIV President Dr Manfred Reinhardt, Dr Martin Hagen and Dr Dietrich Heimann and Professor C.E. Wallington, Australia, Chairman of the Meteorological Panel of OSTIV. The Australian Bureau of Meteorology, the German Meteorological Weather Service, Offenbach, and the New Zealand Meteorological Service provided special analysis material.

I would like to convey my sincere appreciation on behalf of the World Meteorological Organization to all who were involved in this revised version of the soaring forecast manual, especially to the late Professor C.E. Wallington, Chairman of the OSTIV Meteorological Panel whose enthusiasm and advice brought this new edition to its successful completion, and Dr M.E. Reinhardt, OSTIV President, who acted as joint editors. Sincere thanks also to the Commission of Aeronautical Meteorology for reviewing this revised WMO Technical Note.

(G.O.P. Obasi)
Secretary General

SUMMARY

This Technical Note offers the reader an internationally agreed set of guidelines of meteorological forecasting for soaring and other air sports. As pointed out in the introduction, this includes forecasters at busy aerodrome meteorological offices, who may receive enquiries from pilots, and also those who are detached specifically to provide forecasts for contests.

Chapter 1 begins with a description of some technical aspects of air sports. It continues with the various weather factors influencing air sports, conditions preventing or restricting thermal soaring and situations of particular danger to flying.

The most common soaring technique is to use thermal updraughts. Chapter 2 concerns the forecasting of thermal convection, specifically that of onset, duration and strength of thermals, the relation between solar heating and cumulus development and the effect of winds on thermals. It also considers the influence of terrain, vegetation and surface moisture on soaring flight. Description of thermals in mountain areas, of sea-breeze fronts and of cloud streets conclude this chapter.

Chapter 3 deals with forecasting for "wave soaring" and describes wave characteristics, topographical influences and synoptic patterns for lee-wave development.

The forecasting conditions for "thermal waves" and for slope soaring are described in Chapters 4 and 5.

Chapter 6 deals with the use of additional tools such as numerical weather prediction, satellite information and weather radar and Chapter 7 with the preparation, presentation and standardization of forecasts.

Chapter 8 presents examples of outstanding soaring flights with short discussions of their respective weather situations.

Finally Chapter 9 outlines the climatology of soaring conditions.

The Appendix lists some formulae for conversion of the units found in practice.

INTRODUCTION

This handbook is prepared as an aid to all who are concerned with making weather forecasts for gliding and other related air sports. This includes forecasters at busy aviation centres who may receive enquiries from pilots, and also those who are required to provide forecasts for contests.

It is basically to help meteorological forecasters and briefers anticipate and respond to requirements for low- or zero-powered flight operations. The requirements vary according to the type of aircraft and to the types of flight operation involved (i.e. local, cross-country, training, competition, record breaking, etc.). However, is not a pilot's training text.

The handbook focuses primarily on the air-sports user requirements currently most in demand, and which are distinct from more general aviation requirements. Gliding, hang gliding, paragliding and hot air ballooning are covered in some detail. Much of the information is also relevant to other air sports, even though they are not specifically treated. While the handbook may be of interest to pilots, it is not primarily intended for their use.

It begins with a detailed chapter on characteristics of gliding and other air sports — so that the forecaster may appreciate the impact of weather on safety, feasibility, timing and range of operations provide in the expanding world of air sports.

In the subsequent meteorological chapters, the aim is to provide simple methods which do not require elaborate computations. No attempt is made to cover the mathematical theory of the phenomena. There is already considerable literature on these subjects to which reference can be found in the bibliography.

It is assumed that forecasters will be working within the framework of routine analysis and prognosis charts produced by major meteorological centres. Attention is focused on some of the smaller-scale features which are not covered by routine bulletins issued by most major centres. These features are often too small to be handled by computer models which work on a grid length greater than the size of the convective or wave patterns of interest in soaring activities.

A short but significant section concerns use of personal computers, satellite images and radar. We advise that particular attention be given to the use of these plus other (remote sensing) facilities — as tools for developments in future communication and concepts in sub-mesoscale features.

CONTENTS

CHAPTER 1

GLIDING AND OTHER AIR SPORTS

1.1 CONSTRUCTION AND PERFORMANCE

Flight in gliders and other aircraft which have little or no self-propulsion has special meteorological requirements. A pilot flying such aircraft has to use or avoid particular meteorological phenomena to stay airborne, to follow a chosen course, or both.

Success in achieving these aims depends on airmanship, the flying characteristics of the aircraft and the meteorological information available for decision making before and throughout the flight. To be fully effective, the pilot must be able to interpret the meteorological information available and to observe the changing conditions.

The construction and performance of an aircraft imposes limitations on the nature and extent of using or avoiding meteorological phenomena in low- or zero-powered flight. Forecasting for air sports requires at least an elementary knowledge of aircraft characteristics.

The aircraft referred to in this manual are constructed so that they can be dismantled, or derigged, and packed for stowage and transport between flights. Most sailplane containers are enclosed for protection. Hang gliders are normally packed into tubular bags, paragliders into backpacks. Balloon trailers are mostly open, with the balloon envelopes packed into bags.

1.1.1 GLIDERS, ALSO CALLED SAILPLANES

The material most commonly used for sailplanes is reinforced plastic. Some are metal. Older (and a few new) gliders are made of wood and fabric. All sailplanes have ailerons, rudder and elevator controls, as for larger powered aircraft. They also have some form of spoilers to steepen the rate of descent without increasing the forward speed for landing. Some advanced gliders also have flaps. Most sailplanes have an undercarriage comprising a single, partially enclosed, wheel. High performance gliders have a fully retractable wheel.

Sailplanes do not necessarily have to be especially lightweight aircraft. Most modern types can accommodate water ballast—the additional weight being to boost cross-country soaring speed. This water ballast can be jettisoned to reduce weight on approach to landing.

For competition and record purposes, gliders are classified according to several criteria, the most apparent being wing span. The Table 1.1 indicates characteristics for a range of activities. Two-seater gliders are used mainly for training and passenger carrying, but some are built for high performance gliding.

Table 1.1
Characteristics for different types of gliders. The World Class is a new class currently being introduced.

Type (main usage)	Wing span	Weight empty	Gross weight	Best glide ratio	Minimum sink rate
Training (2 seater)	17 m	400 kg	600 kg	1:27 at 75 km/h	0.70 m/s
Club Class	15 m	250 kg	350 kg	1:37 at 85 km/h	0.65 m/s
Standard Class	15 m	300 kg	450 kg	1:43 at 90 km/h	0.60 m/s
Open Class	up to 29 m	500 kg	750 kg	1:60 at 110 km/h	0.45 m/s
FAI 15 m Class	15 m	300 kg	450 kg	1:45 at 100 km/h	0.55 m/s
World Class	11-15 m	80-200 kg	200-320 kg	1:32 at 70-90 km/h	0.65-0.75 m/s

1.1.2 HANG GLIDERS

Hang gliders are lightweight aircraft made of aluminium alloy tubing with fabric-covered wings. Suspended below the wing, the pilot controls the aircraft by shifting position fore and aft and side to side. Training can be given with single-place hang gliders, but two-place training is more common. Hang gliders do not normally have undercarriages; pilots land on their feet. However, there is growing interest in designing a type of hang glider that will include some form of undercarriage. Most hang gliders have the approximate characteristics listed in Table 1.2.

Table 1.2
Characteristics of hang gliders

Wing span	10 m	Empty weight	30 kg	Stalling speed	25 km/h	Effective max speed	70 km/h
Wing area	15 m^2	Loaded weight	70-100 kg	Best gliding ratio	1:12	Terminal diving speed	90 km/h

1.1.3 PARAGLIDERS

Paragliding is probably the simplest way of flying. The equipment is basically a parachute with a rectangular or elliptical wing-like form with integrated air chambers. These chambers inflate when the pilot moves the parachute rapidly against the wind. During flight the chambers remain filled with air, imposing an aerodynamic profile and wing shape to provide lift for soaring. The pilot is able to pull down the wing-tips separately or together with steering ropes, thereby increasing the drag to turn or to change the gliding ratio. The best ratio of gliding ranges between 1:3 and 1:6. Cruising speed can be up to 40 km/h and the stall speed is less than 25 km/h. Counter-balancing their poor gliding ratio, paragliders take advantage of their excellent manoeuvrability which makes them able to use even narrow thermals or slope winds in order to extend their flights. The parachute weighs about 6 kg and can easily be carried in a backpack to a mountain. There the pilot takes off from a suitably inclined strip of grass. Pilots land on their feet after reducing air speed by pulling down both wing-tips a few metres above the ground.

1.1.4 HOT AIR BALLOONS

A hot air balloon comprises an envelope to contain the hot air, and a basket or other structure to carry the pilot, with or without passengers. The envelope is made of ripstop nylon coated on both sides with polyurethane to minimize porosity. The basket is usually made of wicker and rattan, which are still the best materials for the purpose. Propane, stowed in cylinders in the basket, is the most common gas used to heat the air in the envelope. Mounted above the basket is a burner unit which directs jets of flame into the wide open mouth of the envelope. Table 1.3 gives the approximate range of sizes, weights and performances for most types of ballooning.

The primary flight controls apply to movement up and down. To maintain level flight the pilot turns on short bursts of heating at intervals to balance the loss of heat to the outside air. To go up, the pilot uses longer bursts or shorter intervals. To go down the pilot either lets the hot air cool, or opens a circular vent at the top of the envelope to let some of the hot air escape. The altitude of the balloon can be controlled accurately using these methods.

The balloon has no direct power to progress horizontally through the air around it. However, in most weather situations favourable to ballooning, the wind varies with height and by flying at appropriate heights, the pilot can make cross-country progress within a sector bounded by usable wind directions.

Table 1.3
Range of characteristics for most hot air balloons in air sports. The weight in tonnes includes the hot air filling the envelope.

Envelope volume	Height (top to bottom)	Weight tonnes	Free lift kg	Maximum rate of ascent	Terminal descent rate
1600 m^3	20 m	1.5	850	5 m/s	4.0 m/s
8500 m^3	40 m	10	2000	5 m/s	3.5 m/s

1.1.5 GAS BALLOONS

There are many similarities between hot air and gas balloons. But fundamental differences arise from gas balloons' being inflated with lighter than air gas instead of hot air. In Europe the buoyant gas is hydrogen. Helium is not used so much, because it is expensive, especially outside the U.S.A.. To minimize the risk of static discharge on landing, gas balloons usually have antistatic coatings on the envelope material. Gas balloons are generally smaller than hot air balloons.

Up and down control is by dropping disposable ballast to go up, and opening a vent at the top, to let some of the gas out, to go down. During a flight some of the gas is lost by expansion due to insolation and ascent.

1.1.6 HOT AIR AIRSHIPS

A hot air airship is a hot air balloon, shaped like a fat fish with tail fins. It carries a cockpit or cabin, a motor driven pusher propeller and a rudder. Currently, motor driven speeds through the air are up to about 25 km/h. Height control is similar to that of a hot air balloon.

1.1.7 MICROLIGHTS

By current international convention, criteria for microlight aircraft classification are:

Maximum gross weight	390 kg
Maximum wing loading	25 kg/m^2
Maximum fuel load	50 l

Within these specifications, a microlight may be of almost any design. There are two distinctive types of microlight. One is controlled by weight shifting, as in hang gliding. The other has 3-axis controls, as in sailplanes. Characteristics of these types are shown in Table 1.4. Some microlight aircraft are fitted with floats, as for seaplanes.

Table 1.4
Characteristics of microlight aircraft (two-seater).*

	Weight shift control	3-axis control
Wing span	11 m	15 m
Wing area	10 m^2	10 m^2
Empty weight	48 kg	145 kg
Max. take-off weight	300 kg (400 kg)*	300 kg (400 kg)*
Stalling speed	45 km/h (50 km/h)*	45 km/h (50 km/h)*
Cruising speed	70 km/h	90 km/h
Max. diving speed	140 km/h	170 km/h

1.1.8 Motor gliders

Motor gliders are sailplanes equipped with a small motor that at least enables the aircraft to take-off and climb to a height sufficient to simulate gliding flight with the motor stopped. This type was introduced primarily to facilitate early training in gliding. It is still used for this purpose.

However, the type has now developed to include very high performance gliders, with motors that can be retracted completely into the fuselage leaving the smooth aerodynamic shape of the aircraft just like that of a high performance motorless sailplane.

1.1.9 Other low- or zero-powered aircraft

Low- or zero-powered flight also includes parachuting, model flying and kite flying. Science, technology and interest in these sports are fast developing. Some of the requirements in these air sports are similar to those of the more established air sports, such as gliding, hang gliding and ballooning. Considerable development and growth of interest (attracting spectators as well as participants) is going on in this field. But at the time of writing this manual, not enough experience has been accrued to include more than incidental references to distinctive meteorological requirements of these newer (or revived) air sports.

1.2 GLIDING AIRCRAFT POLARS

An aircraft's rate of gliding descent plotted over a feasible range of the true airspeed of the glider is known as a 'speed polar' curve. Characteristic polars shown in Figure 1.1 indicate ranges of airspeeds and associated rates of descent (sink) available for the types named. Stalling speeds of aircraft are just to the left of the minimum rates of sink. Such a curve is used for estimating or calculating criteria such as optimum speed to fly, the feasibility of a planned glide to a destination, or whether a thermal upcurrent is worth using en route. For meteorological forecasters, the curves show aircraft airspeeds and sink rates for comparison with atmospheric winds and vertical motion.

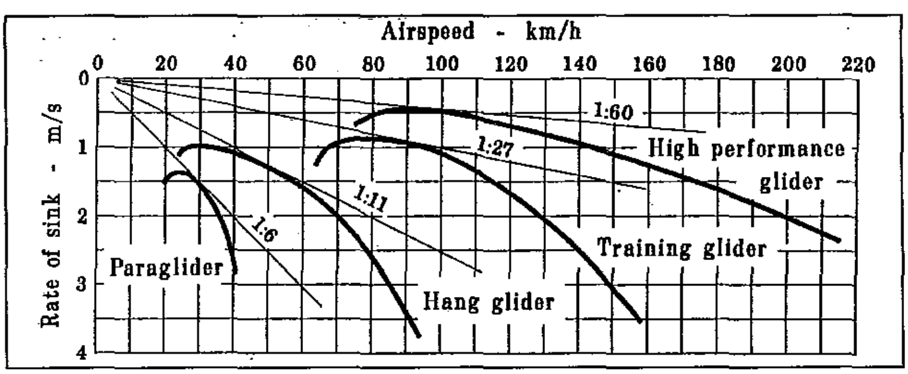


Figure 1.1
Characteristic of polars for gliders, hang gliders and paragliders. Minimum sink-to-airspeed ratios are shown by labelled tangents to the polar curves.

1.3 FLIGHT OPERATIONS–GROUND HANDLING

In preparation for flight, a low powered flight aircraft may have to be rigged, parked and towed or pushed to a take-off position. Most low- or zero-powered aircraft can be rigged and prepared for take-off in about 10–30 minutes.

To prevent an aircraft being moved, swung or toppled over in fresh or gusty winds, unattended aircraft must be firmly tied down and ground handling needs care and attention. In some strong or gusty wind conditions there are limitations in preparing an aircraft for take-off.

1.3.1 SAILPLANES

Rigging a glider primarily comprises fixing the wings and elevator onto the fuselage, connecting controls and adding ballast, if applicable.

On flat airfields, taxiing patterns and tie down procedures are similar to those of general aviation, except that the aircraft are towed, usually by car.

1.3.2 HANG GLIDERS

A derigged hang glider packed in its bag can be carried, at least a short distance, by one person. They are usually rigged close to a launch position, then walked, often by the pilot in harness almost ready for flight, to the launch position. In windy conditions, this manoeuvre can be awkward and require some assistance. Rigging may be impossible on flat or exposed sites in fresh or gusty winds. On hill sites, some shelter may found in rugged terrain or among trees bordering the launch position, which need be only a small clearing. At regularly used hill sites, ramps sloping slightly down into the prevailing upslope wind and drafts are suitable for take-off.

1.3.3 HOT AIR BALLOONS, HOT AIR AIRSHIPS AND GAS BALLOONS

Preparing a hot air balloon includes laying out the envelope, partially filling (with a petrol driven fan) the envelope with air, then using the burners to heat this air until the balloon is full and upright.

A fully loaded balloon with just enough buoyancy to remain upright is unlikely to be moved much by a wind of less than about 15 km/h. When there is (or is any risk of) greater wind speeds, balloons being prepared for take-off are normally tethered, by a short rope, to an object such as a motor vehicle. In fresh or gusty winds it can become difficult if not impossible to fill and heat the air in a hot-air balloon. Seldom is take-off restricted to any particular place and local wind shelter (such as in lee of high trees) may be sought, if necessary.

Filling a gas balloon entails piping the gas into the envelope while adding ballast—normally bags of sand—and adjusting its distribution. It is a slower process than preparing a hot-air balloon. Being smaller than a hot air balloon of similar buoyancy, and not having a wide open mouth, a gas balloon is not quite so difficult to manage in fresh or gusty winds, but it may still be tethered to a heavy object. An inflated balloon is not normally left unattended.

1.3.4 MICROLIGHTS AND MOTOR GLIDERS

With their motors on, these aircraft can be considered as light powered aircraft for ground handling and meteorological requirement purposes: but microlights can be difficult to manoeuvre in fresh or gusty winds.

1.4 FLIGHT OPERATIONS–TAKE-OFF

1.4.1 GLIDING, HANG GLIDING AND PARAGLIDING

1.4.1.1 Aerotow

The most common and widespread way of launching a glider is to tow it with a powered aircraft up to a height where the pilot releases the tow rope and starts gliding. For sailplanes, 600 m above ground is a widely-used release height, especially in competitions. During the ground run along the runway, directional control, especially of heavily laden gliders, can be difficult in cross winds more than 20 km/h. Aerotowing (usually by microlight aircraft) from flat sites is increasingly used in hang gliding as well.

1.4.1.2 Winch or car launch

A winch and reel-in cable, or a car pulling a fixed length cable, can be used to haul the glider up to a release height, usually between about 250 and 500 m. Only a proportion of the winches or cars used have enough power to launch a heavily laden high-performance glider.

Hang gliders can also be winch launched. With a long cable and teamwork between the pilot and winch driver, heights of a few hundred metres have been attained by a form of kiting.

1.4.1.3 'Hill lift' launch

The term 'Hill lift' used here is not one of the conventional names for this type of take-off. But it denotes that a glider type of aircraft becomes airborne by being cast into a wind blowing up a hill slope. An elastic (bungey) rope is used to catapult a sailplane into the upslope airflow—hence the name 'bungey' launch. A hang glider or paraglider pilot (already harnessed into his aircraft) achieves the same effect by running—only a short way—down a hill slope or a specially constructed ramp. This 'foot' launch is the most common and widespread method in hang gliding.

1.4.2 Balloon types

The propane burner unit creates buoyancy for hot air lift-off. Gas balloon pilots throw out some ballast to become airborne.

1.4.3 Microlights, motor gliders

Self-powered for aeroplane type take-off.

1.5 FLIGHT OPERATIONS–APPROACH AND LANDING

1.5.1 SAILPLANES

Approach and landing technique is similar in principle to that of larger powered aircraft. For safety it is best to land into wind, but, like powered aircraft, gliders have limited scope for cross- or down-wind landing. Unlike a powered aircraft, a glider does not have a motor to increase speed to minimize a loss of airspeed due to a sharp wind shear or excessive turbulent fluctuations—or to abort his landing at low level. The last part of a glider approach to land is normally at a speed which the pilot anticipates will be enough to cope with low level turbulence or wind shear.

For a high performance glider, the approach can be a long, very shallow glide—for example, at about 1.25 degrees from, say, 2000 m and 80 km from the landing place. Calculation of the feasibility of the approach is based on glider performance data, assessment of the wind components along the approach path and entail the use of various computing aids. Progress checks on the feasibility are made visually and numerically at intervals of the approach. The pilot normally opens taps to start jettisoning water ballast several minutes before touchdown.

1.5.2 HANG GLIDERS AND PARAGLIDERS

Approach and landing are similar in principle to gliding but the distance, time, airspeed and eddy size scales are significantly different. Both hang gliders and paragliders are more sensitive to some turbulence and wind shear, but are also more responsive to wind fluctuations and provide more scope for pilot response.

1.5.3 MICROLIGHTS

Microlights are closer to hang gliders than sailplanes in their sensitivity to wind fluctuations on approach and landing, but they are not so responsive as hang gliders.

1.5.4 MOTOR GLIDERS

Motor gliders are effectively light powered aircraft with their motors on, and gliders of the type they simulate with their motors off (and retracted, if possible).

1.5.5 HOT AIR BALLOONS

Descent to a landing place depends critically on the wind profile with height. If the wind direction is constant throughout this descent, the approach path will also be constant in direction and the pilot's task will be to control the height of the balloon so as to touch down at a suitable landing place along this constant wind direction. This does not necessarily involve a steady rate of descent to touchdown. More often after descending to a height just sufficient to clear obstacles on the approach path, the pilot then maintains this height until reaching the place selected to complete the descent to touchdown. If the wind is less than about 15 km/h the touchdown is normally gentle and the balloon stays upright when it lands. In fresher wind, the envelope may be blown forward and tip the basket on its lee side. Meanwhile the pilot would have opened the vent as much as possible to let the hot air out and accelerate the collapse of the envelope. In a stronger wind, the basket may be dragged tens of metres, possibly more than 100 m before stopping.

On most occasions wind direction varies with height. So the balloon descends a curved, or more likely zig-zag, path through one or more low-level wind shears.

Because the range of available wind directions is often confined to a limited sector, a pilot cannot normally guarantee reaching a pre-planned landing place. But there is usually enough pre-flight information to assess whether a balloon flight is feasible to an area which contains suitable landing sites. In light winds, a balloon can land in a very small area, not much larger than the area covered by the envelope. If the wind is calm, or so light that the balloon cannot quite get to a selected clearing, the pilot may throw a handling line from the basket to the ground crew (who are normally in radio touch, and follow the flight by road) to pull the balloon to the clearing. If the landing wind is stronger, a larger landing space is required. But a stronger wind also enables the pilot to cover more terrain in which to choose the landing place.

Whenever, a balloon is landed in a small clear space, or in the vicinity of a hazard (e.g. obstruction or electric power line) a sudden wind change or gust can add difficulty and danger to the landing procedure. For safety, a pilot must have enough fuel left to slow the descent, or abort the landing, if necessary.

1.5.6 Hot air airships

Approach and landing is somewhat similar to that of hot air balloons, except that hot air airships have power for very low speed flight.

1.5.7 Gas balloons

Approaches and landing are somewhat similar to hot air balloons in principle, but gas envelopes can be deflated more quickly through rip panels. For long duration (e.g. 24 hours or more) flights, entailing a distinct risk of having to land in fresh or strong winds, a safety device may be activated to release the envelope from the basket on touchdown. For safety, a pilot normally aims to have enough ballast left to use for slowing down, or aborting, landing.

1.6 FLIGHT OPERATIONS–LOCAL AND CROSS-COUNTRY FLIGHT

1.6.1 Gliding, hang gliding and paragliding

After launch the pilot must find a region where the air is ascending faster than the sailplane sinks with respect to the air. While the sailplane remains in this region it gains height. Areas of rising air are found:

- Where the wind blows up the side of a hill (Figure 1.2 a);
- Where the air heated from below becomes less dense than its environment and rises. The updrafts may be capped by cumulus clouds (Figure 1.2 b);
- Where the mainly horizontal flow of air is modified by the development of wave-like flow; commonly observed over and downwind of mountains and may be found to the lee of quite small hills (Figure 1.2 c). Wave-like flow is also found above and close to convective updrafts (thermal waves, Figure 1.2 d).

All these types of updraft may occur at the same time over a single gliding site.

Local and cross-country flights consist of gradual descent where the air has no upward motion, interrupted by climbs to regain height when the pilot encounters rising air. Meteorologically, flight time is limited by the duration of safely usable "lift".

1.6.2 Balloons

Balloons are carried with the wind at whatever height they fly. Cross country flight is determined by the winds within the height band the pilot chooses. Unless turbulence or wind shear is excessive, balloons can travel comfortably in high speed winds. Thermal convection, however, is a bigger problem. Thermal up- and down-drafts, with associated changes in horizontal wind fluctuations can play havoc at all stages of flight—and locally intense convection can dangerously distort, or collapse, the envelope. To avoid these risks, hot air ballooning is usually limited to light wind, during non-convective daylight periods.

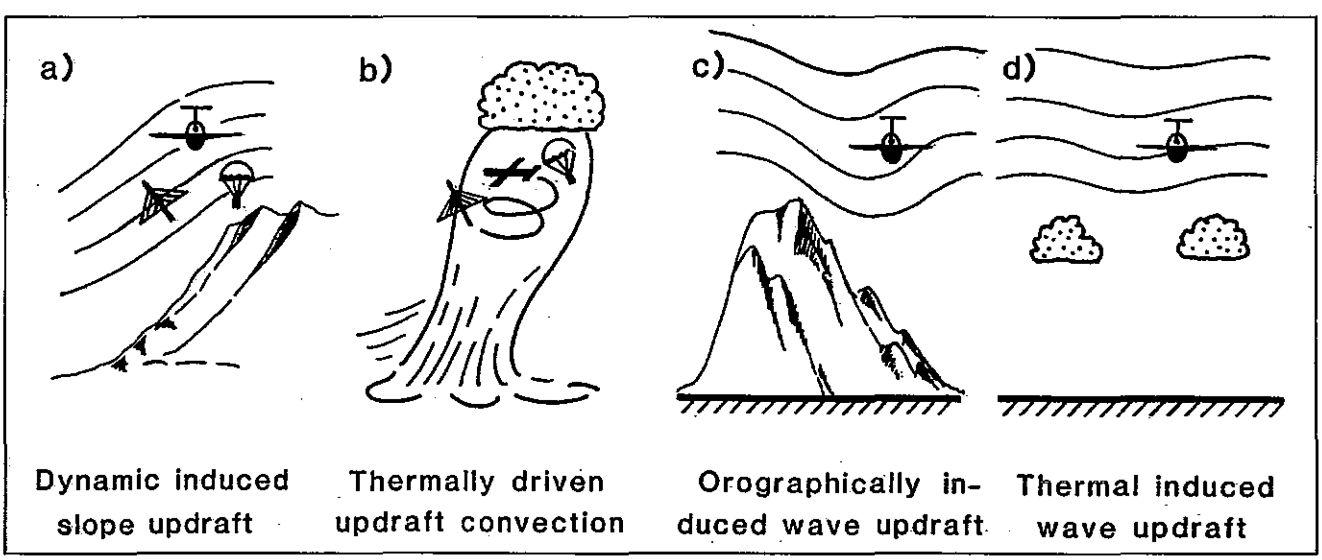


Figure 1.2
Main sources of energy for gliding.

1.6.3 GAS BALLOONS

Cross country flights in gas balloons are mostly higher (above thermal convection) and for longer duration than those of hot air balloons. It is not uncommon for them to take-off in darkness and fly until at least the next day. Pilots are prepared for making a fresh wind landing, if necessary.

1.7 TYPES OF FLIGHT

1.7.1 TRAINING AND LOCAL FLYING

Training and local flights are mostly within fairly close range of an airfield or other suitable landing place. Take-off and landing decisions are made primarily on the meteorological conditions observed by the pilot or an instructor.

1.7.2 CROSS COUNTRY FLYING

Most national organizations require pilots to have some type of formal approval of their knowledge, experience and ability before they are allowed to fly cross country. For such flying, pilots need route or area forecasts, but their planning is often tentative. For safety, they can use their own local observations plus whatever other meteorological information they have obtained to modify their plans immediately or throughout the flight.

1.7.3 COMPETITION FLYING

Formal world and international championships in all established air sports are regulated and authorized by the International Aeronautical Federation (F.A.I.).

Characteristic distance, height and time ranges, illustrated in Figure 1.3 for competition flying in gliding, hang gliding and hot air ballooning, indicate the meteorological scales involved.

The ranges do not denote firm boundaries. Convection clouds, standing or moving waves in the atmosphere, orographic lift and convergence zones enable glider pilots to climb above thermal convection. But cloud flying is not usually permitted in these championships, and climbing above the thermal convection layer is not always an advantage in competition flying. The 'boundary layer' notation for ballooning usually means up to about 1000 m above general ground level for most competition tasks and occasionally up to about 2000 m. In many situations a balloon pilot may descend to only a few metres above ground level during parts of a competition flight.

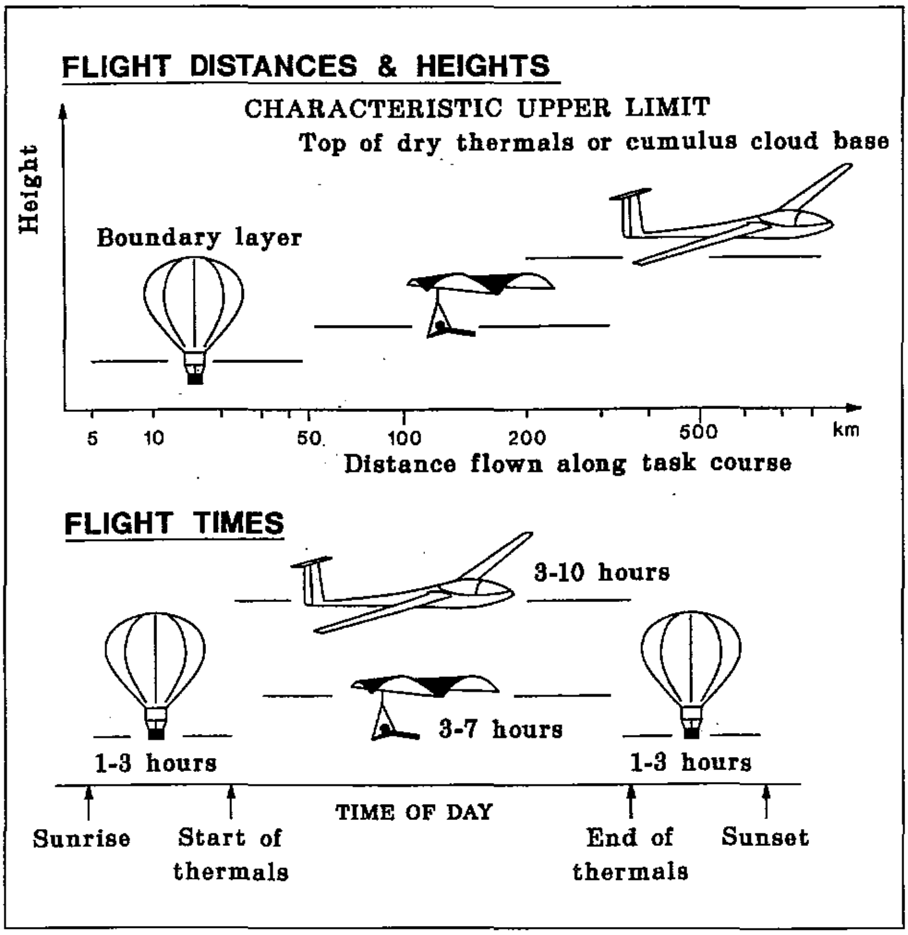


Figure 1.3
Characteristic distance, height and time ranges for competition flying in gliding, hang gliding and hot air ballooning.

Competition gliding usually comprises a number of tasks in which pilots accrue competition points. Gliding and hang gliding competition tasks normally entail flying around or along courses via turn points. Points are awarded for speed and distance achieved. Only one task per competition group or class is set on a competition day.

Hot air ballooning tasks basically require pilots to fly to specified ground targets and, in some cases, make substantial changes of course. Pilots are required to drop markers as close as they can to the targets. On any single flight, during the morning or afternoon, a pilot may be required to complete 1, 2 or 3 tasks in sequence.

During championships, each day's task setting and consequential operational decisions have to be made before take-off times. It is very difficult, and often impossible, to change some of these decisions after they are made. For example, once a large number of hang gliders, together with ground crews, vehicles, spectators and facilities are positioned for take-off appropriate to a predicted wind direction, a change of runway or site may not be feasible—even to accommodate a significant wind change. After pilots have started to fly on the set course, it is practically impossible to change the set course. Thus meteorological information and forecasts are crucial to the success and safety of competition flying.

Motor gliding and microlight aircraft competition flying have some similarity with gliding in that cross-country tasks are set and skillful use of rising air can enhance flight efficiency.

Competition gas ballooning is mostly distance achievement. Competition flying heights, durations and distances are greater than those of hot air ballooning. Classic annual events entail flights of one or two days duration. Take-offs are often in the evening. Flight levels are chosen to use the upper wind profile to advantage and avoid convection currents.

Table 1.5 shows typical numbers of competing pilots in regular championships in gliding, hang gliding and hot air ballooning.

Table 1.5
Numbers of competing pilots in championships.

Championships type	Gliding	Hang gliding	Hot air ballooning
World Championships	70-120	80-200	70-110
International Regional	70-90	60-120	70-90
National Championships	60-90	50-80	40-80
State & Provincial	30-60	30-60	20-50

1.7.4 Record Flying

Most requirements are similar to those for competitive flying, but some types of record have specialized planning and operational requirements that should be clarified by close liaison between the meteorological services and aviators involved.

Flight duration records are neither advocated nor encouraged in air sports.

1.8 AIRCRAFT INSTRUMENTS

Gliders, hang gliders, motor gliders and microlight aircraft normally have air speed indicators, altimeters, particularly sensitive variometers (rate of climb and descent indicators) and compasses. Some also have blind-flying instruments. This instrumentation is often augmented with electronic aids (to calculate optimum speeds to fly and dead reckoning navigation information) and audio aids to hear (by tones) rather than look at variometer data.

Balloons normally have altimeters and variometers. Hot air balloons also have thermometers to indicate the air temperature at the top inside of the envelope.

For many years recording barographs have been used to produce height-time graphs for flights. Digital recording barographs can now be used for computer-aided post flight analysis, if required. More sophisticated equipment is also used for digitally recording and analyzing more detailed and specific information, including air temperature and humidity associated with thermals and other features of meteorological interest along a flight path. This type of electronic development is about to be augmented by use of small ground position (by satellite) indicators. Many pilots will be unable to afford expensive instrumentation, but there are already enough air sports aircraft with such equipment to obtain data for feed-back into meteorological studies.

1.9 AIRCRAFT AND METEOROLOGICAL REQUIREMENTS

For safety, satisfaction and success, an airsports pilot requires aircraft characteristics and meteorological conditions such that he or she can:

- manage the aircraft on the ground—before and after flight (alone or with helpers)
- take off
- remain airborne with the aid of useable upcurrents
- avoid or get out of weather hazards, especially dangerous vertical currents
- be within range of a suitable landing place
- plan a safe approach to landing and touchdown.

The nature of the meteorological requirements may be deduced from the aircraft characteristics and operational types of flying. Essential depth and detail of the meteorological practice involved is presented in the following chapters.

1.10 HAZARDS

Hazards similar to those in general aviation are mentioned only briefly, or omitted, on the assumption that practising aeronautical meteorologists will already be aware of them. This section calls attention to hazards that are particularly related to gliding, hang gliding and ballooning.

1.10.1 Fresh winds, cross winds, turbulence during ground handling and take-off

Air sports aircraft are prone to damage in windy conditions. Such aircraft must be sheltered from the wind, securely tied or held down in such conditions. In some situations, where safe flight can be maintained once airborne (for example, in a bungey type launch) manpower may be used to hold an aircraft in position until the sudden take-off.

Winch type launching can be hazardous if the launch is through an area of wind shear or fluctuation which causes a sudden loss of airspeed—especially at low levels where the aircraft may not have enough height to recover airspeed.

The aerotow combination of tug (powered aircraft) and glider (especially if heavily laden) can be difficult or dangerous on take-off.

If a hot air balloon is filled and ready for flight in fresh winds, an experienced pilot can take off by actuating a quick release to the rope tethering the balloon to an object on the ground, typically a heavy vehicle or a tree.

1.10.2 Turbulence in flight

Turbulence depends not only on air movement but also on the size, weight, shape and airspeed of the aircraft going through the air.

Turbulence to sailplane pilots usually means their having to make substantial basic control movements to maintain adequate flying control. Loose objects may be thrown about the cockpit. They will experience noticeable acceleration forces, but it is very rare for a modern sailplane to be severely damaged by turbulence. Most of the turbulence encountered in gliding is in rotor-type flow. In such turbulence, control of a hang glider or microlight aircraft is likely to be difficult, if not impossible. Control by pilot weight shifting in hang gliders and some microlights ceases. If a hang glider or microlight aircraft gets out of control, the pilot usually has the option of deploying a personal parachute or an aircraft parachute—supporting the aircraft and the pilot.

When a balloon encounters turbulence, the shape of the envelope will be distorted. Slight distortion is not necessarily damaging, but it is likely to cause some loss of hot air through distortions in the mouth of the envelope. Thus, more heat and fuel will be needed to maintain height thereby reducing the planned duration of the flight. If the turbulence is more intense, there is a serious risk that the envelope may be so distorted that it becomes difficult or impossible to direct the jet of flame into the envelope. The collapsed balloon can then descend at a perilous rate.

1.10.3 Wind shear in flight and on final glide paths

At flight levels, wind shear alone does not normally present a hazard to gliders or hang gliders. Wind shears are quite common in balloon flying. Apart from a type to be described later, almost all of the shears encountered are noticeable, useful (for balloonists) and innocuous.

Final completion of record-flying glide paths towards the end of a cross-country flight are often shallow. Final glide decisions are made by the pilot in light of anticipated winds along the glide path. If the final glide encounters an unexpected wind shear which steepens the glide path, the pilot may not be able to reach the landing place and is likely to have reduced options for safe alternatives.

1.10.4 Wind shear at low levels on final turn and approach to landing

As in general aviation, a sudden reduction of airspeed due to wind shear is a potential hazard. A modern high performance glider with long wing span may be close to stalling speed, but may not have the aerodynamic warning symptoms that are more noticeable in lower performance aircraft. A low level turn can also be hazardous when the long wing span extends across a sharp wind shear or 'curl-over' eddy. With adequate warning or anticipation of such shears, a sailplane pilot normally makes the final turn and approach with excess speed to counter the effects. Hang gliders and microlight aircraft are also vulnerable. They are more manoeuvrable which is an advantage but have a lower speed range to offset the shear effects.

1.10.5 Wave flying

Especially gliders, but also hang gliders and microlight aircraft are frequently flown in waves with safety. The potential hazards are: rotor flow turbulence; closing of gaps in the cloud below (leading to inaccurate navigation, unplanned and possibly inexperienced descent through cloud, which may contain turbulence or icing conditions and may hide high ground).

1.10.6 Icing

Few sports aircraft types have anti-icing devices. Hot air balloons are an exception, then heated envelopes are useful thawing agents.

1.10.7 Rain

Rain has an adverse effect on the aerodynamic efficiency of high performance glider wings. The reduction in performance coupled with downdraught, turbulence, or glide-path problems can be hazardous.

1.10.8 Hail

Pilots of hang gliders and microlights are more exposed. Hail may also damage rigid aircraft both in the air or on the ground. Apparently superficial hail damage to high performance sailplane wings can be expensive to repair.

1.10.9 Visibility

A particular hazard in competition gliding is the risk of collision when a large number of aircraft are flying in close proximity in a shallow thermal soaring layer with poor visibility usually due to pollution—from a local or far distant source. Collision risk is also significant when mountain slope soaring aircraft are confined to a shallow, polluted layer.

1.10.10 Substantial up- or down-drafts

Low performance sailplanes, hang gliders, microlight aircraft, balloons and parachutes may not have either enough airspeed or sufficient maximum climb or descent rates to avoid being carried upwards or downwards into hazardous situations.

Seemingly small altocumulus with virga can produce isolated small scale microburst hazards for early morning or late afternoon ballooning. The momentum of a balloon (with 2000–9000 kg of air in the envelope) adds to the downdraft hazard.

1.10.11 Low level moving waves

Moving waves, or packets of waves, associated with low level inversions are more common than is generally known. Such waves can produce wind and vertical motion effects on air sports aircraft that are difficult to distinguish from small scale microburst effects.

1.10.12 Lightning strike

During a winch or car launch, the launch cable is an effective lightning conductor, at the ends of which the pilot and winch driver are in danger unless they are suitably shielded. Static discharges in flight are not uncommon, but seriously damaging strikes have so far been rare.

CHAPTER 2

FORECASTING THERMAL CONVECTION

Thermal convection is, as far as synoptic meteorology is concerned, a sub-scale process and involves turbulent mixing of the boundary layer by convective elements which show a great variety in size and structure. A typical time scale is some ten minutes and the diameters are typically of some hundred metres.

Solar heating of the ground releases convective elements which rise until they reach a stable atmospheric layer, the inversion (Figure 2.1). Ascending thermals experience turbulent lateral entrainment of surrounding air and their moisture and temperature becomes modified. To describe convection, knowledge about the vertical profiles of temperature, moisture, and wind is needed. These profiles are permanently changed by synoptic processes such as large scale subsidence or ascent and horizontal advection and by convection itself. Ascending and descending convective elements accomplish the turbulent transport of sensible and latent heat and momentum.

Heating of the ground is influenced by a great number of parameters: available insolation depends on latitude, season and time of day, and on cloud cover and

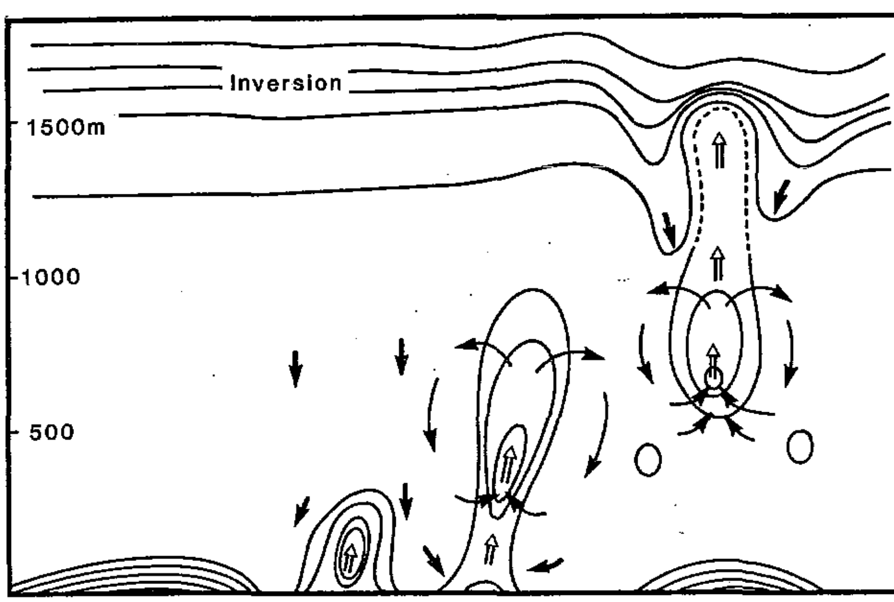


Figure 2.1
Release of a thermal and its penetration into a stable layer or inversion. Lines represent potential temperatures.

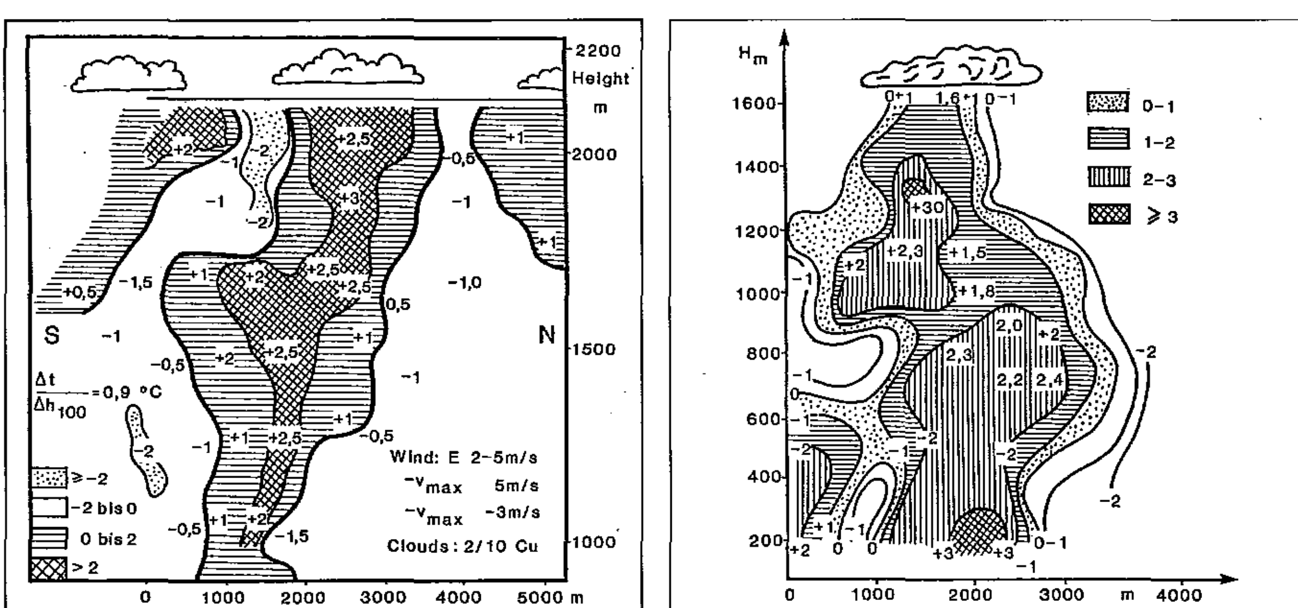


***Figure 2.2** (below)*
(a) Field of measured updraft velocities of air under a shallow cumulus layer (Vieweg-Pielsticker, 1956)
(b) Distribution of air velocities under a cumulus med. cloud, July 27, 1968 at Orel, USSR (Konovalov, 1976)

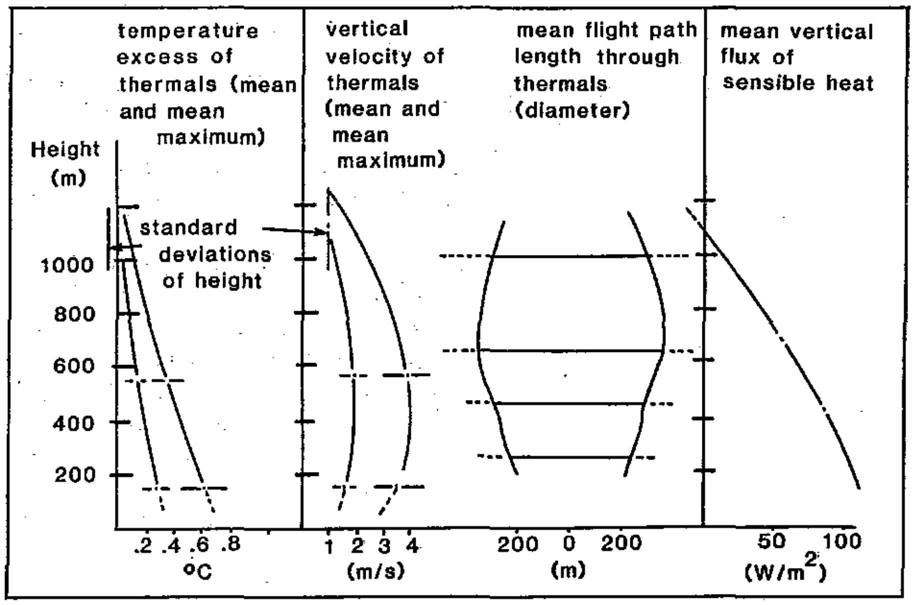


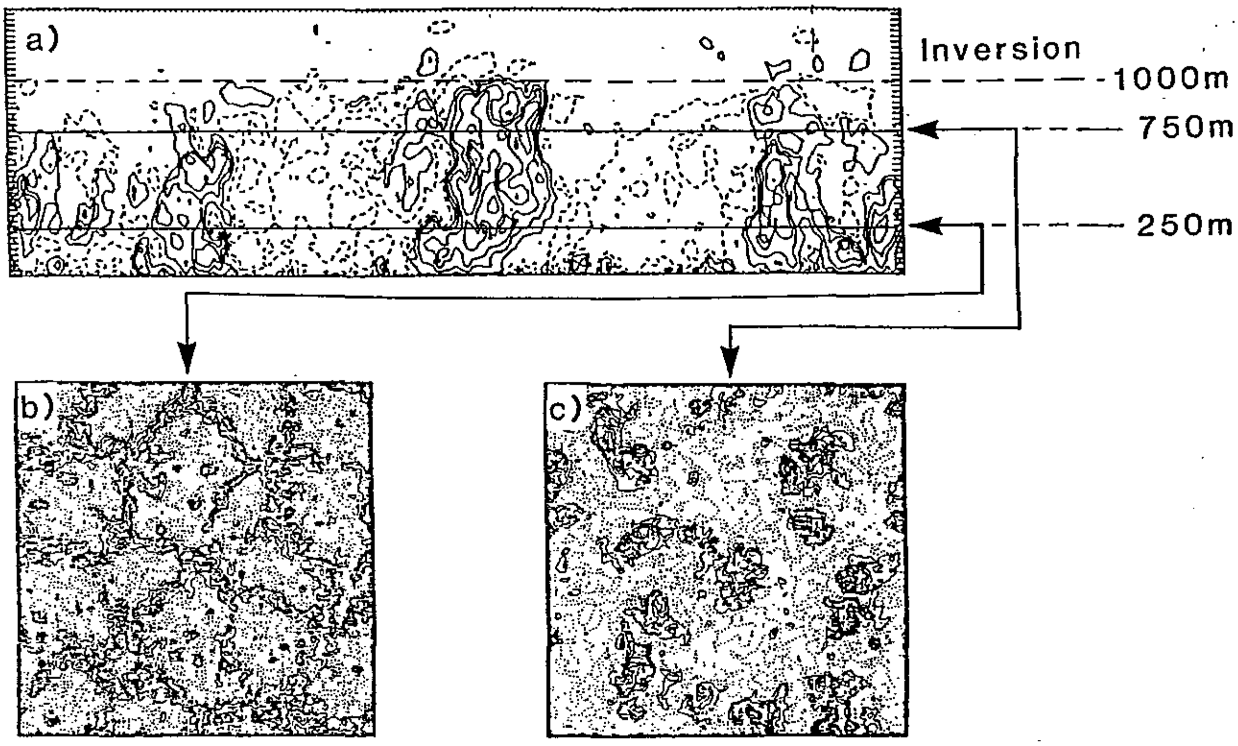
Figure 2.3
Mean properties of thermal convection in relation to height, standard deviations are included (Lindemann, 1981

turbidity. At the same time, the exposure of the surface and characteristics of the soil (type, albedo, moisture content and vegetation) determine the amount of heat driving thermal convection.

Usually the dimensions of rising 'thermals' are large enough to allow sailplanes, hang gliders and paragliders to circle inside their boundaries and to climb with them provided, of course, that vertical velocity of the rising air is greater than the sinking speed of the sailplane relative to the rising air.

Exact measurements of structure and dynamics of thermals are difficult because of the size of areas and column heights to be scanned through in the relatively short lifetime of a thermal (about 20 to 40 minutes). Some examples of measurements are given in Figure 2.2 (a) and (b). Finally, only a statistical description of shape and velocity of thermals can contribute to the general view on their characteristics as e.g. has been measured by Lindemann (1981) using motor gliders (Figure 2.3). While attempts at measurement have been made ever since thermal convection was detected, numerical simulation could only very recently be brought to a realistic and impressive description,

Figure 2.4
Numerical simulations of thermal updraft rising to an inversion layer at1000m height (a) Vertical cross-section. Solid lines are updrafts, dotted lines are downdrafts. Notice the individual updraft parcels in the larger column (bubbles in the bubble). (b) Horizontal crossection at 250 m height (c) at 750 m height (Schmidt and Schumann; 1989).



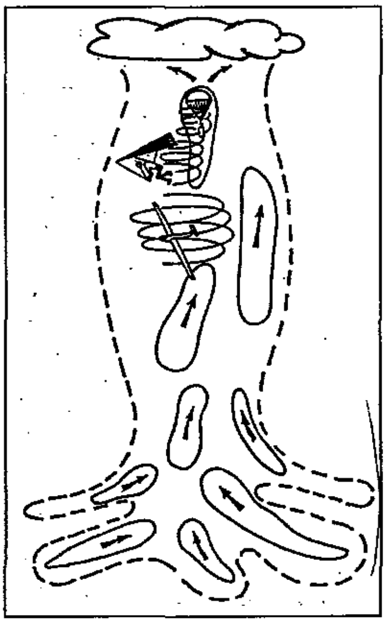


Figure 2.5
Schematic view of bubbles in the bubble.

as done by Schmidt and Schumann (1989) using Large Eddy Simulation techniques with the high resolution of 50 metres. Results are given in Figure 2.4 (a) to (c), where a vertical cross section of thermal updraft shows clearly three larger updraft bubbles (solid lines) with embedded smaller bubbles of different updraft velocities and in between the downdraft regions with not very marked downdraft velocities (dotted lines). The horizontal cross-section shows a well-developed cellular structure in the first 250 metres, where updrafts are concentrated along the polygonal boundaries. At 750 metres, updrafts have become concentrated in selfstanding columns with moderate to strong velocities and with an internal fine structures of bubbles.

As a general conclusion from gliding experience and theoretical simulation, thermals can be described as extended updraft areas, frequently with embedded parcels of air of different vertical speeds, allowing different aircraft a differentiated use of the parcel structure, as shown in Figure 2.5: Paragliders can use the smaller bubbles with higher updraft velocities, while hang gliders are circling 'in' and 'out' and sailplanes can only use a small part of the parcel. The character of thermals can be generally expressed as 'bubbles in the bubble'.

Because of this complicated situation thermal convection cannot be forecast easily.

Sailplane pilots wish to know mainly:

- When convection will begin;
- How long the convection will persist;
- How high the thermals will extend;
- The area where thermals will occur;
- The strength of the thermals;
- If showers or thunderstorms will develop.

To answer these questions the forecaster needs to examine representative soundings and consider the changes which will take place due to large scale vertical motions, horizontal advection and solar heating. The techniques for forecasting convective activity may be considered under the following headings:

- Selection and modification of upper-air soundings (2.1.2);
- Assessment of solar heating (2.2.1);
- Assessment of dew-point changes (2.2.1);
- Influence of terrain vegetation and surface moisture (2.2.1);
- Consideration of the effect of wind, clouds and advection on the strength of thermals (2.2.3);
- Consideration of mesoscale developments such as sea breeze or other convergence lines (2.3.2 and 2.3.3);
- Consideration of patterns in convection caused by the vertical profile of the wind field (for example 'cumulus streets') (2.3.4);
- Consideration of man-made thermals (2.3.5).

2.1 SYNOPTIC FEATURES

2.1.1 FEATURES ON SYNOPTIC CHARTS

2.1.1.1 General collection of favourable features

(i) Surface charts

On surface charts, forecasters have to look for:

- High or area of high pressure;
- Anticyclonic curvature of the isobars;
- Gradient winds less than 10 m/s (20 kt);
- Absence of a frontal system close enough to produce extensive layer clouds;
- Air mass which has originated from a colder region;
- Relatively low dew-points;
- Good visibility.

(ii) 850 hPa or 700 hPa contour charts

The 850 hPa chart is recommended if the general elevation of terrain is below about 600 m (2000 ft). The 700 hPa chart is more useful when the ground level is higher. Forecasters should look for areas:

- Where the contours show anticyclonic curvature;
- Of weak flow with high geopotential (pressure contour height values);
- Where the pattern of isotherms indicates either no advective changes of temperature or cold air advection;
- Where humidity is relatively low, with dew-point depression greater than 5K.

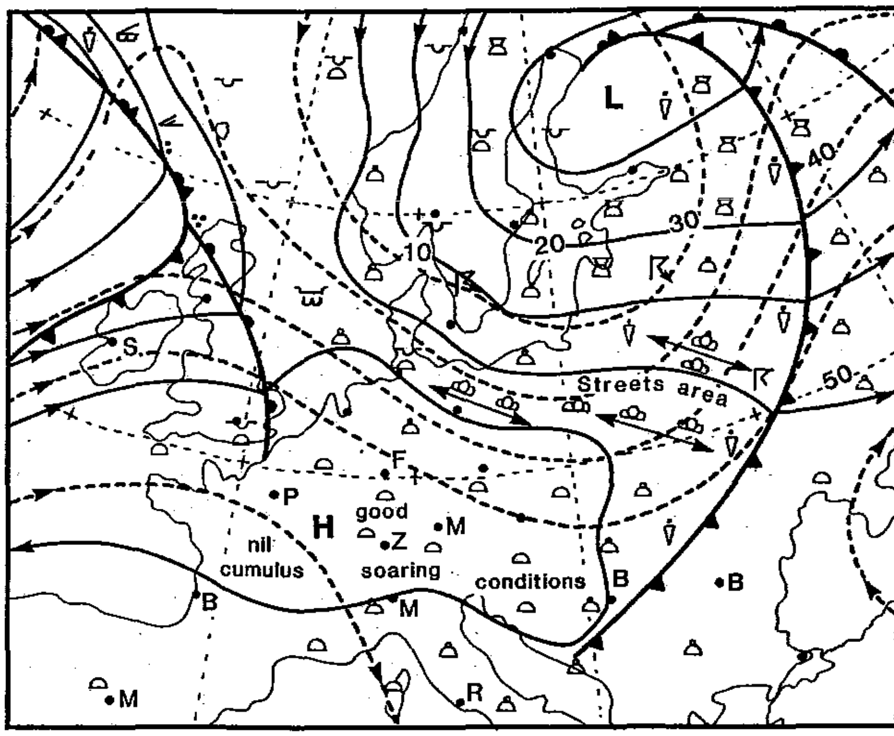


Figure 2.6 (a)
Example of weather pattern for soaring over Europe (3 Aug. 1988). Surface isobars are shown in solid lines, 500 hPa contours in dotted lines. Symbols for fronts, weather and clouds follow international standards. Cloud streets are indicated by lines of cumuliform cloud

(iii) 500 hPa and 300 hPa contour charts

- Rise of geopotential after the passage of an eastward moving upper trough;
- Near upper-tropospheric highs;
- Areas of weak negative vorticity advection.

2.1.1.2 Areas of different soaring conditions

Figure 2.6 (a) and (b) shows an example of conditons over Europe with areas of favourable and unfavourable weather noted.

(i) Good soaring conditions

In the surface high-pressure zone over southern Central Europe, air is cold and unstable in the lower layers but convection is limited by subsidence. Relatively low humidity is likely and cloud base should be high.

(ii) Reduced soaring conditions

Over France and Spain the air has been dried out due to subsidence and solar heating. Soaring conditions are still sufficient for cross country flights although no or only few cumulus clouds occur. In the northern part of the surface high pressure zone the cloudiness increases. Large cumulus clouds appear which may form cloud streets.

(iii) Bad soaring conditions:

Near and east of the trough there is deep convection with cumulonimbus clouds, showers, and local thunderstorms. Near fronts the sky is overcast. Precipitation is likely and visibility is reduced.

2.1.2 Upper-air soundings

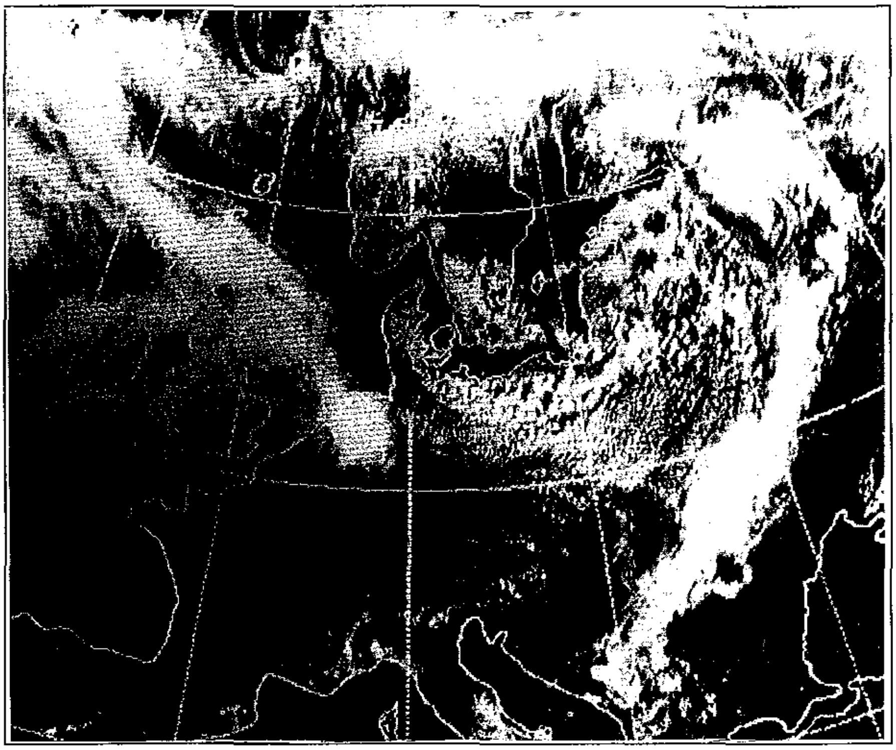
2.1.2.1 Selection and modification

Representative soundings must be selected in order to describe the soaring conditions for different regions during the day.

The forecaster can judge which radiosonde observations are needed from the chart analyses for the sounding times and the prognostic charts covering the period of soaring. As many contour charts as possible should be examined at this stage to estimate the representativeness of available soundings. Charts for 850, 700 and 500 hPa are worth studying to see that the values of these levels reported by the selected soundings really fit the general pattern of temperature and of the relative thickness of the layers.

A stationary and ageing air mass will take the characteristics of the underlying ground (and the use of any available 'thermal maps' is recommended) whereas a recently intruded cold air mass tends to be quite homogeneous. It should also be kept in mind, however, that large-scale vertical motions due to cyclonic or anticyclonic influences will distort these soundings. It is not uncommon for the subsidence inversion in a developing sharp ridge of high pressure at the rear of a cold front to be lowered by 500 m in 24 hours. On the other hand, a slow rising motion (a few centimetres a second) tends to destabilize the atmosphere.

Figure 2.6 (b)
(b) Visible satellite image of 3 Aug. 1988.



When soundings are widely separated it may be necessary for the forecaster to interpolate between two or more to gain a representative temperature profile for the time of the sounding. Interpolation of soundings too far apart is liable to cause error. An aircraft sounding up to about 3 km or at the top of a substantial stable layer should be requested, especially in critical cases such as soaring contests. Light aeroplanes can often be used to make low-level soundings, using a psychrometer to measure the temperature and dew-point. The optimum time for an aircraft sounding depends partly on the type of prediction method to be used. If the method enables heating to be predicted in time steps up to maximum temperature, it is wise to make the sounding as late as is operationally feasible. If the available heating data is only in the form of total heating between two events (e.g. minimum to maximum temperature), then the best time is shortly after sunrise. For step-by-step methods, two ascents at appropriate times are ideal and often worth the extra cost to users at major events. Comparison of an aircraft sounding and the nearest rawinsonde may point to changes which have already happened and provide some knowledge about further development.

Measurements of the wind profile using a pilot balloon and a simple theodolite may complete the data set.

2.1.2.2 Features to look for in upper air soundings

When vertical profiles of temperature and humidity are plotted on aerological diagrams the following features indicate good conditions for thermal soaring:

(i) Depth of the dry adiabatic layer:

If heating of the ground is sufficient, a dry adiabatic lapse rate occurs from the surface to a height of at least 1000 m. For good soaring the dry adiabatic lapse rate should extend to a height in excess of 1500 m above the ground.

(ii) Moisture content:

The moisture content of the air should be such that the cloud base at midday forms at least at a height of 1000 m above ground level. This level is usually a close approximation to the actual condensation level provided that the dry-bulb temperature is rising towards the day maximum value. Relatively dry air aloft usually gives the best soaring conditions provided that there is just sufficient moisture for convective clouds to appear. A dew-point depression in excess of 10K near and above the tops of cumulus is usually a good sign.

(iii) Depth of instability:

The vertical extent of cumulus clouds should be sufficient for the development of nothing more than isolated light showers. Cumulus cloud tops should not reach the -10°C isotherm, otherwise showers may occur.

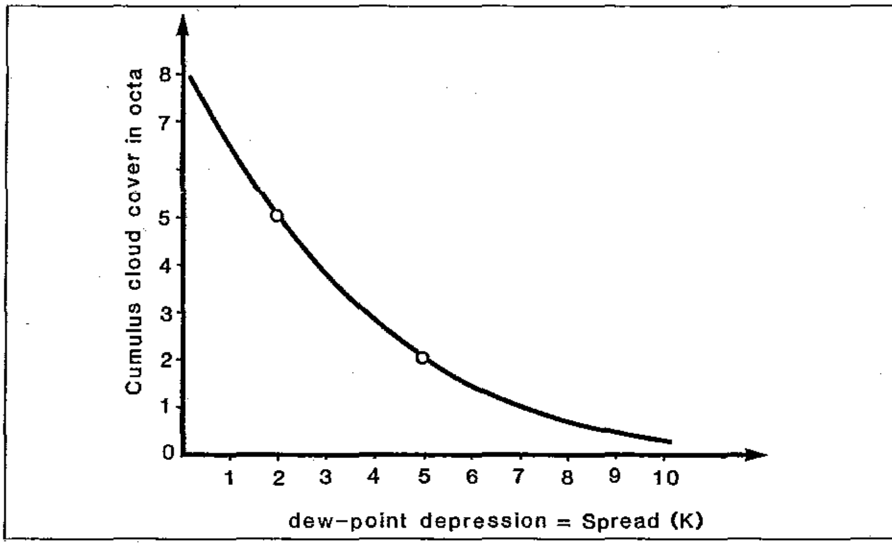


Figure 2.7
Expected cloud coverage in relation to the dewpoint depression (spread) at an inversion.

(iv) Dew-point depression at the inversion:

If convective cloud tops are limited by a marked inversion, the air at and below the inversion should have a dew-point depression (spread) of at least 5 K. Cumulus clouds tend to spread out beneath an inversion and if the air is moist the cloud cover may become 6/8 or more (Figure 2.7).

(v) Humidity above the convection level:

Above the level of convective instability the relative humidity should be less than 50 per cent. Moist air may indicate the subsequent development of upper-cloud layers which would reduce or cut off insolation.

2.1.2.3 Contrasting thermal requirements for ballooning

Forecasting thermal convection is also important for ballooning and parachuting, but in an opposite sense. For both of these air sports, thermal soaring can be disruptive and, in some situations, dangerous. Favourable conditions occur mostly before and after thermal soaring conditions prevail. The pre- and post-thermal soaring conditions are also more likely to have light wind conditions – which are required for most types of operations in these sports.

Winds in detail (at about 100 m intervals, or less) up to about 1500 m above ground are of such importance, especially in competition ballooning, that some teams make pilot balloon soundings themselves.

Gas balloons are also affected by fresh or gusty winds and thermals, but when they make long flights they often file a flight plan to take off late in the day and cruise at altitudes above thermal convection.

	local time											
Month	05	06	07	08	09	10	11	12	13	14	15	Max
January					3	18	35	48	58	61		61
February				1	15	33	50	65	75	80		81
March			2	17	35	53	68	81	90	95		97
April		4	19	37	54	71	86	98	107	112	115	115
May	4	19	36	54	70	86	100	110	119	124	127	127
June	8	23	40	58	74	89	102	113	122	127	130	131
July	4	19	36	53	69	84	98	109	118	123	126	126
August		8	24	41	59	75	89	101	110	116	119	119
September			10	27	44	60	76	88	96	102	104	104
October			1	13	29	45	60	72	80	85		86
November					11	25	38	49	57	61		61
December					2	15	30	42	50	53		53

2.2 FORECASTING THERMAL SOARING

2.2.1 SOLAR HEATING;

2.2.1.1 Assessment of heating

The development of the convective boundary layer is mainly connected with the diurnal variation of the surface temperature. To predict the surface temperature one may apply one of the following three methods:

- Solar heating tables;
- Solar heating overlays for aerological diagrams;
- Maximum temperature predictions.

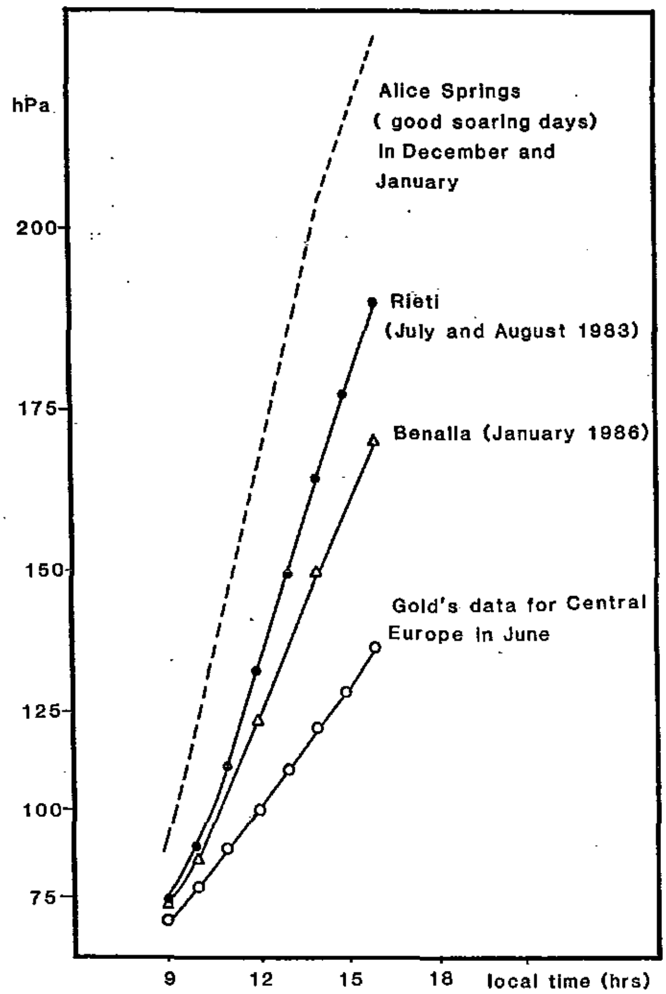


Figure 2.8
Depth of adiabatic layer (in hPa) which is changed from isothermal to an adiabatic state by insolation. Valid for various locations during the best soaring season.

Using the first two methods one is able to estimate the surface temperature rise and thus the development of thermal convection, whereas the third method predicts the maximum temperature (which corresponds to the stage of maximum development of thermal convection). All these procedures are based on ideal conditions (calm anticyclonic conditions and a dry surface). They need some modification whenever there are departures from these assumptions. The methods are all appropriate for inclusion in numerical forecasting schemes using personal computers (see chapter 6.1).

Because of the strong dependence on geographical parameters, the figures will have to be adjusted for different regions. The tables and overlays are only examples and confined to Central Europe. Figure 2.8 shows heat energies found to be applicable to a few other parts of the world. The values at Alice Springs and Benalla (Australia) and Rieti (Italy) are mean values over about 20 days of soaring during international events.

The first step is to examine the prognostic chart on which the main areas of layer cloud have been sketched. From this chart the forecaster should obtain an estimate of the proportion of the total sunshine which will be available at ground level. If the sky is expected to be mainly clear during the first part of the day, the following methods can be used to calculate the effect of solar heating.

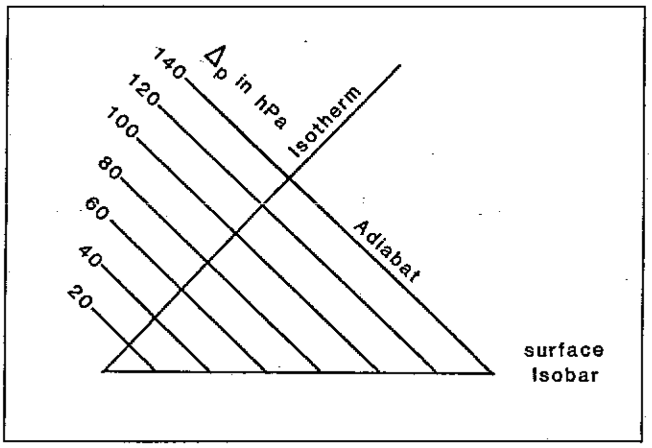
The early morning sounding, which is usually very stable can be approximated by an isotherm whereby the areas between the actual sounding and the isotherm are balanced in the familiar fashion (Figure 2.9 (b)). As the sun heats the ground an adiabatic layer forms and grows higher and higher. The surface temperature determines which adiabat is reached. The area between the surface isobar, the isotherm and any given adiabat is a triangle (Figure 2.9 (a)) which represents the amount of heat (energy) added to the atmospheric layer at a given time of day. The intersection of the isotherm and the adiabat occurs at a certain pressure level which corresponds to an equivalent depth of the heated layer. As the surface temperature rises, this depth increases.

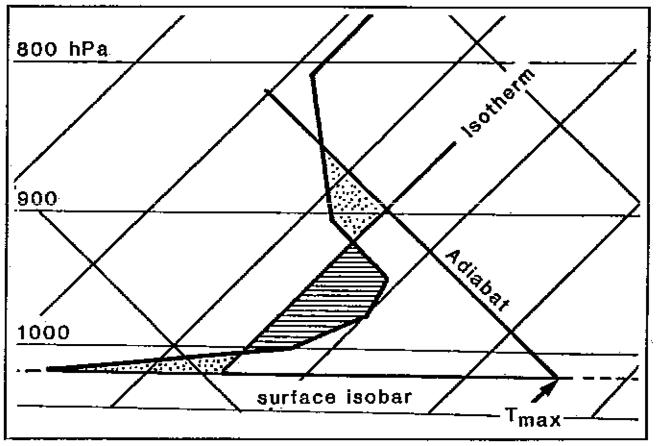
2.2.1.2 Solar heating tables

The supply of solar heat available during a day determines what depth can be reached and what the maximum temperature will be. Table 2.1 (opposite) gives this depth in hPa as a function of local time. The table is valid for the latitude 52 north and assumes flat and relatively low-lying ground. These values do not take into account any superadiabatic gradients close to the surface. Add 2 hPa under clear skies and light winds in summer to allow for superadiabats. Approximate correction for cloud is:

8/8 Ci—use 90% of depth in hPa;
8/8 As—use 60% of depth in hPa;
8/8 Sc—use 50% of depth in hPa;
8/8 Ns—use 35% of depth in hPa.

Table 2.1 (left)
Depth of adiabatic layer (in hPa) which is changed from isothermal to an adiabatic state by insolation, valid for the latitude of 52° North over flat ground in Great Britain.





2.2.1.3 Use of solar heating in transparent overlay

A solar heating overlay must be constructed to fit the size and type of aerological diagram used. The examples illustrated in Figure 2.9 (a) and 2.10 (a) are designed to be used on a particular scale of tephigram and would need adaptation for use on other sizes or types of aerological diagram. The scale can be graduated in two ways

2.2.1.3.1 Markings on the overlay

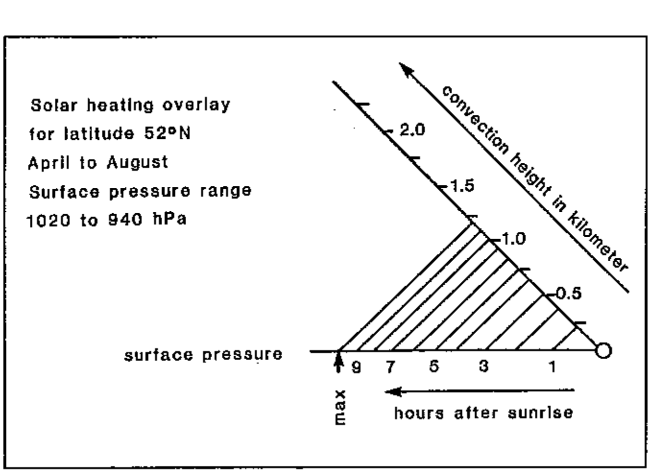
Figure 2.9 (a) shows a tephigram overlay which may be used in any month of the year. The graduations are drawn at intervals of 20 hPa and the lines through the isotherm are drawn parallel to the dry adiabat. The scale is used as follows.

First, look up the heating value from a solar heating table or a figure similar to Figure 2.8. Mark this value on the scale, interpolating between the numbered adiabats as necessary. Next, place the overlay on the aerological diagram with the line marked 'surface isobar' lying on the value equivalent to the surface pressure. Move it along the isobar until the isotherm cuts the sounding with equal amounts of energy on both sides of the isotherm. On a tephigram where energy is directly equivalent to area, this process simply applies to the isotherm line. On diagrams where energy is not exactly equivalent to area, certain adjustments are needed. Figure 2.9 (b) shows the appearance when the scale is correctly placed with equal areas on either side of the isotherm line. The point at which the dry adiabat cuts the surface isobar then indicates the surface temperature which will be reached. The process can be repeated using the values given for each hour after sunrise to obtain a series of temperatures at hourly intervals.

These temperatures may then be plotted on a graph to predict the rate of rise of temperature from dawn till the time of maximum temperature.

Alternatively, the development of thermal activity can be analyzed by another type of overlay (Figure 2.10 (a)).

It carries a graduation of isotherms corresponding to the hourly values of the heating table (Table 2.1). It is also possible to reconstruct this overlay using Figure 2.8 for regions other than Great Britain. Using the fact that there is a period on either side of midsummer when the mid-day solar elevation varies little for several weeks and, as



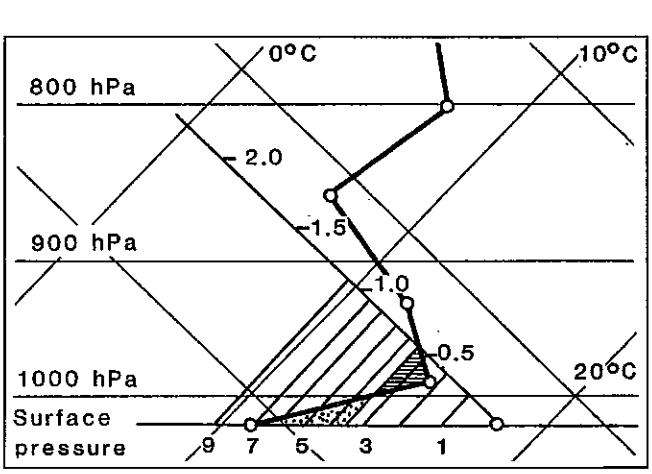


Figure 2.10
(a) Alternative solar heating overlay for tephigram. Parallel lines (1–9 and max along the surface pressure line) are isotherms. The length of each line is equivalent to the value given in the heating table for each hour after sunrise. Along the dry adiabat, heights are marked
(b) Application of alternative solar heating overlay to sounding plotted on a tephigram. Temperature profile at dawn is represented by the heavy black line. The overlay is in the position when thermals first reach 600 m. Shaded and dotted areas represent positive and negative energy balanced about an isotherm (thick line) which indicates a time of 3.3 hours after sunrise. The surface temperature is indicated by the zero point on the righthand end of the surface pressure line.

Figure 2.9 (opposite)
(a, far left) Solar heating transparent overlay for tephigram.
(b, left) Application of solar heating scale to a sounding plotted on tephigram. The thick black line shows observed temperature profile. Solar heating overlay is superimposed for a maximum heating value of 120 hPa. Surface pressure is 1020 hPa: the adiabat and isotherm of the scale intersect at 900 hPa. The scale is placed so that the isotherm line divides the profile with equal areas (hatched and stippled) on either side. The maximum temperature is found where the adiabat meets the surface isobar

a consequence, the solar heating with respect to sunrise does not vary significantly, a single scale fits during the period from April to August with little loss of accuracy.

With this scale it is not necessary to construct an hourly rise of temperature curve on every occasion nor is it necessary to use both a solar heating transparent overlay and a heating table.

The method works very quickly because the overlay already contains the hourly values of the heating table. Therefore the predicted time and height of the consecutive stages of developing convection can be obtained directly. Figure 2.10(b) shows the use of the second type of overlay.

The procedure to predict the time when thermals reach the necessary height (600 m for starting cross-country flight) is as follows. Place the overlay with its surface pressure line on the corresponding isobar so that the 600 m marking at the dry adiabat meets the temperature profile of the sounding. Look for the isotherm which cuts the temperature profile with equal amounts of energy to the right and to the left of it (dotted and shaded areas). In our example this estimated line (thick, dashed) indicates 3.3 hours after sunrise. The zero point of the overlay marks a surface temperature of 18.5°C.

NOTE: On most sunny days the lapse rate becomes superadiabatic just above the surface. The method described above does not take into account the superadiabatic layer. As a result the observed maximum surface temperature is normally a little above the calculated value. However, the temperatures measured on a sounding made in mid-afternoon generally show that the temperature profile follows the predicted dry adiabat.

2.2.1.4 Predicting maximum temperatures

When plotted soundings are not available, the maximum temperature may be predicted by a simplified alternative method (Table 2.2 and 2.3, Callen and Prescott, 1982). The thickness of the layer 850/1000 hPa is proportional to its mean temperature. The obtainable solar heating, depending upon the time of the year, changes a stable layer (see assumptions below) into a dry adiabatic. Thus one can obtain a surface maximum temperature which must be related to the mean temperature of the layer.

Table 2.2
Unadjusted maximum temperature (°C) in terms of 1000-850 hPa thickness measured in geopotential meters (gpm) (after Callen and Prescott, 1982)

Thickness (gpm)	max. Temp.	Thickness (gpm)	max. Temp.	Thickness (gpm)	max. Temp.
1230	-0.8	1300	10.1	1370	21.1
1240	0.8	1310	11.7	1380	22.6
1250	2.3	1320	13.3	1390	24.2
1260	3.9	1330	14.8	1400	25.7
1270	5.5	1340	16.4	1410	27.3
1280	7.0	1350	17.9	1420	28.9
1290	8.6	1360	19.5	1430	30.4

Cloud classification	Mar	Apr	May	June	July	Aug	Sep	Oct
Cl + Cm 3/8, Ch 5/8	-1.5	0.5	2.5	3.5	3.7	2.8	1.2	-1.0
Cl + Cm + Ch 4/8 to 6/8	-2.0	-0.5	1.3	2.3	2.4	1.8	0.4	-1.6
Cl + Cm 6/8	-3.0	-1.4	0.3	1.2	1.4	0.7	-0.7	-2.4
Overcast with precipitation	-3.7	-2.4	-1.0	0.0	0.2	-0.4	-1.5	-3.3

Table 2.3
Adjustments for the maximum temperature (Table 2.2) to allow for cloud classification and seasonal effect.

First select the thickness applicable and find the unadjusted maximum surface temperature. Second use the cloud classification and the month to obtain the temperature adjustment.

The assumptions made are that the lapse rate before dawn is approximately three-quarters of the saturated adiabatic lapse rate, the relative humidity of the layer is 75 per cent and the surface pressure is 1020 hPa. This method is valid for latitudes near 50 degrees north. Errors due to variations of surface pressure and also humidity are usually small. The values given are usually found to be sufficiently accurate for soaring forecasts in England.

The advantages are that the basic data are easy to extract from the coded TEMP messages (Part A) since the heights of the 1000 and 850 hPa layers are always given. The values for a number of stations can be plotted on a convenient chart and the probable maximum temperatures looked up and noted beside each station.

2.2.1.5 Influence of turbidity in the atmosphere

Atmospheric turbidity is caused by the absorption and scattering processes of aerosol particles which are present throughout the atmosphere. The combined effect of absorption and scattering always decreases the solar input to the earth's surface and the absorption increases the heat input to the atmospheric layers itself. Therefore a weakening of thermal activity can be expected in a turbid atmosphere. As an example, over a continent aerosol particles reduce the atmospheric transmissivity along a vertical path to a typical average value of 80%.

Superimposed, the following effects lead to a further reduction of the atmospheric transmissivity due to aerosol particles:

(i) Sun elevation

The extinction of the direct solar beam increases with the path length through an atmospheric dust layer, reducing solar radiation at the surface at low sun.

(ii) Atmospheric moisture

When the relative humidity in an atmospheric layer rises above 60%, aerosol particles of soluble substances take up water and increase in size. At the same time, the extinction of the aerosol particles is amplified.

(iii) Man-made aerosol sources:

Aerosol particles emitted from man-made sources (soot, for example) in most cases absorb solar radiation strongly. As a consequence, a significant reduction of thermal activity can be expected downwind of polluted industrialized or urbanized areas.

2.2.1.6 Influence of Terrain, Vegetation and Surface

The quantity and quality of thermals in a nearly homogeneous plain region differ even under similar synoptic situations; some of the factors responsible for this are listed below.

(i) Reflection from the ground:

Surfaces with a high albedo which reflect a large proportion of the incoming solar radiation are likely to supply less heat to the air above than surfaces which reflect very little of the incoming radiation. The extreme cases are ice and snow, which may reflect between 65 and 85 per cent of the incoming solar radiation, and various cereal crops, which reflect only between 10 and 20 per cent (Wallington, 1977).

(ii) Surface moisture and vegetation:

The kind of soil and especially its moisture and vegetation determine the intensity and frequency of thermals. The energy available for thermal production at the surface is determined by the radiation balance, reduced by the vertical flux of latent heat and the vertical flux of heat into the soil.

- The radiation balance is dependent on the albedo of the surface which is a function of the kind and colour of soil and vegetation.
- The vertical flux of latent heat is dependent on the availability of moisture for evapotranspiration and thus on vegetation which transports moisture from below. Extensive strongly evaporating vegetation prevents the development of a wide range of thermals. The evapotranspiration differs between the different kinds of vegetation, the growth status and the density.

For Central Europe the evapotranspiration is:

- small for bare soils, some conifers and forest clearings,
- large for meadows, sugar beet, some corn and intensive agriculture.

- The flux of heat into the soil is not only dependent on the kind of soil but also on the moisture content. Rain is unfavourable for thermals partly because it increases the rate of flux of heat into the soil.

(iii) Effect of topography:

Very large homogeneous surfaces are less active as thermal sources than varied terrain where poor and good surfaces are mixed. Higher ground is usually better drained than the valleys; it is drier and the slopes which face the sun heat up more rapidly than the level surfaces below. Consequently thermals may develop over quite small hills earlier than over flat terrain. Thermals persist longer over westward-facing slopes in the evening. The effect is less marked after a long spell of dry weather.

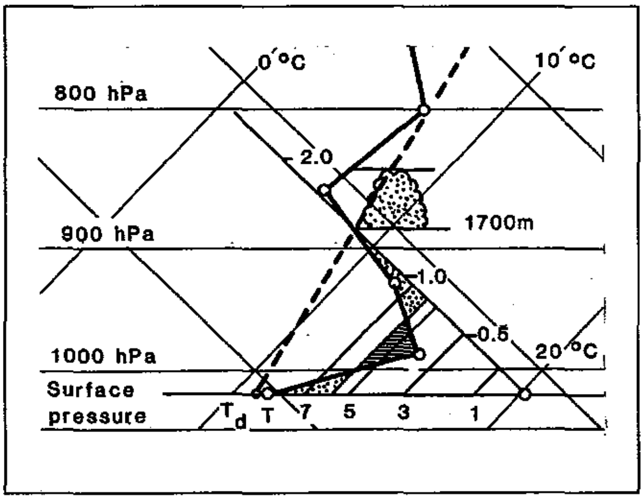


Figure 2.11

Estimation of the cloud base and tops. T = surface temperature, Td = surface dew-point. The dashed line is a line of constant mixing ratio. The time of the first cloud development is estimated using the solar heating overlay (6 hours after sunrise)

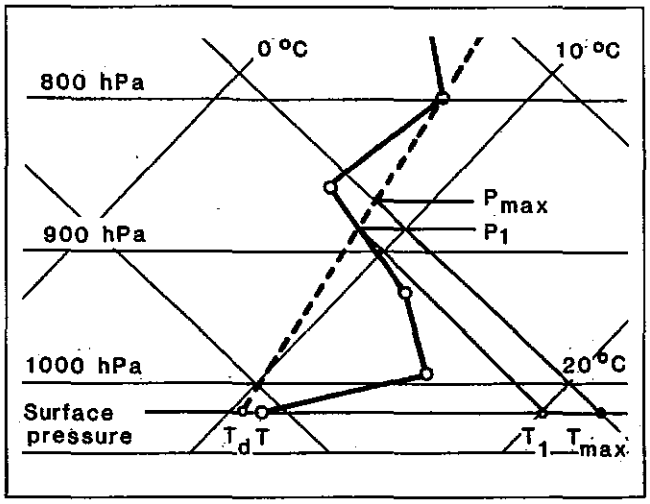


Figure 2.12

Development of cloud base during the day. Td = surface dewpoint in the morning, T1 = surface temperature when first cumulus appears to form, Tmax = maximum temperature in midafternoon, P1 = pressure at base of first cumulus, Pmax = pressure at base of cumulus in mid-afternoon.

2.2.2 Development of Cumulus

To predict at what time and height cumulus will form, first estimate the surface dew-point (see 2.2.2.1 for methods of assessing this value). Then follow the humidity mixing ratio line (dashed line, Figure 2.11) through the surface dew-point until it cuts the temperature profile of the sounding. This gives the height of cumulus base. Move the overlay to the right so that the dry adiabat meets this point and estimate the isotherm which balances the areas of energy on either side of it (as described above). It indicates the time after sunrise (about 6 hours, to be read at the scale on the surface pressure line). The height of the cumulus base can be read at the scale on the dry adiabat of the overlay (about 1400 m in our example).

If dry air is mixed by lateral entrainment into the thermal, the cloud base might be higher than the surface dew-point suggests, but this effect can normally be neglected. For middle latitudes a good approximation of a representative surface dew-point seems to be the average value of the layer between the surface and 500 m.

Provided that representative values of temperature and dew-point can be forecast, the base of cumulus can be estimated by taking the difference of these temperatures in Kelvin and multiplying by 400 to find the cloud base in feet or by 120 to obtain the value in metres. If the dry adiabat intersects the environment curve at a lower level than the intersection with the humidity mixing ratio line, cumulus will not form.

Cloud tops are determined following a wet adiabatic line from the cloud base up to the level where the temperature profile of the sounding is crossed (1700 m in the example).

The cumulus base will rise in the course of further solar heating (Figure 2.12). The growing height, time and surface temperature can be evaluated by moving the overlay to the corresponding positions to the right until the maximum given by the isotherm marked 'max' is reached. The average height of cumulus tops can be read at the scale on the dry adiabat of the overlay also (1700 m). The corresponding surface temperature is always indicated by the zero point of the overlay.

2.2.2.1 Assessment of dew-point changes

A crucial and difficult point in forecasting thermal convection is the assessment of the surface dew-point variations and the effects of possible horizontal advection of moist air. The horizontal and vertical distribution of moisture has a large impact on cloud development which might decrease insolation and reduce further development of thermal convection. The horizontal distribution of moisture can be indicated by analysis of surface dew-points, dew-point depression in contour charts as well as a chart of the 850 hPa dew-point. This is a useful way to assess future advective changes.

As mentioned before, the mixing within the boundary layer tends to equalize the vertical distribution of moisture. Because the thermal elements are formed originally close to the surface, the raised condensation level depends largely upon the difference between the dry-bulb and dew-point temperature at the surface (Figure 2.11). As dew-point reference for forecasts, the dew-point shortly before sunrise (minimum temperature) should be selected. Cloud base forecasting for a predescribed area requires knowledge of available dew-points in that area to provide an averaged value for calculation of cloud base height.

2.2.2.2 Prediction of cumulus under an inversion

Generally, because of evaporation of moisture at the ground, the amount of water vapour in the atmosphere decreases with height. Every thermal carries moisture upwards, while in downdraft areas dry air replaces this moist air. The dew-point will rise at the top of the unstable layer where the thermal dies out. Whether a stratocumulus layer is formed or not depends entirely on the vertical moisture distribution (see Figure 2.13).

In areas of strong anticyclonic curvature of the isobars, a marked subsidence inversion is always present, with very dry air immediately on top of it. When a thermal reaches this level and a cumulus cloud has formed, the top of this cloud in contact with this dry air will mix and evaporate rapidly. When a windshear is present above the inversion, time-lapse pictures show the cloud to have a rolling motion. For a short period in the counterflow the inversion is forced downward 50–100 m below cloud base level, as Reinhardt (1971) has shown. It is this mixing with dry air that keeps the cloud amount at 1/8 to 2/8.

When, on the contrary, cyclonic influences are present, the air is moist. In this case, within a few hours of the onset of thermal activity the cloud cover increases to 5/8 - 7/8. As a result, radiation will diminish and the cloud cover may also decrease temporarily and locally.

2.2.2.3 Spreading out of cumulus to form a stratocumulus layer

When the humidity below a stable layer is high, and the cloud base is much lower, cumulus congestus will form soon after the onset of thermal activity. The tops of these clouds penetrate temporarily into the stable layer and after having lost their buoyancy they spread out to form a stratocumulus or altocumulus layer, depending on the height of the stable layer (Figure 2.13).

The distinctive features of such soundings are:

- A well-marked inversion resulting in a very uniform level of cumulus tops;
- High and increasing relative humidity below the level of the inversion. In this example the air is unusually moist.

The formation of a stratocumulus layer may still occur even with dew-point depression less than 2K reported by radiosondes beneath the inversion (Figure 2.7). The depth of the moist layer determines the persistence of the stratiform cloud layer.

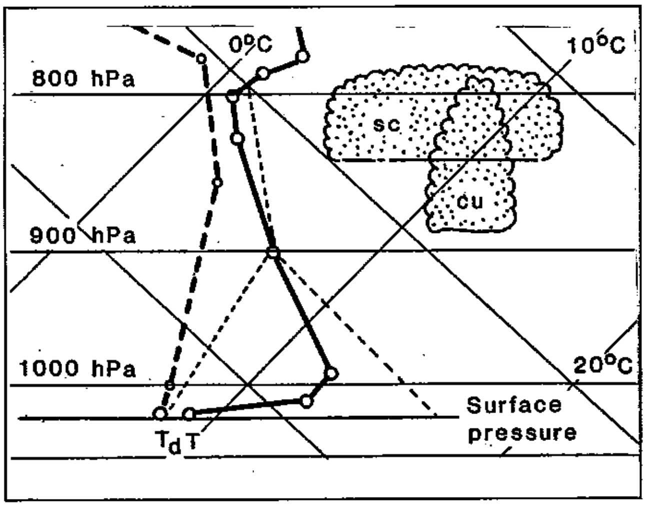
Synoptic features which may favour such developments are weak cyclonic curvature of the isobars on surface charts and/or the previous presence of an old frontal system which has been frontolysed. There is often a belt of more moist air beneath the inversion along the line of old frontal systems which, because of their weakness, have been left off in the analyses issued by meteorological centres.

2.2.2.4 Cumulus development without inversion

When a weak stable layer exists at a higher level, accurate prediction of cumulus tops is not possible without knowledge of mesoscale features which may act to strengthen or weaken convective activity (Figure 2.14). It should be mentioned that if the tops of cumulus clouds encounter a very dry and sufficient deep layer, cloud droplets will evaporate and the cooling may subsequently stop a further rise.

2.2.2.5 Dry thermals

When the air in the whole convective layer is fairly dry, only dry thermals will occur. Figure 2.15 (a) shows an example where the line of constant mixing ratio starting at the surface dew-point does not cross the temperature profile. Therefore no clouds can develop. Sometimes cumulus clouds form in the morning, only to disappear in the afternoon (Figure 2.15 b). This type of profile is likely near the centre of an anticyclone where marked subsidence has occurred.



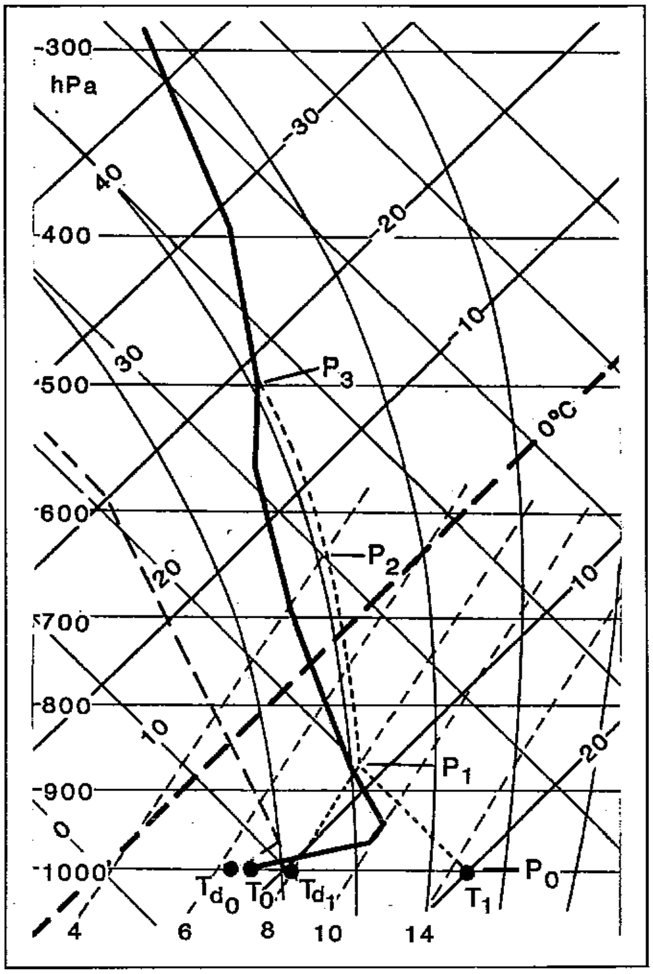
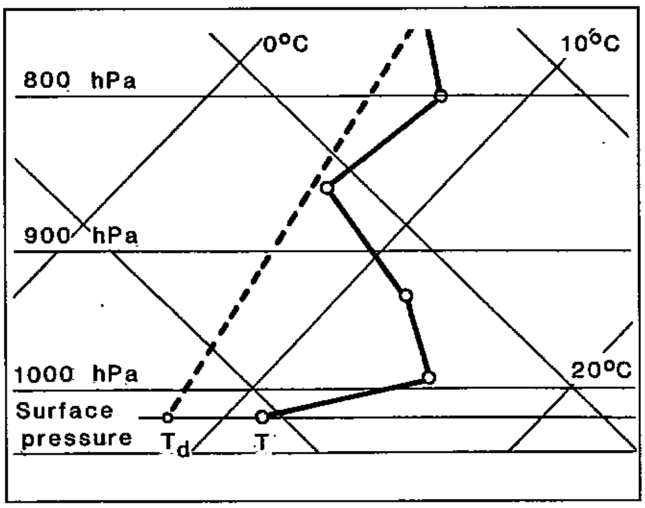


Figure 2.13
An example of temperature and dewpoint profiles indicative of the development of a layer of stratocumulus formed by the spreading out of cumulus beneath an inversion.

Figure 2.14
Cumulus development with no inversion.
Td0 = surface dew-point; T0 = surface temperature, Td1 = surface dew-point and T1 = surface temperature, when cumulus development starts. P0 = surface pressure; P1 = base of cumulus; P2 = top of majority of cumulus population. This level is where the temperature profile begins to turn to a more stable lapse rate. P3 = top of highest cumulus when cloud amount is scattered or broken



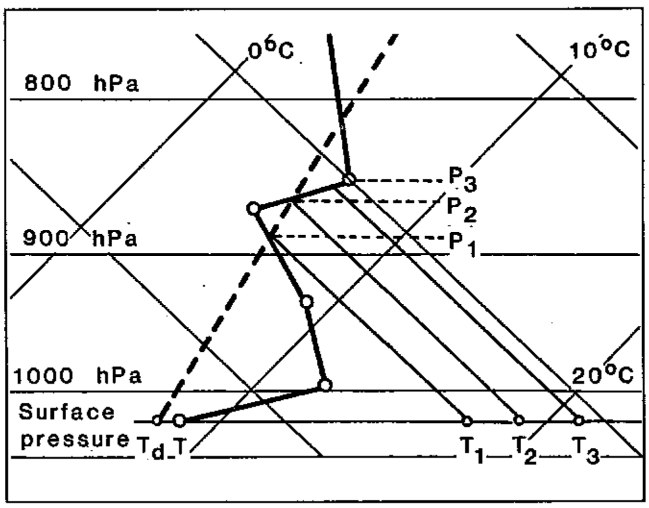


Figure 2.15 (a)
Dry thermals.
T = surface temperature, Td = surface dewpoint.
Since the line of constant mixing ratio (dashed) does not cross the temperature profile, no clouds can develop.

Figure 2.15 (b)
Dispersal of cumulus clouds during the day.
T = surface temperature, Td = surface dew-point,
T1 = temperature when first clouds are formed with base at P1,
T2 = temperature at noon, cloud base has reached P2, clouds disappear,
T3 = temperature in the afternoon with dry thermals reaching up to P3

2.2.3 Strength of Thermals

Whether pilots wish to fly long distances or speed around a specified circuit, they need to be able to fly as fast as possible. The flying speed can be calculated from the performance polar curve (Figure 1.1) of the sailplane. These calculations show that the optimum speed depends upon the average rate of climb that the pilot achieves. The cruising speed a glider pilot can achieve depends on the strength of thermals encountered while soaring. The faster the pilot climbs in a thermal, the higher the speed that should be used flying between thermals.

2.2.3.1 Soaring and thermal strength: pilot's reports

The actual vertical velocity of the air in a thermal will always be larger than the rate of climb achieved by the sailplane. The strength observed by the pilot and used in his calculations is the true vertical velocity of the air less the sinking speed of the sailplane relative to the air. The difference is of the order of 1 m/s when the sailplane is circling at an angle of bank of about 45 degrees. The forecaster has to distinguish carefully the vertical velocity of the air from the rate of climb of the sailplane and should make it clear whether figures refer to the true vertical velocity or the possible climbing speed of a sailplane. In order to plan the length of a flight, the pilot must use the mean strength of thermals and ignore reports of isolated exceptionally strong thermals.

A thermal may be regarded as a column of ascending air. The height and diameter of the column show wide variations, but in almost every example the maximum upward velocity is found in one or more cores within this column. To achieve a fast rate of climb the pilot tries to circle in the core of the thermal. When his circles are centered at the core of the thermal, the rate of climb is usually fairly constant for periods of a minute or more. If his circles are not concentric with the thermal core, the rate of climb will show rapid fluctuations. Since the pilot seldom has any visual indication of the centre of a thermal, he relies on instrumental readings of rates of climb and any feelings of vertical acceleration experienced when flying through the boundary of a thermal. As a result pilots report a wide variation of thermal strengths even when (as during a contest) the pilots have all flown on the same route at about the same time.

The rate at which a sailplane can climb in a thermal whose 'lift' is concentrated at the core, and decreases with distance from the core, depends on the diameter of circle flown by the sailplane and its sinking speed in circling flight. Sailplanes with low wing loadings and relative short span, and hang gliders, can usually fly circles of smaller diameter and are thus able to climb faster in the strong core of a thermal. Such a sailplane or hang glider is at a disadvantage in straight flight, however, because then the performance of a sailplane with long wing span and high wing loading is superior.

Modern high-performance sailplanes are designed to sacrifice a small percentage of climbing speed in exchange for a much superior gliding angle at high speed. To accomplish a good performance at high speed, sailplanes need a higher wing loading than for slow circling flight and, to achieve this, water ballast is carried in the wings on a day when strong thermals are expected. The ballast is jettisoned if thermals become weak and before landing.

The improvement in performance achieved by high-performance sailplanes carrying water ballast is greater than might be expected, partly because modern sailplanes can fly both faster and farther before the pilot needs to use a thermal to regain height. Flying faster reduces the effect of adverse winds. By flying farther between thermals the pilot can reject weak thermals and only circle in strong lift. Consequently the pilots report strong lift more frequently than pilots of older, slower-flying sailplanes. An older-style sailplane, unable to glide long distances between thermals, is often obliged to circle in every thermal encountered, whether it be weak or strong. In such circumstances the pilot rarely encounters the strongest thermals and is likely to report weak or moderate thermals even on a day when pilots of fast, modern sailplanes report strong thermals.

2.2.3.2 Classification of thermal strength

A simple classification of thermal strength is sometimes required for forecasting. Based on the mean rate of climb and the depth of the convection layer the following classification is suggested. For arid climates the rates of climb should be multiplied by a factor of 1.5 to 2. For complete estimation of the thermal characteristics, wind and cloud cover according to section 2.2.3.5 and 2.2.3.6 should be taken into consideration.

(i) Weak

Top of convection layer below 1000 m above ground (for mountainous regions at least up to the main mountain tops). Mean rate of climb up to 1 m/s.

(ii) Moderate

Top of convection layer below 1500 m above ground (for mountainous regions at least 500 m above the main mountain tops). Mean rate of climb up to 2.5 m/s.

(iii) Good

Top of convection layer below 2000 m above ground (for mountainous regions at least 1000 m above the main mountain tops). Mean rate of climb above 2.5 m/s.

(iv) Excellent

Top of convection layer above 2500 m above ground (for mountainous regions more than 1000 m above the main mountain tops). Mean rate of climb above 5 m/s.

2.2.3.3 Prediction of thermal strength

Clearly the ground temperature depends on the solar heating which varies with season, time of day, latitude, cloud coverage, mist or fog and on the characteristics of the location (elevation, exposure to the sun, type of soil, albedo, moisture content, vegetation). The situation is complicated by the occurrence of unpredictable and ever-changing temperature contrasts on the surface.

Buz (1975) made a major study of thermal strength as a function of a variety of parameters using glider flights as well as surface and upper-air measurements in the U.S.S.R. on days with little cloud development. The strongest and statistically most significant correlations were found to exist between rate of climb and temperature contrasts on the underlying surface.

Running a dynamic convection model (such as the one of Ogura and Takahashi, 1971) on a personal computer, one may simulate the life cycle of a single 'thermal' (even taking into account to some extent cloud physics). As output one can get vertical profiles of vertical velocity based on the assumption of a certain temperature excess of the 'thermal' (see Section 6.1).

The present state of knowledge does not offer reliable calculating methods for precise prediction of thermal strength and there is no simple guide to cover all conditions. Empirical tables and convection indices are used to estimate the strength of thermals.

2.2.3.3.1 Tables to estimate thermal strength

Empirical tables are useful to suggest values for the mean rate of climb which will be experienced by sailplanes (Table 2.4). The figures are average values based on a large number of pilots' reports in the U.S.A. and France (Lindsay, 1972; Siacchitano, unpublished). The general principle is that the greater the height to which a thermal column rises, the faster the rate of climb will be.

No values for thermal strength are suggested if large cumulus or cumulonimbus develop, since rates of climb under such clouds may be far outside the ranges suggested above. In arid climates (Australia, South Africa) the figures have to be multiplied by a factor of 1.5 to 2. Additionally the convective layer extends to greater heights and the enhancing effect of small cumulus is no longer significant.

Table 2.4
Mean rates of climb for different weather situations.

	Max. height of dry adiabatic lapse rate	Mean rate of climb
Cloudless thermals	1 km 2 km 3 km	1.0 m/s 2.0 m/s 3.0 m/s
Cloud-capped thermals (with small cumulus)	1 km 2 km 3 km	1.2 m/s 2.4 m/s 3.6 m/s
Cloud-capped thermals with cold advection occurring	1 km 2 km 3 km	1.5 m/s 3.0 m/s 4.5 m/s

2.2.3.3.2 Convection indices

Convection indices are frequently used to estimate the strength and quality of thermals. A variety of indices have been developed in the past. Some of them are used only to estimate the probability of the occurrence of thunderstorms. The indices are based on a simplified analysis of the temperature sounding. For this reason they can never give as much information on the thermal development as can be evaluated from the complete sounding. They can be valuable if temperatures are available to be analyzed as described in the previous sections.

(i) Showalter stability index

The index is determined by raising an air parcel from the 850 hPa level dry adiabatically to the level of saturation. From this level the parcel is raised wet-adiabatically up to the 500 hPa level. The difference between the parcel's temperature and the temperature of the environment at that level gives the index. The index is positive if the parcel is colder than the environment. Showalter indices below +4 indicate the occurrence of showers and if the index is below -2, thunderstorms should to be expected.

(ii) Thermal index

The dry adiabat drawn from the forecast maximum temperature is followed up to 850 hPa. The temperature at this level minus the actual temperature gives the index. A negative index indicates positive buoyancy which indicates that thermals are still present at this altitude. Negative values of the index therefore stand for moderate to excellent thermals. For elevated terrain the 700 hPa level may be used instead of the 850 hPa level.

(iii) Soaring Index

The soaring index forecasts lift rates and development of convective clouds, and is expressed by:

$$S = \text{temperature}_{850} - \text{temperature}_{500} + \text{dew-point}_{850} - \text{dew point depression}_{700}$$

where the numbers indicate the pressure levels. The interpretation of the soaring index is:

below -10	no or weak thermals;
-10 to 5	dry thermals or $^1/_8$ Cu with moderate thermals;
5 to 15	good soaring conditions;
15 to 20	good soaring conditions with occasional showers;
20 to 30	excellent soaring conditions, but increasing probability of showers and thunderstorms;
above 30	more than 60 per cent probability of thunderstorms

This index was developed for the western United States, but it might be adjusted for other areas. The soaring index gives no reliable values if the depth of the convection layer ends below 700 hPa.

2.2.3.4 Effect of advective changes

Advective changes in the layer of thermal activity influence the strength of thermals (see Figure 2.16). When colder air is advected, the observed strength of thermals is stronger and thermal activity persists later in the day. Conversely, when warmer air is advected, the thermal strength usually decreases and thermals die out earlier.

2.2.3.5 Effect of wind

(i) Light winds

When there is no wind throughout the depth of the convective layer, thermals are usually relatively wide and persist longer than in windy conditions. They form less frequently in calm conditions and tend to be confined to regions where the ground surface heats up more rapidly. Thermals are released by an initial impulse (vehicles, departing/landing aircraft, industrial plants, etc.). Light winds (less than 10 kt) favour the development of relatively wide, well-spaced thermals which pilots find

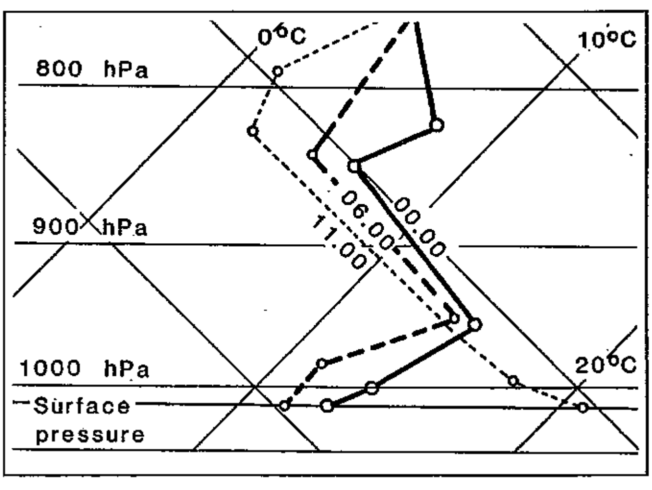


Figure 2.16

Cold advection and thermal strength. This diagram shows the changes resulting from eleven hours of cold advection in the levels between 900 and 760 hPa. The time of successive soundings is written beside the temperature profiles. At 1100 hours a superadiabatic lapse rate was reported near the surface. During the afternoon the cloud base was observed to be 1500 metres with shallow cumulus extending up to about 2 km. The mean thermal strength was reported as 2.5 m/s with the strongest thermals 4.5 m/s. Strong downdrafts were also observed close to the thermals.

easy for soaring. The release of thermals is confined to topographic features (forest edges, buildings, etc.). Ascending thermals are affected by the environmental wind field and tilted from the vertical (see Figure 2.17 (a))

(ii) Moderate and strong winds

Winds with increasing speed cause mechanical turbulence in the air flow near the surface. This distorts and tends to disrupt thermals close to the ground. Above a certain height (approx. 200 to 500 m) thermals become suited for soaring (see Figure 2.17 (b)).

Above homogeneous terrain, moderate winds start to trigger organized formations of updrafts parallel to the wind. Over mountainous terrain, interference with dynamic airflow effects has to be considered, for example surface slopes in combination with upsloping wind regimes improve the release and strength of thermals.

(iii) Vertical shear

Thermals rising through a layer of wind shear become distorted, making it difficult, sometimes impossible, for the pilot to climb further. Under certain conditions organized convection (cloud streets) can develop (2.3.4). Wavelike undulations in the clear air near and above the rising thermal are observed, if the wind shear layer persists at this altitude (Chapter 4).

2.2.3.6 Effect of clouds on thermals

Stratiform clouds (Ci, Cs, As) with high cloud coverage reduce the available radiation energy at the surface, and therefore impede the development of thermals. The same is true if cumulus clouds spread out beneath an inversion.

In spite of certain solar insolation and reduced warming of the surface, the high instability of airmasses, for example polar cold air outbreaks, can offer unexpectedly good soaring conditions (even if the cloud coverage exceeds 7/8).

2.2.3.7 Persistence of thermal activity into the evening

Thermal activity usually stops when the surface temperature starts to decrease. This happens at different times at different locations and cannot be predicted precisely. But experience in Central Europe suggests that in the absence of advective changes this is normally about two hours before sunset.

Four main factors influence the persistence of thermal activity into the evening:

(a) The heat input needed to maintain a dry adiabatic lapse rate from the surface. If cold air advection is taking place, the heat required to maintain this adiabatic lapse rate is small; thermal activity may then continue until the sun is a few degrees above the horizon. In extreme cases of cold air advection, thermals may still be found under active cumulus one or more hours after sunset.

(b) Topographic effects. Where slopes face the setting sun, thermal activity persists much longer than over flat ground.

(c) Vegetation effects. Open fields lose heat rapidly when the sun is low but woods and cities have a greater heat-storage capacity. Weak thermals are often observed at low levels over woods and cities for an hour or more after thermals have stopped in open country.

(d) Atmospheric haze. When there is a layer of haze trapped beneath a stable layer, solar heating is reduced below the level necessary to maintain thermal activity at an earlier hour than on days of clear visibility.

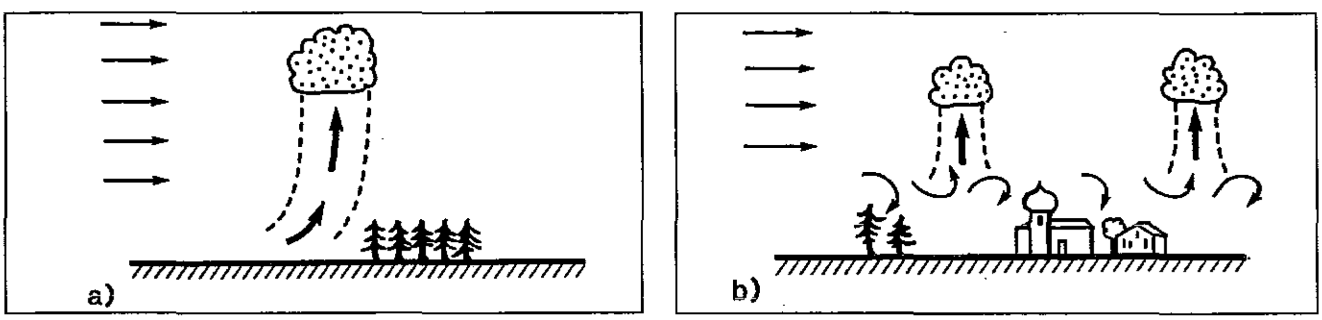


Figure 2.17
(a) *Release of ascending thermals by light wind;*
(b) *moderate or strong wind without vertical shear but lowlevel turbulence.*

2.3 SPECIAL FEATURES OF THERMAL CONVECTION AND CIRCULATION

2.3.1 Thermals in mountainous terrain

There are several differences in the amount, intensity and duration of thermals developing over plains and those developing over or near mountains.

These differences result from the following factors:

- sloped terrain;
- elevated heat sources;
- elevated moisture sources;
- different radiation conditions;
- reduced volumes of air.

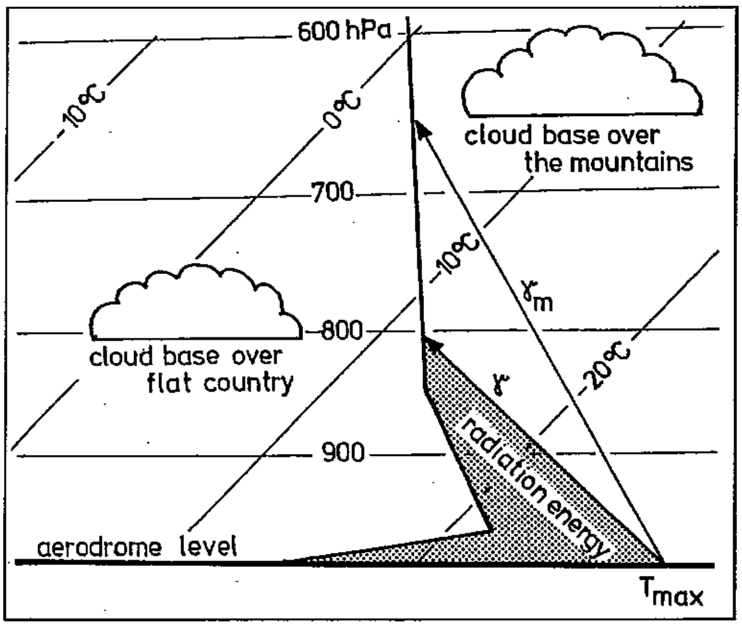
Therefore, soundings have to be looked at very carefully when being applied to mountainous areas. Data from mountain stations should be used to adjust the profiles. It is recommended that aircraft soundings be obtained and that adjustments be made to the solar heating table and the solar heating overlay (2.2.1).

Not all the complexities that modify thermal activities can be considered in a routine gliding forecast. A simple forecasting method is to define a so-called diabatic gradient γ_m (Figure 2.18). The value of γ_m should be defined for different mountainous areas after a sufficient amount of statistical data (including pilot reports). For the Alps (mountains up to 3000 m) γ_m= 0.7 was found. In hilly terrain with tops reaching about 800 m above the valleys 0.85, can be applied.

The factors mentioned above and their influence on thermal activity are discussed in 2.3.1.1, while some additional effects are described in 2.3.1.2.

Figure 2.18

Estimation of the thickness of the convection layer (or cloudbase) over mountains. First calculate Tmax according Figure 2.10 (b), then use γ_m (diabatic lapse rate for mountainous area) to estimate the thickness of the convection layer (or cloudbase) over mountains.



2.3.1.1 Factors influencing thermal activity in mountainous areas

(i) Sloped terrain

Slopes facing the sun receive more incoming radiation than those oriented in other directions, except for short periods when the sun is almost directly above an area. Therefore the development of thermals is confined to the sun-facing slopes. 'Mountain thermals' are often quasi-stationary, pulsating and stronger than thermals over plains under similar conditions. The intensity of this effect depends on angle and orientation of slopes, surface conditions and wind.

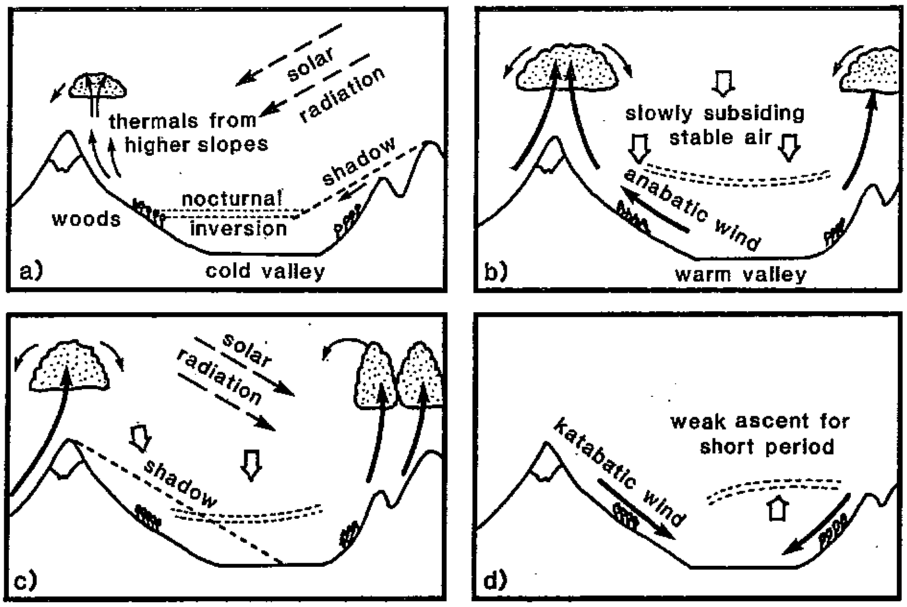
A complete diurnal cycle of thermal activity is shown in the following sequence (Figure 2.19).

Morning: Thermals develop on elevated slopes facing the sun while parts of the valley are still in shade (Figure 2.19 (a)).

Noon: Thermals occur on both sides of mountains and the general flow is upslope. Compensating subsidence is found over the centre of valleys (Figure 2.19 (b)).

Afternoon: Thermals occur over the slopes which have been shaded in the morning; towards sunset thermal activity is limited to a few west-facing slopes (Figure 2.19(c)).

Figure 2.19
Sequence of thermal activity in mountain areas. (a) Morning; (b) noon; (c) afternoon; (d) evening



Evening: Radiation cooling produces a downslope flow. As a result slow upward motion is caused over the valley. This upward motion may give lift of 0.5 m/s and more until about one hour after sunset. The lift is not exactly over the centre of the valley but displaced towards the slopes which were the last to get direct radiation (Figure 2.19 (d)).

(ii) Elevated heat sources

- Elevated heating causes thermals to start earlier over mountains than they do over plains. Thus thermal convection can start over mountains before valley inversions have been broken down.
- Thermals rising alongside irradiated slopes do not cool adiabatically as long as they incorporate overheated air parcels rising from the slopes. The adiabatic gradient can only be applied above crest height (Figure 2.20).
- Elevated heat sources tend to reduce the intensity of subsidence inversions by extending the well mixed layer vertically.

(iii) Elevated moisture sources

The amount of precipitation in mountainous terrain exceeds the amount of precipitation in valleys or plains. No general value for the additional moisture can be given, because it depends on a variety of factors including

- type of soil (run-off characteristics)
- extent, temperature and albedo of snow-fields or glaciers. Cloudiness in general increases over snow-covered areas, when temperature and dew-point are positive and therefore a large source of moisture is provided (Figure 2.21).

(iv) Radiation conditions

- Due to the reduction of industrial haze, radiation in mountainous terrain is often more intense. There might be an even greater difference since valleys are often filled with haze trapped beneath an inversion, particularly during the cold season. Mountain slopes have been soared even when valleys were under fog.
- Snow capped peaks or glaciers reflect nearly all incoming radiation; sometimes a small convergence zone can be observed between the katabatic wind and the ascending warm air from below. This convergence zone is favourable for the instigation of thermal updrafts (Figure 2.22).

(v) Reduced volume of air

In valleys, less air has to be heated, so it reaches a higher temperature than the air in the surrounding plains. This heating differential creates valley winds which support the thermal activities in the mountains producing more intense and persistent thermals.

2.3.1.2 Other factors affecting thermal activity

(i) Inversions

- Night time inversions develop or intensify in valleys because of the katabatic flow from the surrounding slopes.
- Low-level inversions developing because of cold air advection in the lowest layer do not increase in height over mountainous area, leading to a reduced operating height in higher terrain (Figure 2.23).

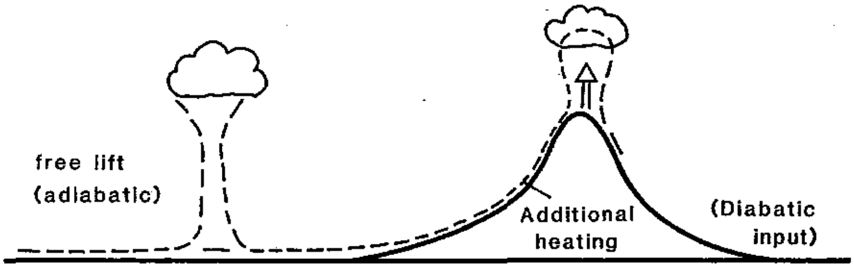


Figure 2.20
Additional heating by elevated heat sources.

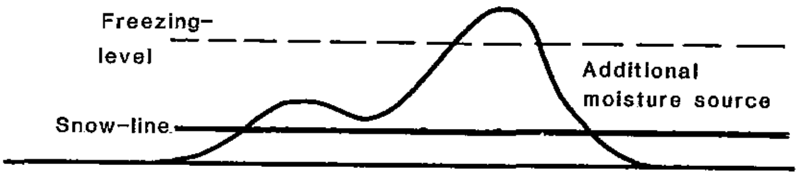


Figure 2.21
Additional moisture source between the snowline and the freezing level.

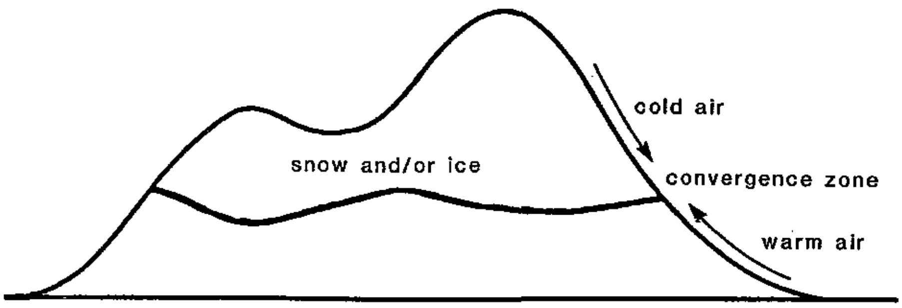


Figure 2.22
Convergence zone at the snow line.

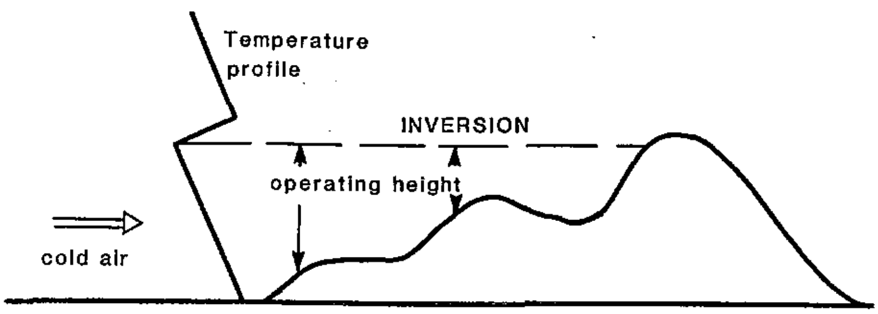


Figure 2.23
Reduced operating height due to an inversion

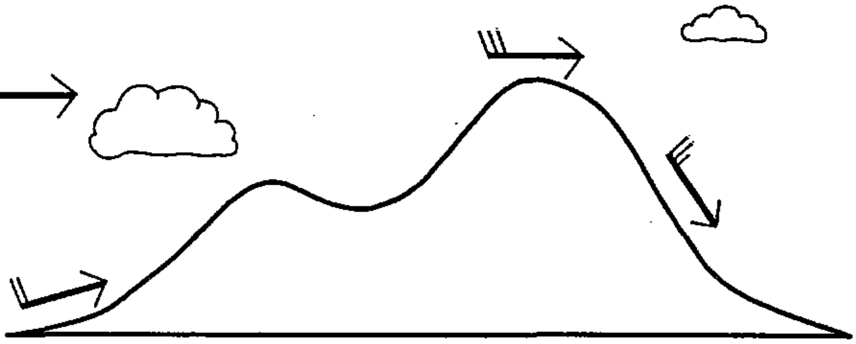


Figure 2.24
forced lifting and lee effects

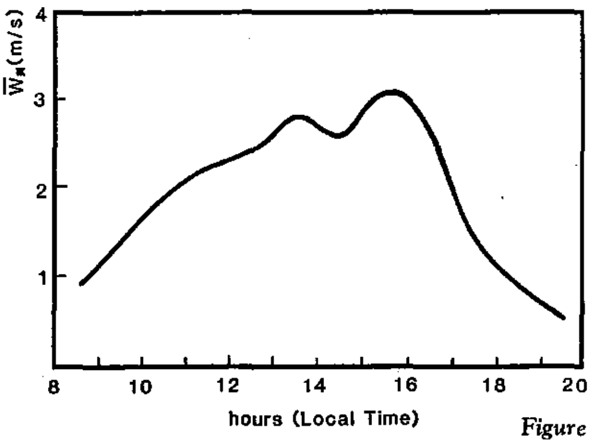


Figure 2.26
Diurnal variation of mean lift rates in the Northern Alps.

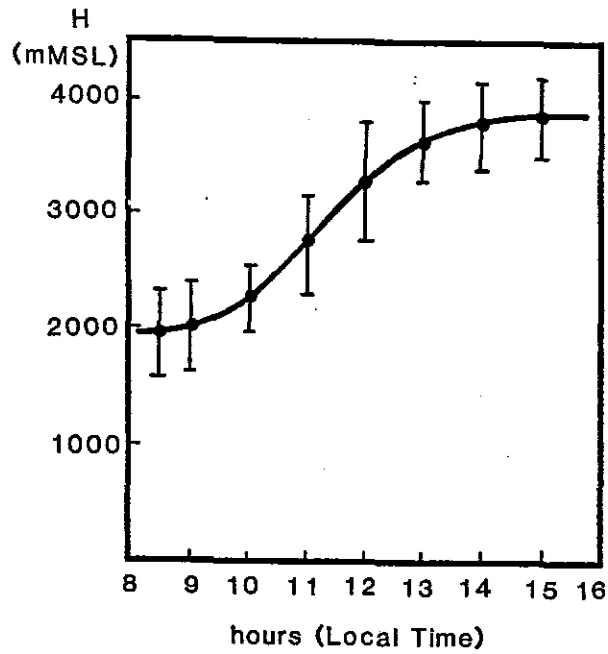


Figure 2.25
Diurnal variation of the height of cloud base for the northern Alps.

(ii) Forced lifting and lee effects

For flows of more than 15 knots across the mountains upslope and lee effects have to be considered (Figure 2.24).

(iii) Cloud base and thermal strength

Since air aloft generally contains less water vapour than air at low levels, in the absence of high-level sources of moisture the cumulus base is usually elevated over mountainous terrain.

The diurnal variation of the cloud base is also influenced by the structure of the terrain. An example of the diurnal variation of the height of cloud base for the northern Alps for weather conditions suitable for long-distance flights is shown in Figure 2.25, and the diurnal variation of mean lift rates for the northern Alps is given in Figure 2.26.

The prediction of thermal intensity over mountains is much more difficult than over flat terrain. There is some hope that forecasting of thermal strength will be improved, because there is a good correlation between mean lift-rates and the height of cloud base (see Table 2.4).

2.3.1.3 Valley and mountain winds

Under a general slack gradient, the thermally driven 'Valley and Mountain Wind' circulation may provide slope-soaring conditions, wherever appropriate orographic features exist. Figures 2.27 (a) to (h) show the sequence of events for the development of the 'valley and mountain wind' circulation. Figure 2.27 (a) shows conditions near sunrise with the mountain wind still blowing and the slope updraft starting. Figure 2.27 (b) shows the slope updrafts in the morning when the mountain slopes have been heated and the mountain wind has stopped. At noon—Figure 2.27 (c)—the valley wind has started. Figure 2.27 (d) shows the valley wind in the afternoon when the slopes are in shadow and the updrafts have ceased. In the late afternoon katabatic wind will set in on the mountain slopes—Figure 2.27 (e). Figure 2.27 (f) indicates the condition soon after sunset when katabatic winds have developed on all slopes and the valley wind has diminished. Later on in the night the air starts moving down the valley—Figure 2.27 (g). Figure 2.27 (h) shows the situation shortly before sunrise when only the mountain wind is observed.

Local topographic configurations cause many variations in the simple circulations described. The wind along the bottom of the valley may locally reach a considerable speed (approximately 20 kts). Where the valley narrows, the valley wind as well as the mountain wind gains speed and depth. In cases where smaller hills within the valley lie at some angle to the main direction of the valley, very regular slope-soaring conditions will be provided on the windward-facing slope of such hills. The valley winds are of great importance for safe landing of sailplanes in the valley floor.

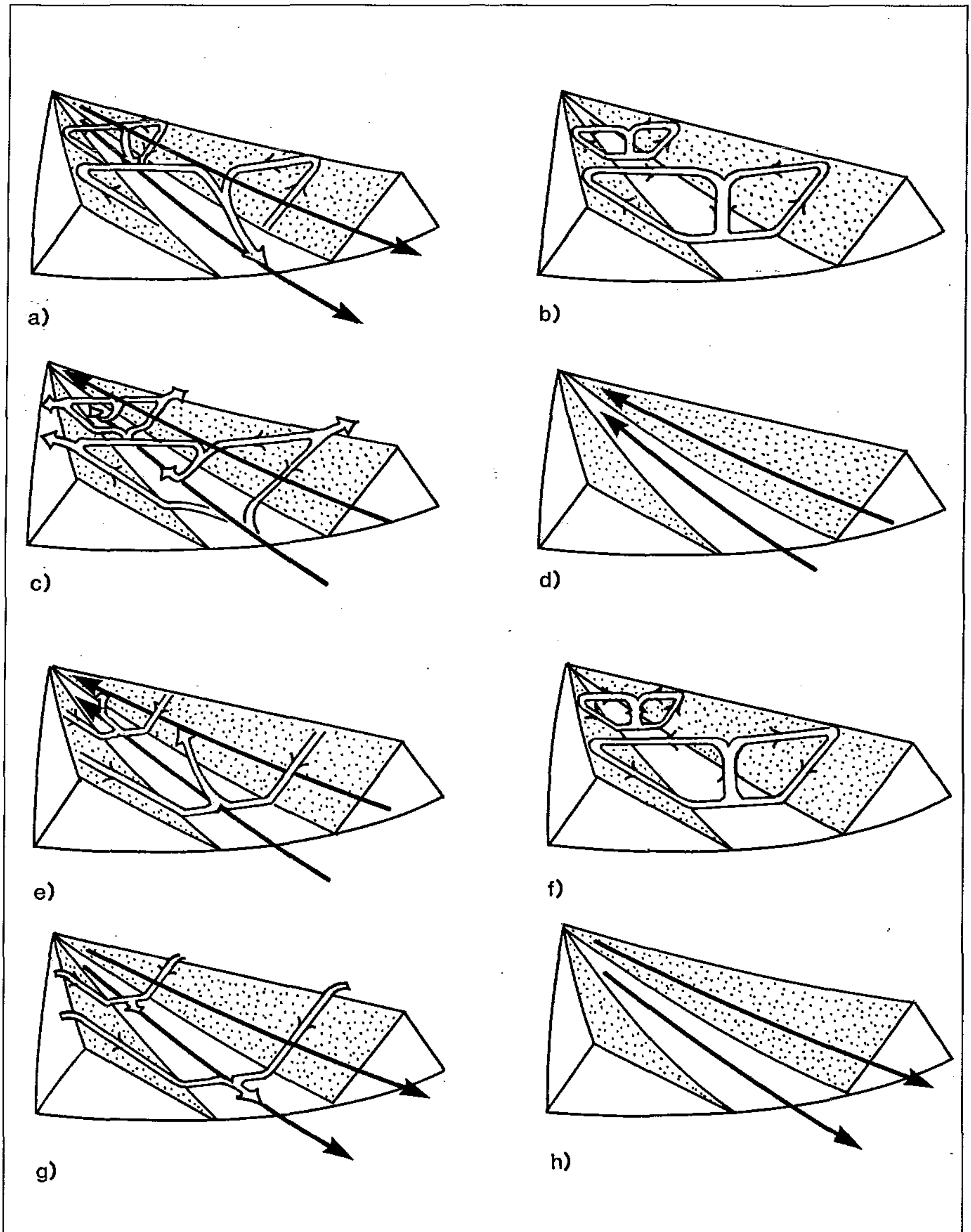


Figure 2.27

Schematic view of the slope wind as well as the valley and mountain wind circulation. (a) Sunrise, start of slope updraft with ongoing mountain wind; (b) morning, slope updrafts; (c) noon, slope updraft and valley wind; (d) afternoon, valley wind; (e) evening, slope downdraft and valley wind; (f) early night, slope downdraft circulation; (g) night, slope downdraft and mountain wind; (h) shortly before sunrise, mountain wind.

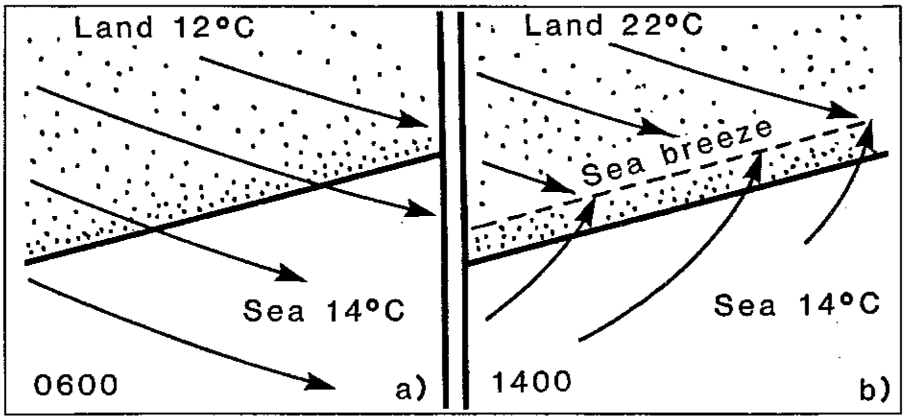


Figure 2.28
Normal sea breeze.
(a) morning situation;
(b) afternoon situation.

2.3.2 Sea breeze

The pattern of convection is often modified by small convergence lines caused by local effects and differences. These phenomena, some of them of a very small scale, have a great influence on soaring. A common cause of such convergence lines in coastal regions is the sea breeze. The sea breeze front is a convergence line that marks the boundary between air which has been heated over land during the day and cooler air flowing inland from the sea or a large lake.

A brief summary of the requirements for a sea breeze is:

(a) Differential heating producing higher temperature over land than over sea.
(b) A light off-shore component of airflow during the morning. No real sea breeze is likely if there is already an on-shore component in the morning (Figure 2.28 (a)).
(c) Convectively unstable air is needed over land. The greater the depth of instability over land, the less the temperature contrast needed for the development of a sea breeze. If the air over land is so stable that thermals are very shallow or non-existent, sea breeze fronts are unlikely, even when there is a marked temperature contrast of 10 K or more–Figure 2.28 (b).
(d) Usually the sea breeze has a typical daily variation that depends on the temperature contrast between land and sea. In small systems with low inland penetration it follows the heating of the sun. When large systems with considerable inland penetration occur, the sea breeze can continue all night or even into the next day.
(e) Maximum inland penetration varies a lot. In Europe, the maximum inland penetration is in the order of 50 to 80 km while in Australia, the sea breeze has been observed up to 400 km from the coast. The inland penetration of a sea breeze front can be seen on the satellite picture (Figure 2.29).
(f) The speed of inland penetration is usually in the order of 5 - 10 knots. It depends on the maximum temperature contrast between land and sea and the development of clouds at the frontal layer. Sometimes the sea breeze penetration slows down in the early afternoon, then accelerates in the late afternoon.

2.3.2.1 Features of the sea breeze

- Convection inland with flow of air from land to sea at high levels.
- A shallow influx of cooler air from the sea.
- A weak flow of warm air over land is checked where it meets the sea air. The warm air is forced to rise over the cooler air, producing a narrow line of ascending air which may be marked by a belt of convective clouds or at times a change of visibility without cloud. There is a narrow frontal layer between the two types of air. The surface winds in this frontal layer are light.
- The sea air moves inland. Some of the air rises at the front and returns seaward beneath the warmer land air. That makes a well marked inversion over the sea air.
- The sea air often has a higher dew-point than the land air and, when it rises in the frontal layer, the cloud base is lower, forming ragged 'curtain clouds'.

2.3.2.2 Orographic effects on the sea breeze

In the case of a narrow peninsula the sea breeze may penetrate from both coasts to form a convergence line near the middle of the peninsula. If the synoptic wind has

Figure 2.29
Complex convective structure over the south of Sweden. A synoptic size trough in a weak westerly flow, well-developed sea breeze along the east coast and small scale convergence zones caused by sea breezes from the lakes.

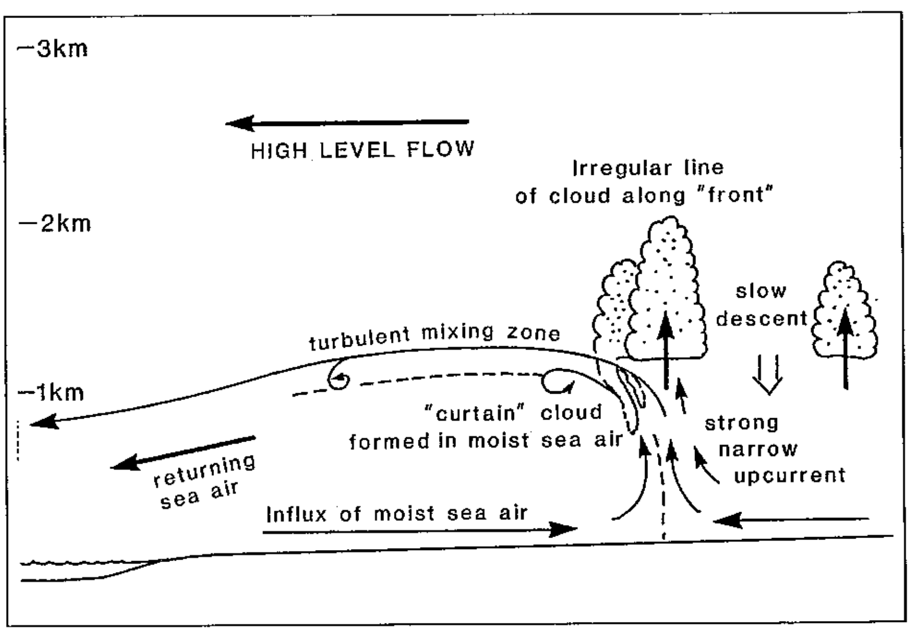


Figure 2.30
Cross-section of a sea breeze.

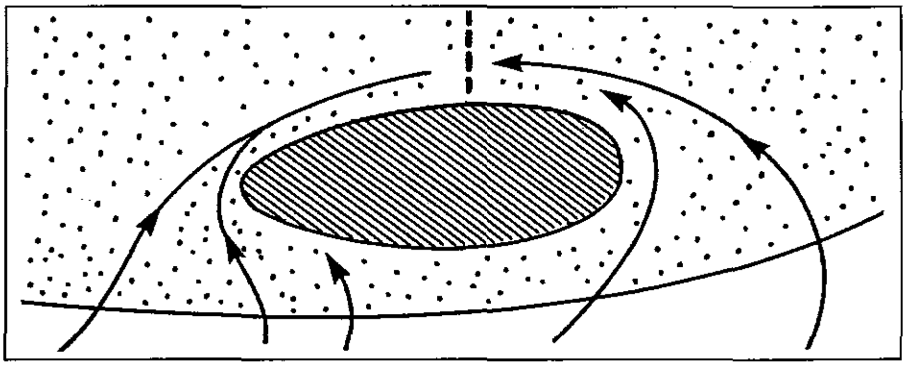


Figure 2.31
Sea breeze front around a hill.

a component across the peninsula, the convergence line will be displaced towards the downwind side, even across a bay.

The depth of the sea breeze flow is normally shallow, so its penetration inland is influenced by the height of the ground. A range of hills whose height is a substantial fraction of the depth of the sea air will deflect the sea breeze or prevent its inland penetration. An isolated block of hills may produce a convergence line on its landward side where currents of sea air rounding each end of the hills meet on the far side (Figure 2.31).

If there is a deep convective layer with high instability, the sea breeze is intensified by mountains and valleys due to greater and different insolation at the slopes. In the case with a short distance between mountainous region and the sea, as in the Mediterranean area, the sea breeze may start in the early morning while the mountain breeze is still going on. The front of the sea breeze has then acts as a virtual mountain ridge and may help to produce mountain waves until the front has reached the mountain ridge.

2.3.2.3 Effects of the sea breeze on soaring

The air coming from a relatively cold sea or lake requires a longer time to be heated until thermals are produced. That means that wind from the sea or large lakes often prevents soaring at quite a large distance from the coast. The sea breeze is topped by a low inversion which makes thermals small and weak. Therefore one is unlikely to find soarable convection on the coastal side of a sea breeze front. On the warm side of the sea breeze front, cumulus convection is often well developed and gives good conditions for soaring along the coast. In a well developed sea breeze front it is possible to fly over long distances till sunset, even when the normal inland thermals have died out.

2.3.3 Convergence lines

More or less transient convergence lines of varying scales are fairly common in the atmosphere. Besides synoptic scale convergence lines there are small scale convergence lines with characteristics very similar to sea breeze fronts, which form when there are areas with different surface temperatures over land. Some reasons for differently heated ground should be mentioned here:

- Heating of the ground delayed or prevented because for example the foundation of fogs or clouds or recent showers in one area and good heating in an adjacent region with sunlit surface.
- Low land and hilly terrain with different rate of heating, producing a temperature gradient.

Frictional differences produce fairly long-lived convergence lines if the wind is favourable. The following can be described as convergence subsyniptic scale lines.

- Minor convergence lines which do not move may be found along ridges which are heated much more than the surrounding flat land especially when the wind is parallel to the ridge.
- Convergence lines are also found where the mountain wind meets the prevailing wind, so-called down-slope lines. In mountains, a convergence line with different cloud bases can be produced over the crest of hills, when the valley breeze over one of the slopes is flowing against the gradient wind from the other side of the ridge (Figure 2.32).

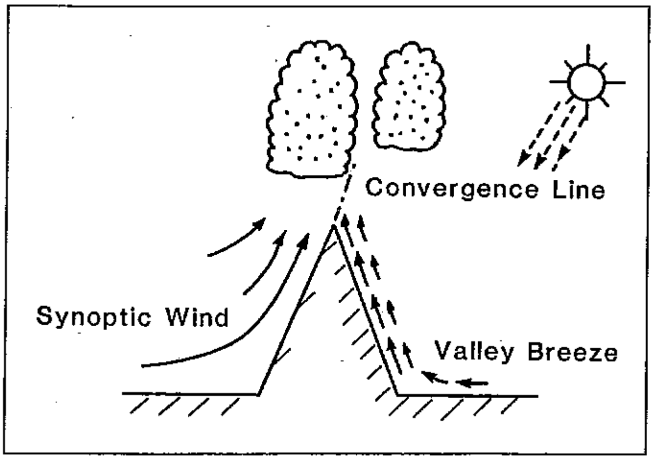


Figure 2.32
Convergence line over a hill

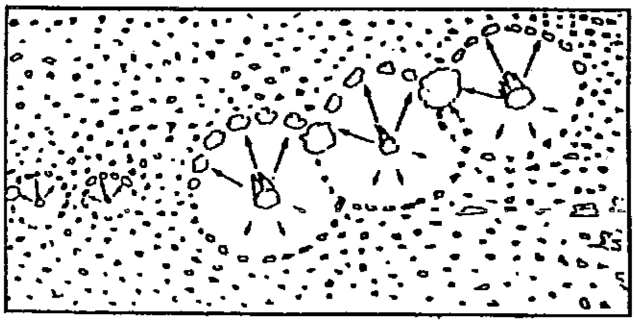


Figure 2.33
Convergence or intersection of convergence lines from thunderstorm downdrafts.

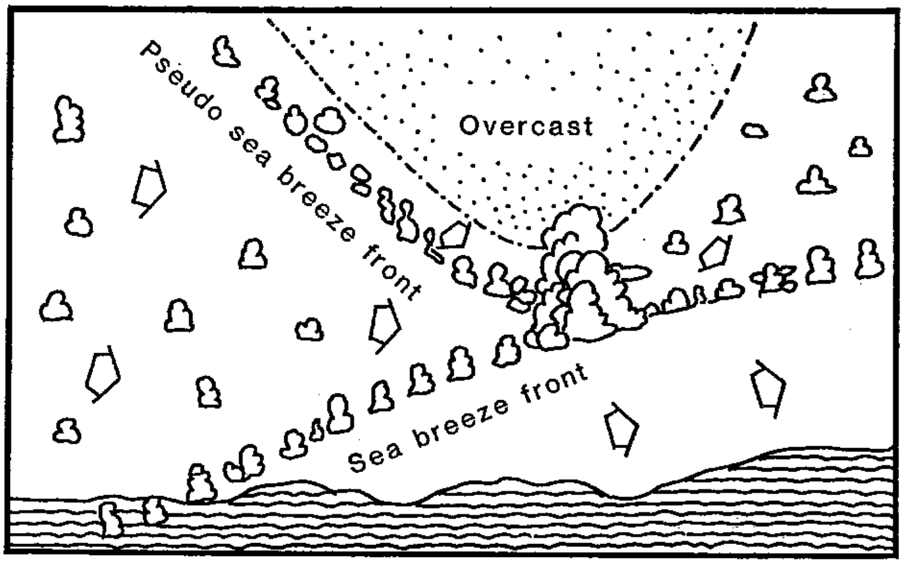


Figure 2.34
Convergence or intersection of convergence lines for a sea breeze front and pseudo sea breeze front. Plan view of cumulus clouds, winds and convergence lines and zones are denoted by schematically sketched clouds, arrows and larger clouds respectively

- Radar and satellite images show that showers often generate in favourable areas and then move with the wind. If the prevailing wind flow is moderate or strong, convection lines are formed.
- A likely location for the formation of a new convective cell is in the convergence zone caused by the outflow of cold air from downdrafts of a convective storm. The interreaction of convergence lines is very favourable for fresh convective development as in Figures 2.33 and 2.34.

2.3.4 Cloud streets

Cloud streets are a type of organized convection especially useful for glider pilots. They enable the pilot to achieve high cross country speed by flying along and beneath cloud streets, rather than circling in thermals. Cloud streets extend sometimes hundreds of kilometres over a large area as satellite pictures impressively show (Figure 2.35). They consist of regularly spaced bands of cumulus clouds. A cross-section normal to the wind direction (Figure 2.36) shows the pattern of vertical movement. This system represents the least energy-consuming mode of vertical motion when the wind profile is curved (Kuettner, 1971). In case of low humidity, updraft streets without visible cloud may develop.

2.3.4.1 Requirements for the development of cloud streets

- Fresh winds near the ground;
- Wind direction nearly constant with height in the convective layer;
- An inversion or stable layer to limit the vertical development of convective currents, usually at a height of 1.5 to 2 km (Figure 2.37);
- Curvature of the wind profile (Figure 2.37). The wind speed should increase with height to a maximum of at least 10 m/s in the middle or upper part of the convection layer. Above this level the wind may decrease or increase again.

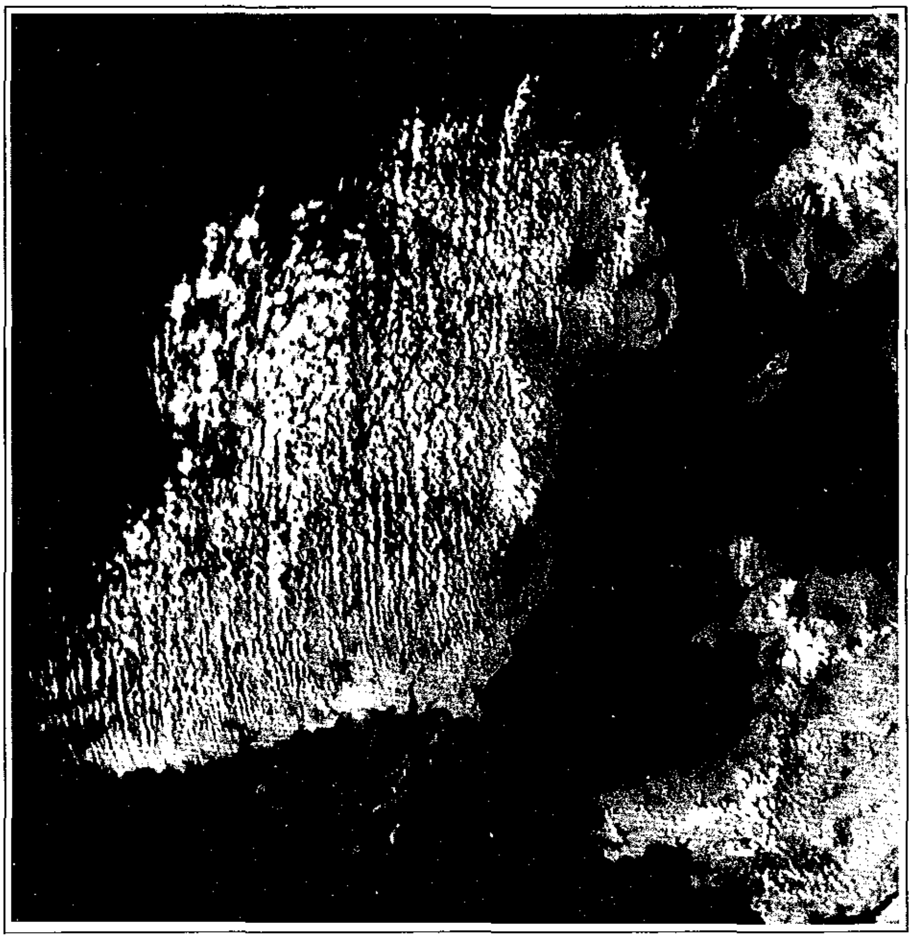


Figure 2.35
Satellite image of cloud streets over Ireland.

2.3.4.2 Spacing and alignment of cloud streets

The distance between adjacent streets has been observed as approximately three times the height of the inversion or stable layer. Cumulus streets are aligned parallel to, or within a few degrees of, the direction of the wind in the convective layer. Bends in the wind flow are often indicated by bends in the cloud streets. A single line of cumuli often extends to more than 100 km downwind; the entire field may extend over 1000 km downwind and has been observed to have a width in excess of 500 km. On very high-resolution satellite pictures up to 100 nearly parallel lines of cumuli have been identified.

2.3.4.3 Synoptic situation

The synoptic conditions for the horizontal pressure and temperature distribution within the convective layer are as shown in Figure 2.38. The direction of the isotherms compared with the direction of the surface isobars must indicate cold air advection. From this a component of the thermal wind results which reduces the pressure gradient aloft. In this way the demand of the curved wind profile is fulfilled. Cloud streets most frequently occur in strong cold air outbreaks, but they are also observed in a fresh inflow of moist warm air. The convective boundary layer in which they occur may be quite shallow, rarely more than 2 km deep. If there is vertical shear in both wind speed and direction, thermal waves will form over the cloud streets (see chapter 4).

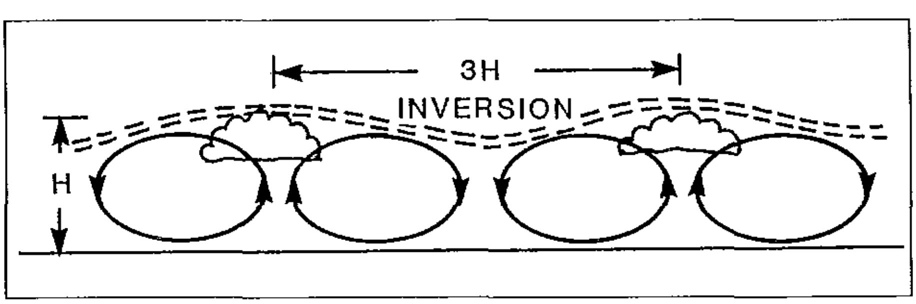
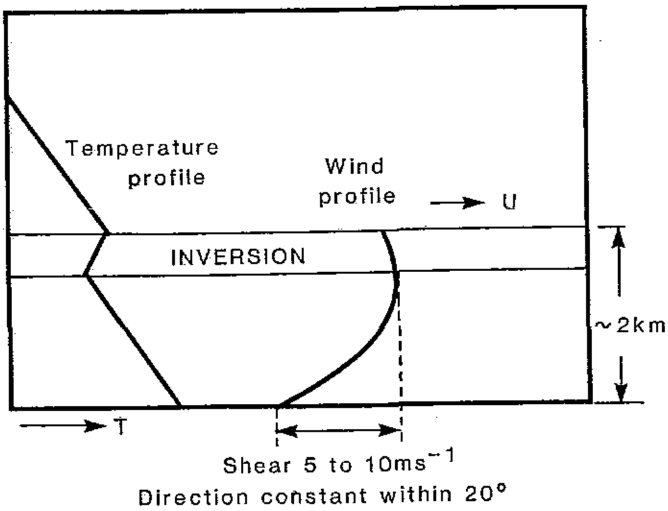


Figure 2.36
Cross section of cloud streets shows the pattern of vertical circulation



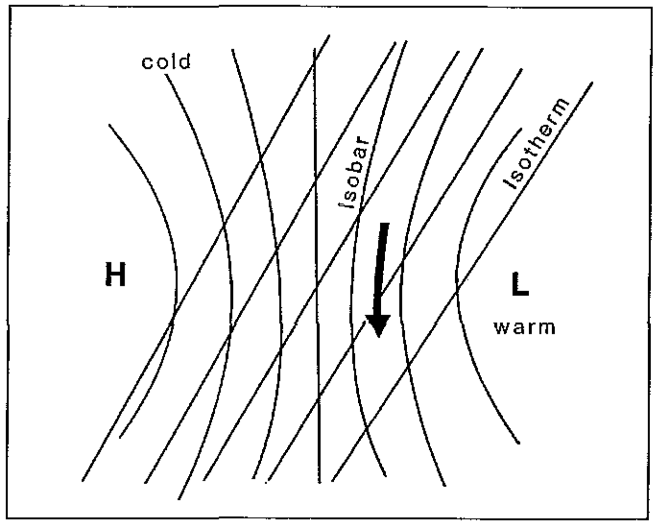
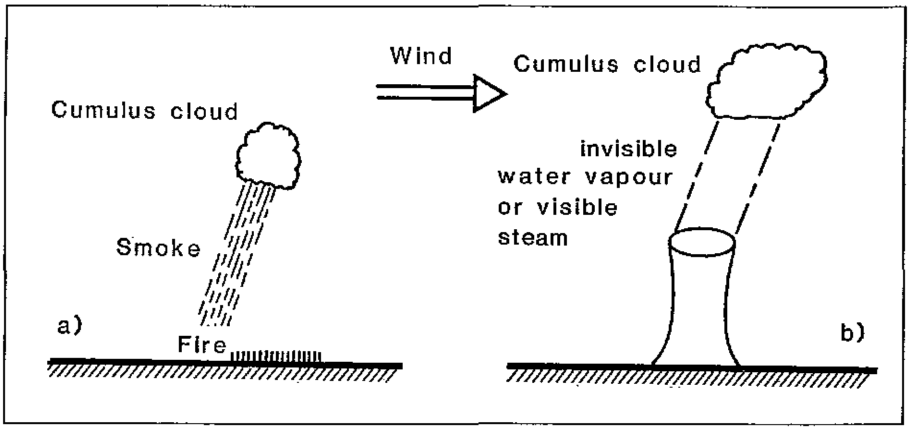


Figure 2.37 (above)
Temperature and wind velocity profile for cloud streets

Figure 2.38 (above right)
Pattern of isobars at the surface and isotherms representing the whole convective layer favourable for cloud street development

Figure 2.39 (right)
Schematic view of the generation of thermals by a stubble fire (a) and a cooling tower (b)



2.3.5 Use of man-made heat sources

Pilots flying in the neighbourhood of man-made heat sources report an enhancement of thermal convection which results from the larger amount of heat released to the atmosphere. Such man-made heat sources are:

(a) 'Stubble fires' made by farmers in late summer (Fig. 2.39 a);
(b) Industrial and power plants including cooling towers representing large thermal energy density (Fig. 2.39 b);
(c) 'Prescribed burning' as done in the U.S. to prevent or control forest and bush fires.

Due to high energy density, thermals which develop from these heat sources are sometimes quite narrow and as a consequence quite turbulent. Cooling towers, especially, produce severe turbulence under conditions of negligible horizontal winds. Heights obtained by sailplanes over these sources may sometimes exceed those in natural convection by hundreds of metres. The visibility is often reduced by smoke or by the high amount of steam released by cooling towers. The importance of man-made heat sources for a sailplane pilot is much greater in the morning, when the natural convection has not yet developed, and in the late afternoon, when convection is dying down. During day-time, when natural thermals are fully developed, the effect of man-made heat sources is often submerged in natural convection, especially if the convection layer is deep.

CHAPTER 3

FORECASTING MOUNTAIN WAVES

The broadly horizontal flow of air is frequently found to contain wavelike undulations where the vertical component of velocity is greater than the sinking speed of a sailplane. A soaring pilot can gain height by flying in the region of ascending air on the upwind side of such a wave. Here the pilot experiences a very calm updraft caused by the laminar flow.

There are several sources of waves which can be used by sailplanes. The strongest waves are found above and in the lee of mountains and have been termed 'mountain waves' or 'lee waves'.

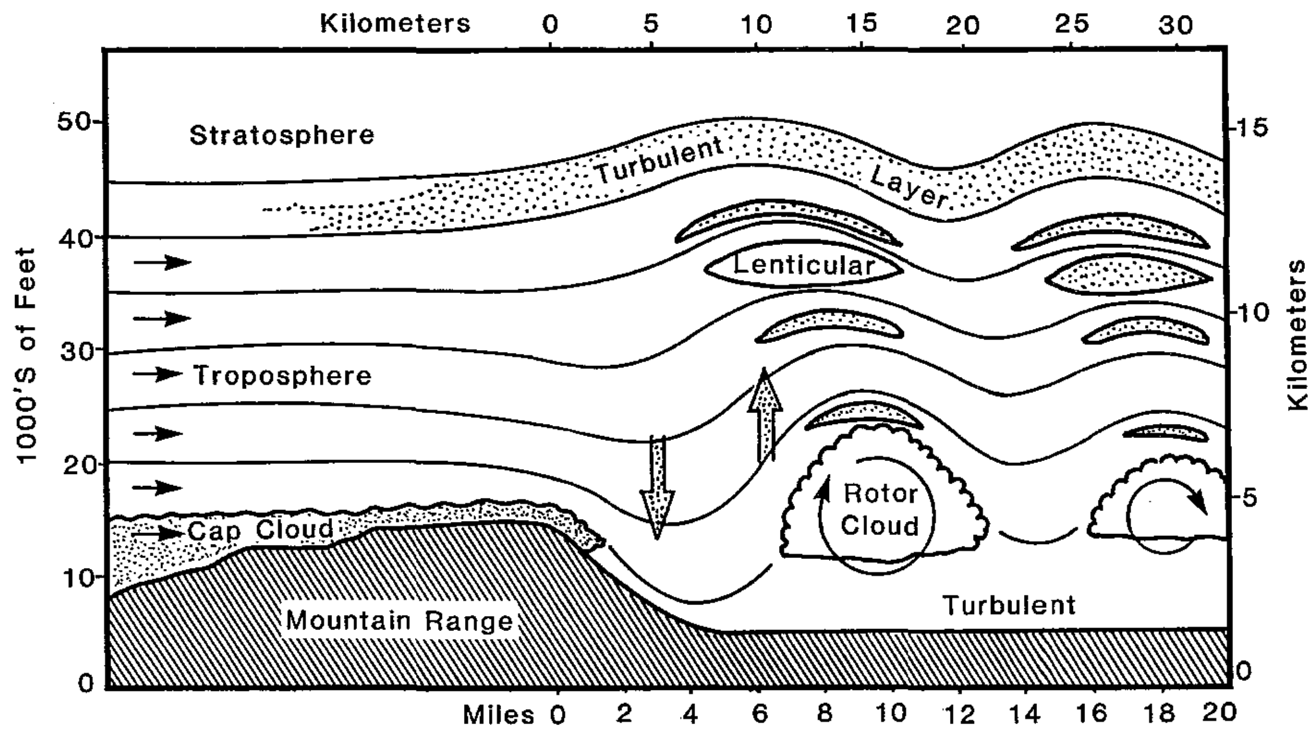
Figure 3.1 shows a typical streamline pattern of a well developed wave in the lee of a mountain range. All significant visible weather phenomena are shown, such as lenticular clouds, rotor clouds, and a cloud wall 'cap cloud' developing on the windward side of the mountain range and evaporating on the leeside, sometimes looking like a waterfall. The strong leeside downdrafts often produce cloud gaps (known as 'foehn gaps' in the Alps), which sometimes allow visual flying even in a moist air mass.

Lee waves were first explored by German soaring pilots in 1933. By 1937 sailplanes had reached a height of over 7 km. In 1986 a height of almost 15 km was reached by a sailplane flying in mountain waves to the lee of the Sierra Nevada range in California (see section 8.5). Observations show that wave flow occurs up to a height of 30 km (100 000 ft).

It is conceivable that sailplanes might use the travelling waves found in jet streams but it is rare for a sailplane to reach the necessary altitude and nobody has, as yet, flown in such waves.

Mountain waves are covered in a number of books and papers published in recent decades, including the WMO Technical Note No. 34, *The Airflow over Mountains* (1960), which has a summary of observational and theoretical studies of mountain waves. More recent developments have been included in WMO Technical Note No.127 *The Airflow over Mountains, Research 1958–1972*, published in 1973, and in the review by Ronald Smith: *The Influence of Mountains on the Atmosphere* (1979). These publications also give extensive lists of references on the subject.

Figure 3.1
Schematic flow diagram of mountain wave



3.1 MOUNTAIN WAVE CHARACTERISTICS

The occurrence of mountain waves varies from season to season. Observations in the northern hemisphere have established that mountain waves are a cold season phenomenon (see Figure 3.2)

3.1.1 WAVE TYPES;

There are two basic types of mountain waves: one propagating its energy mostly vertically up and one propagating it mostly horizontally downwind. Which of the two types prevails depends on the vertical wind and temperature profiles and the shape and height of the mountain range.

- The first type, the so-called 'vertically propagating wave' may reach all the way into the stratosphere, but has few or no secondary waves farther downstream. It is distinguished by a single high level cloud deck whose leading edge runs parallel to the mountain range (see Figure 3.3). This is the most favorable wave for high altitude soaring.
- The second type, the so-called 'trapped wave' is indicated by many repetetive wave clouds (up to 20 or more) which sometimes show up spectacularly on satellite pictures. Unfortunatly these waves don't reach very high (about 3 to 5 km) because, due to their relatively short wavelength, they are trapped between a high level wind and the ground (see 3.2.1. below). They are useful for low-level wave flights, for example 'down wind dashes'.

Most waves contain characteristics of both wave types (see Figure 3.3).

3.1.2 ROTORS

Rotating turbulent airmasses, called 'rotors', are almost always present beneath the nearly laminar wave flow aloft. (see Figure 3.4). Rotors may reach to altitudes exceeding the highest mountains and often carry excessive up- and downdrafts. Their turbulence can be hazardous, especially under the first wave, for example when an air tow has to penetrate upstream under their cloud base in order to reach the primary wave updraft.

3.1.3 CLOUD FORMATION

Wave clouds are the best indicators of wave activity. They are stationary (with the air flowing through them), often lens shaped (lenticular) and almost always multi-layered (Figure 3.5) whereas rotor clouds are cumuliform. Even small fracto-cumuli beneath the wave clouds indicate considerable rotor turbulence.

3.1.4 BREAKING WAVES

Under conditions of strong vertical wind shear, wave slopes may steepen until the waves break–similar to waves breaking in the ocean surf. Wave-breaking leads to the most severe turbulence in mountain waves, because in the stably stratified atmosphere breaking waves move cold air on top of warm air. This is especially true in the stratosphere. Wave breaking may occur at lower levels in the rotor zone or near the tropopause in the lower stratosphere, for example in the negative shear zone on top of the jetstream core. Soaring in these zones should be avoided.

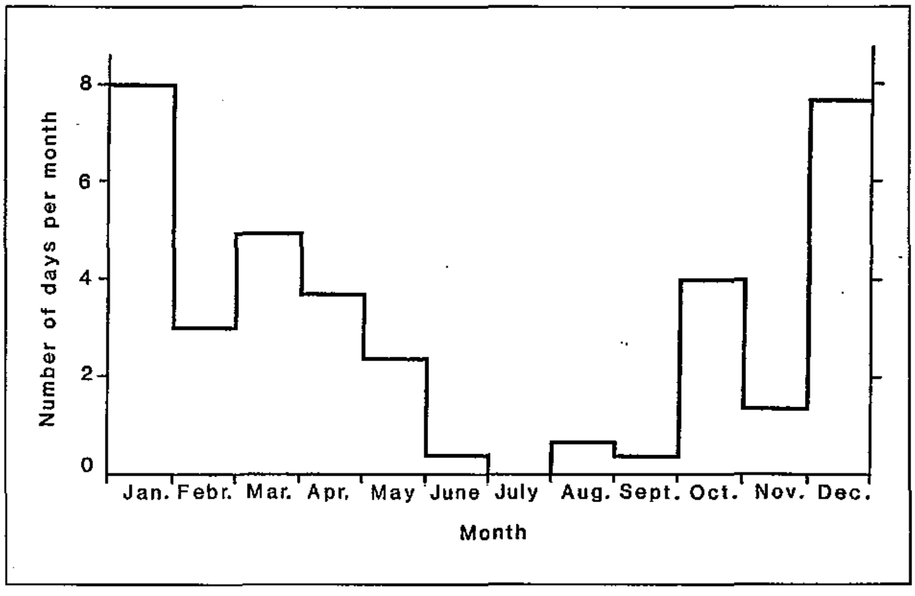


Figure 3.2
Monthly frequency of lee wave clouds from over 100 observations in Europe (after Cruette, 1973)

Figure 3.3
Satellite picture of 500 km long "Chinook Arch" cloud in the lee of the Canadian Rocky Mountains (Alberta). Note trains of shorter ('trapped') wave clouds at lower levels from smaller mountain ranges. (After Lester, 1975)

3.1.5 Extreme wave and rotor situations

Under rare atmospheric conditions a high mountain range can induce a Niagara fall-like perturbation of the whole atmosphere whereby the troposphere may be squeezed to half its depth and streamline amplitudes may reach over 6 km (Figure 3.6). Such extreme wave flow is associated with down slope winds of over 50 m/s on the ground and severe turbulence aloft. Such wave flow presents a serious hazard to flights through it.

Under jetstream conditions high reaching rotors may develop excessive up and downdrafts and destructive turbulence. Such rotors have a straight leading edge and sit far back to the lee from the mountain range. They may extend for hundreds of kilometers parallel to the ridge, see Figure 3.7.

3.2 WAVE FORMATION AND 'TRAPPING'

The development of mountain lee waves depends on the characteristics of the airstream and the topography.

3.2.1 Air stream characteristics

The two primary factors are the temperature stratification and the vertical wind profile. Since wave motions are only possible in a stable medium, the vertical temperature profile must be stable—the prevailing condition during winter time. An inversion at or above the crest level of the mountain range is also a necessity. It assures that the cold air under the inversion sweeps down the mountain lee slope rather than forming a lee vortex.

Figure 3.4
Severe rotor, showing profile and increase of wind from mountain top to valley floor.

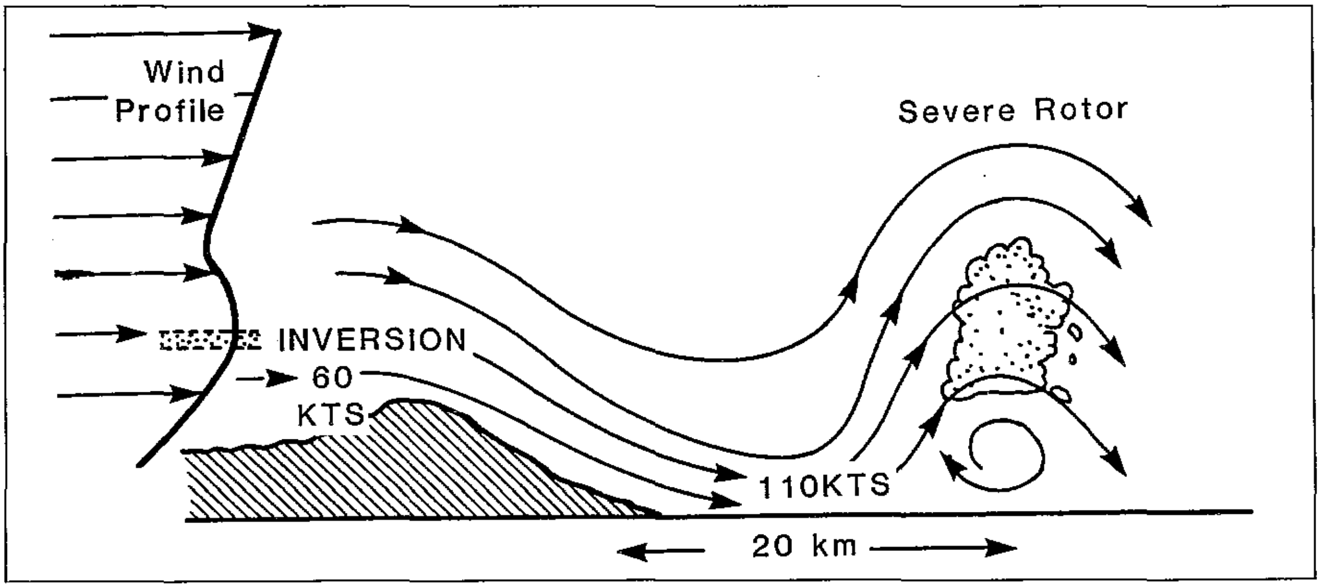


Figure 3.5
Multilayered lenticular cloud in the lee of the Sierra Nevada (Photo R. Symons)

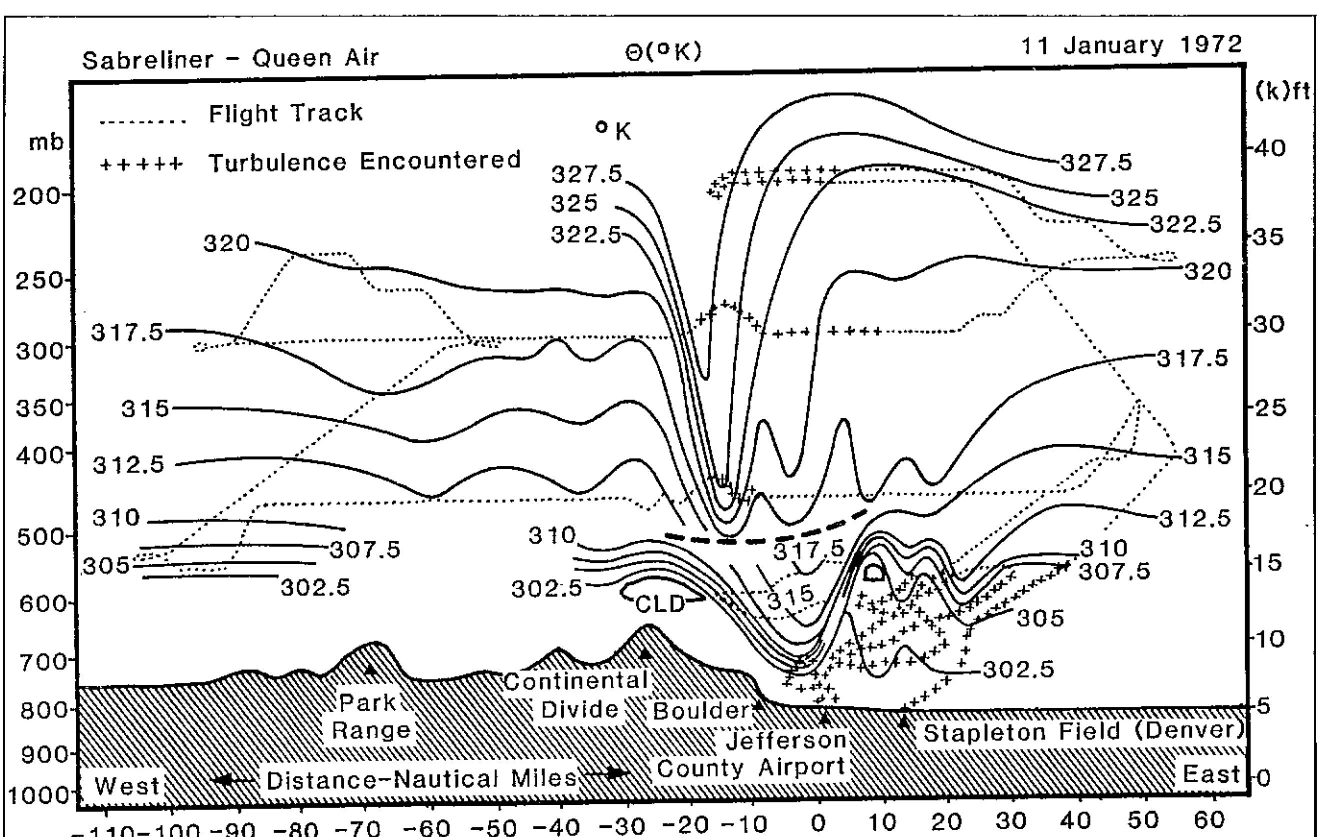


Figure 3.6
Severe mountain wave over the Rocky Mountains of Colorado. Solid lines are potential temperature representing approximate streamlines, CLD indicates position of cloud (Klemp and Lilly, 1975).

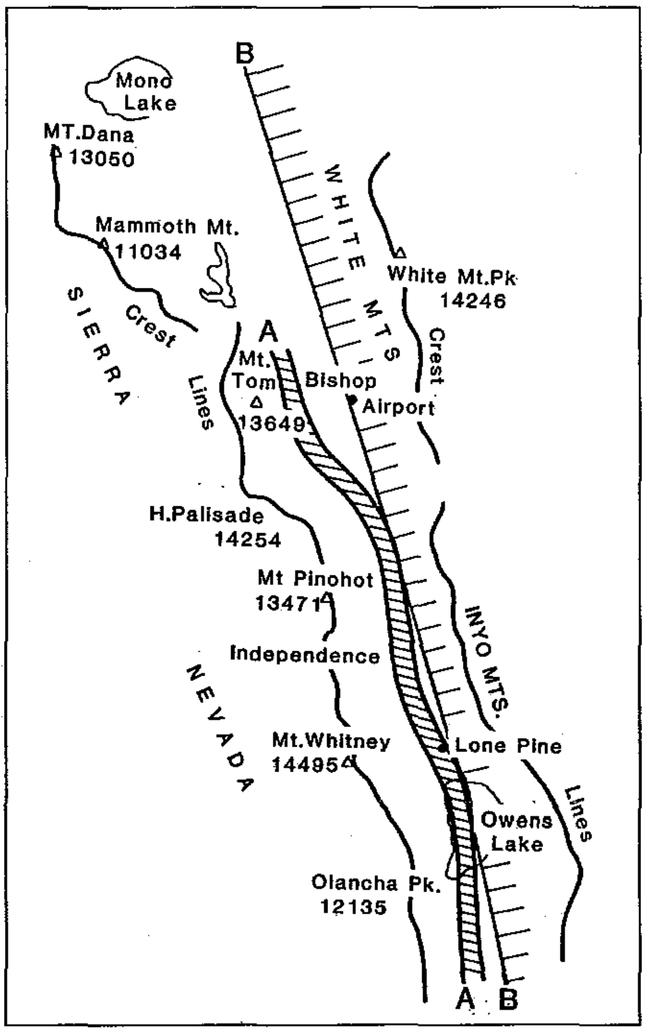


Figure 3.7
Rotor with extreme turbulence.
A-A: Normal position in the lee of the Sierra Nevada.
B-B: Extreme position creating severe turbulence.
Distance B-B: about 200 km.
Wind from left.

The flow direction must obviously be normal to the mountain range or, at least, within ±30° of this direction. The flow must be strong enough to prevent local disturbances and convective motions from overwhelming the organized wave flow. 12-15 m/s appear to be the minimum wind speed at crest level.

Wave updrafts are approximately proportional to the wind speed, so a favourable profile to produce moderately strong waves shows an increase in wind speed with height to at least 20 to 25 m/s . A typical, sharply pointed jetstream profile is, however, not favourable, because it tends to trap the waves within a 'duct' between the ground and a 'reflection level' where the upper winds become too strong (see below). A more favorable wind profile is 'blunt', i.e. with a broad maximum near 40 m/s. Obviously it takes a suitable combination of vertical wind and temperature profile to produce a strong wave.

This relation is expressed by the so called 'Scorer parameter' (Scorer 1953),

$$\ell \approx \sqrt{\frac{N^2}{U^2} - \frac{1}{U}\frac{\partial^2 U}{\partial z^2}}$$

with

$N = \sqrt{\frac{g}{\theta}\frac{\partial \theta}{\partial z}}$	Brunt-Vaisala-frequency,
U	horizontal wind speed,
g	acceleration of gravity,
θ	potential temperature,
z	height.

The second term under the square root containing the curvature of the wind profile can often be neglected. ℓ can be interpreted as a measure of the 'natural wavelength', λ_n, of an air parcel oscillating freely in its stable environment, whereby

$$\lambda_n = 2\pi / \ell$$

This is a theoretical value. In reality, individual particles don't oscillate in their environment, but the whole air mass moves up and down. Since ℓ changes with height, λ_n does the same: The natural wavelength grows with height, because of increasing winds. In contrast, the wavelength of the mountain wave itself, λ_m, consists of a wave motion of the whole airmass, not a single air parcel, and is longer than λ_n. It also depends on other factors such as the mountain shape. In order for mountain waves to exist, the wavelength, λ_m, must be larger than λ_n at all levels. If, for example, in a jetstream the wind increases so much with height that the two wave lengths become equal at a certain height, the mountain wave cannot propagate any higher and is reflected downward at this level. We have the case of a 'trapped wave'. The energy of the wave, instead of propagating further upwards, propagates down stream and forms many consecutive low-level waves because the 'duct' between the trapping level and the ground (or boundary layer) protects the waves from dissipation, like light waves in a fiber optics cable.

3.2.2 Topographic effects

The primary influence of the topography arises from the height of the mountain range, its length normal to its wind direction and the depth and steepness of its lee slope.

Low mountains can produce lee waves of great vertical extension. For example a maximum height of 8000 m was reached in the lee of the Deister, a chain of hills reaching only 300 m above the plain in Northern Germany.

The higher the mountain, the larger its obstacle effect on the airflow and the greater the chance that it reaches into a higher wind regime. As a consequence, the wavelength will be larger and there is less likelihood that the wave can be trapped.

Consequently, the wave may reach to great heights. If, furthermore, the lee slope is steep and deep, the amplitude of the streamlines will be large and the intensity of the vertical motions strengthened. With the proper blunt wind profile such a high and steep mountain will produce a strong wave in the eyes of a soaring pilot.

A long mountain range of fairly constant height will—due to its quasi-two-dimensionality—minimize the possibility for the air to flow around the obstacle as it does at an isolated, three-dimensional mountain.

Parallel ridges may increase the amplitudes of lee waves if the natural wavelength corresponds to the spacing of the ridges.

Figures 3.8 to 3.10 illustrate the dramatic difference between the effects of a high mountain and one half its size, according to a numerical simulation of a flight

Figure 3.8
Wind speed normal to mountain range vs. altitude. See text for further explanation.

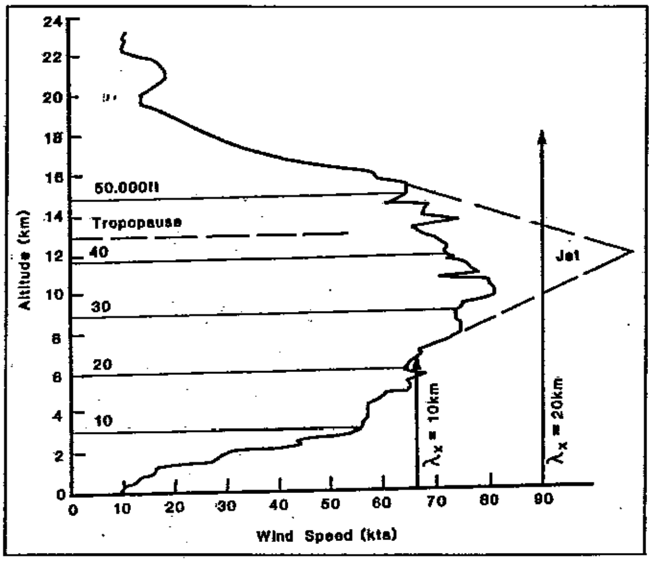
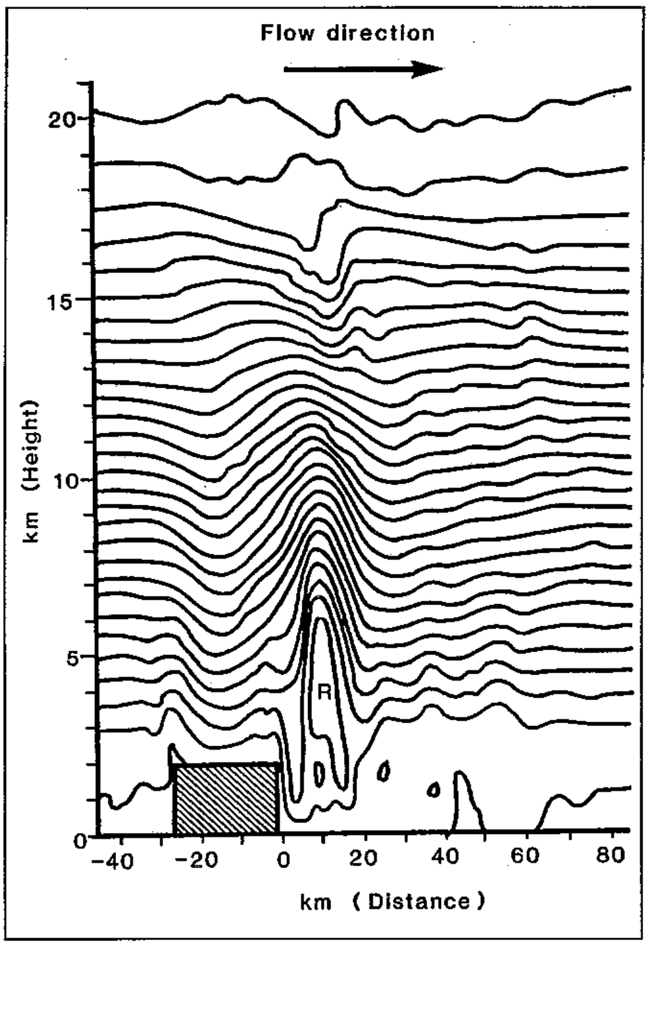
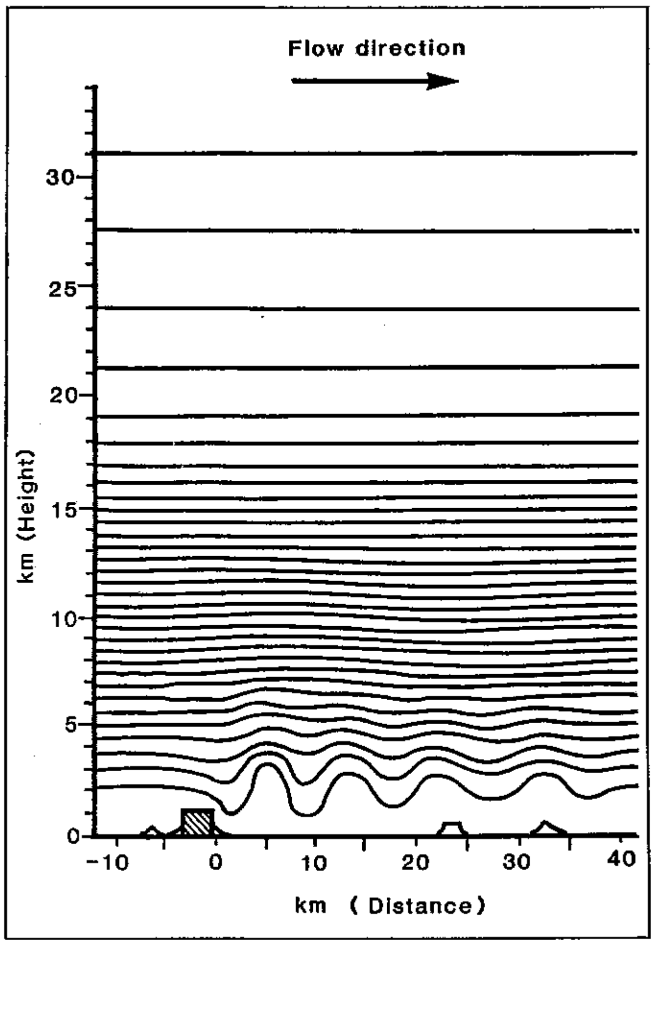


Figure 3.9 *(below)*
Numerical simulation of airflow over a 2 km high mountain obstacle with steep lee slope (after Falabella and Wurtele). Vertically propagating wave with rotor (R). Upstream wind profile as shown in Figure 3.8.

Figure 3.10 *(below right)*
As Figure 3.9 but for a 1 km high mountain obstacle. A train of trapped low level waves has formed.





day on which sailplanes fly over the Californian Sierra Nevada to more than 12 km altitude. The upstream wind sounding is shown in Figure 3.8 and indicates a blunt wind profile of about 40 m/s maximum strength (solid line), whereas a typical jetstream profile (dashed line) would probably have peaked near 55 m/s or higher. The mountain with a steep, 2 km deep lee slope–approximating the Sierra Nevada–produces an intense, vertically propagating wave which penetrates into the stratosphere (Figure 3.9). In contrast, the mountain range with a 1 km deep lee slope produces a train of low-level trapped waves (Figure 3.10). Both patterns are often seen on the same satellite picture (see Figure 3.3). Looking at the wind profile (Figure 3.8) one notices that the higher mountain range reaches into a much higher wind regime, producing a wavelength of over 20 km, while the smaller mountain with its weaker air stream produces only a wavelength of about 10 km. Figure 3.8 indicates that the smaller wavelength is trapped under about 6 km altitude while the larger one can penetrate into the stratosphere. If there had been a sharply peaked jetstream overhead (dashed curve) the longer wavelength would also have been trapped, though probably at a higher level, near 10 km.

It should be pointed out that mountain ranges of such excessive height that they block the major part of the troposphere, such as the Himalayas, do not seem to favor the development of strong mountain waves in spite of consistently high winds. They are too high to allow the flow of cold air to pass over their crests and to activate the necessary downslope flow. At the same time, they influence the synoptic flow themselves to such a degree that the upper jetstream flow blows parallel rather than normal to their crest line. Individual peaks, however, may create lee waves at high levels which, it appears, can only be reached by high-powered motor gliders.

3.2.3 THE ROLE OF THE TROPOPAUSE

Sharp inversions can also act as reflection levels trapping waves underneath. For high altitude soaring flights to penetrate into the stratosphere, the tropopause should be high and smoothly shaped. This will also reduce the chance of a strong negative wind shear with breaking waves and high turbulence near and above the tropopause. Figure 8.5.3 shows an example of a very high and smooth tropopause–correctly forecast–which allowed the present world altitude record holder R. Harris to reach nearly 15 km height over the Sierra Nevada. (see his flight report in 8.5). In contrast Figure 3.11 shows the vertical motions of a sailplane in breaking waves between 11 and 12 km height under conditions of strong negative wind shear in the tropopause. Up- and downdrafts alternate quickly between plus and minus 20 m/s in severe turbulence.

3.2.4 THE NATURE OF THE ROTOR

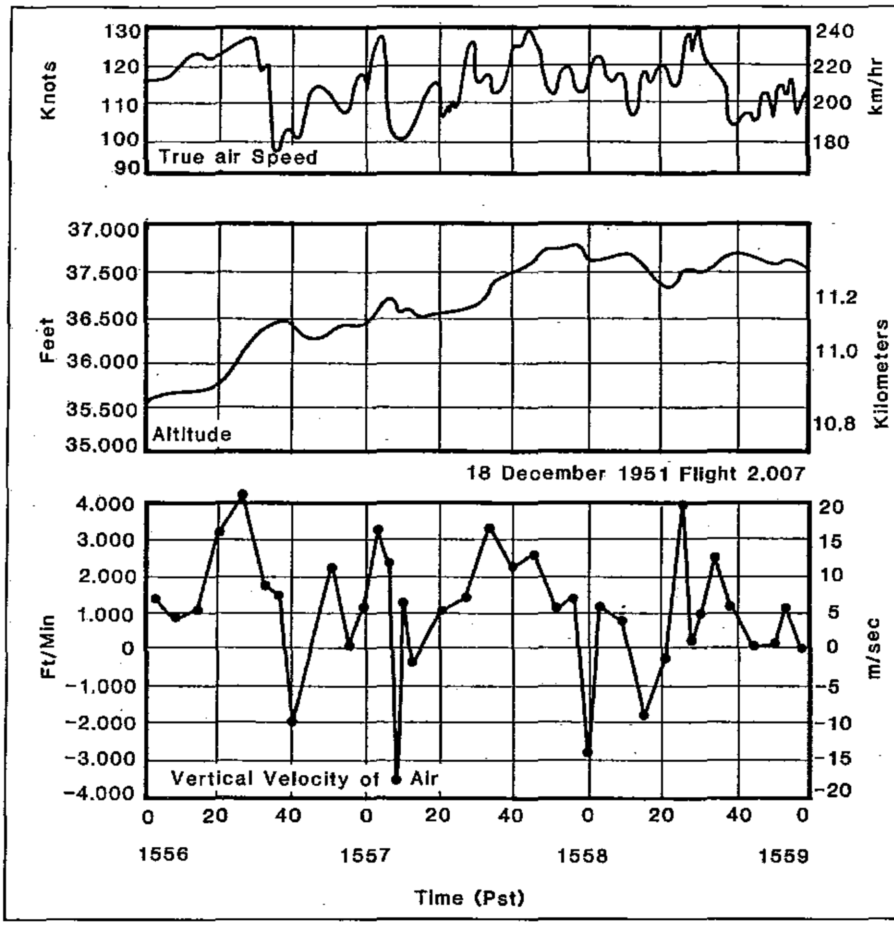
The rotor phenomenon is still under dispute, especially the question whether it is part of the wave system or a more independent entity. The prevailing opinion views it as a hydraulic jump. As the cold air rushes down the lee slope in a visible 'cloud water fall', it picks up speed, shoots along the valley floor with supercritical speed and returns farther downstream to subcritical speed in a hydraulic (or pressure) jump, thereby transforming much of the kinetic energy gained during the fall into severe turbulence. It is not yet understood what determines the precise position of the rotor; but observations indicate that, the farther back its position is on the valley floor, the more severe its turbulence (see also section 3.1.6 above and Figure 3.7). Most likely the position is determined by the height of the upstream inversion in relation to the mountain height.

3.3 FORECASTING CRITERIA FOR ALTITUDE AND CROSS-COUNTRY SOARING FLIGHTS

Forecasts of mountain-wave activity and related turbulence are done routinely today, often as part of a daily aviation forecast. While these general wave forecasts are quite satisfactory, the prediction of details of interest to the glider pilot such as precise timing, wave and rotor intensity etc. are extraordinarily difficult.

Since wave flights require far more preparations than ordinary thermal flights and often involve substantial travel, the pilots need at least a 48 hour warning and a detailed 24 hour forecast. Typical pilot questions are :

- From when to when can wave activity be expected?
- Will its intensity be weak, moderate or strong?
- How strong will be rotor development and turbulence?
- Will fronts or low clouds be moving in and at what time?



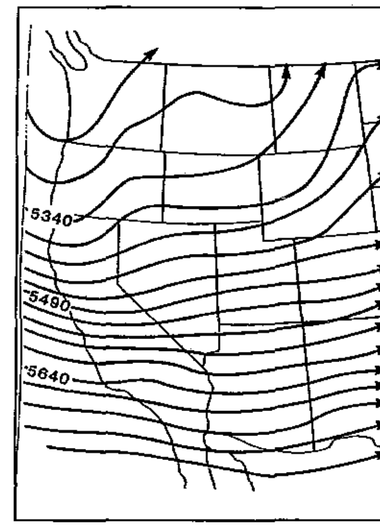


Figure 3.11 (left)
3 minute record of severe turbulence encountered by a sailplane at 11 km altitude near the tropopause over the Sierra Nevada.

- Will there be severe ground winds?
- For out and return (crosswind) flights along the mountain range: How broad will the high wind belt be and where will it be terminated first?
- For downstream (tailwind) cross country flights: What will be the downstream conditions, i.e. wave activity, cloud cover, upper winds, precipitation?

From rules earlier sections of this chapter it is clear that there are a number of forecasting that can be derived from aerological soundings and from topographical features. However, the synoptic situation is of equal importance.

3.3.1 Synoptic criteria

Nearly all good wave conditions at mid latitudes are connected with prefrontal situations. For a mountain range with approximately N-S orientation, optimum wave activity can be expected with a strong zonal flow in a phase just ahead of a fairly shallow upper trough and the jetstream in a position a few degrees north (in the northern hemisphere) of the soaring area. If the jetstream is expected to be directly overhead conditions are not at optimum, because moisture may move in, the waves may be trapped and turbulence could be high. If the jetstream is expected to pass south, it is usually too late, as cold air will penetrate and fill the lee-slope valleys. Vorticity advection techniques are helpful in pinpointing the optimum wave phase.

For long cross country flights it is best to fly downwind at high levels and to regain altitude only over the highest mountain ranges encountered. Straight flights of the order of 2000 km are considered possible with the very high ground speeds and glide ratios possible. The technique requires a synoptic condition of nearly straight flow over several thousands of kilometres between about 700 and 200 hPa. Operational models are good enough today to predict such situations for more than 48 hours. This straight flow is quite rare in comparison to flows with alternating troughs and ridges which, however, may offer favorable conditions for high altitude flights.

Figure 3.12 shows an example of an ideal weather situation over the western USA for both long distance and high altitude flights. Flight attempts on this day actually led to distance and altitude records. The special difficulty for the forecaster

Figure 3.12 (left)
Near straight zonal flow at 300 hPa over the western USA favorable for high altitude down stream flights between 1000 and 2000 km. On this day (19 March 1952) record flights in altitude and distance were performed, among them the 13400 m multi-place world record.

lies in the prediction of the proper take-off time–which usually has to be in the early morning–and the synoptic developments farther downstream. Even in such straight jetstreams, minor troughs travelling eastwards may bring periods of heavy cloudiness and interruptions of wave activity. Optimum timing of such wave flights requires close personal cooperation between pilot and forecaster, and excellent knowledge of local and regional weather including the propagation characteristics of cold fronts through valleys and related clouds and precipitation.

For E-W oriented mountain ranges such as the Alps, a good wave forecast duplicates the difficulties of foehn prediction, its onset and termination, because foehn and lee waves (so called foehn waves) are intimately connected. Often the glider pilot is his own best forecaster, because of his personal knowledge of terrain features, but close cooperation with an experienced regional forecaster is required for proper timing, especially for alpine-type out-and-return flights along the mountain range.

3.3.2 Aerological Criteria

From the earlier sections of this chapter it is clear that upstream soundings contain important forecasting criteria :

a) Temperature profile

The vertical temperature profile should not be conditionally unstable and should contain a pronounced inversion near or above the mountain crest level with less stability above.

b) Tropopause

A high tropopause without sharp inversion may allow climbs to very high levels without encountering clear air turbulence, provided other factors are likewise favorable.

c) Wind Profile

The wind direction from about 850 hPa up should be uniform within about 20 to 30° normal to the crestline of the mountain range. The wind speed exceeds 20 m/s above 500 hPa (see Figure 3.8). Strong vertical wind shear or a sharply peaked jetstream are not necessarily favorable as they tend to produce a train of low level 'trapped' waves and turbulence. High altitude turbulence is indicated if the wind decreases sharply in and above the tropopause.

d) Rotor prediction

The prediction of the intensity of rotor development and related turbulence is still an unknown. Indications are that a combination of a fairly high cold airmass flowing and falling over the lee slope and strong wind shear leads to highly turbulent, high reaching rotors with possibly severe ground winds on their upstream side. For this situation to occur, the upstream inversion must exceed the crest height by about half the depth of the lee slope, but not more.

Before take-off the best indication for the glider pilot to expect a rough rotor is a large cloud 'waterfall' over the lee side of the mountains combined with strong surface winds.

3.3.3 Topographic Criteria

a) Mountain height

As discussed earlier, in most cases the higher a mountain range the more it favours intense, high-reaching lee waves. This does not, though, apply to mountain ranges of excessive height such as the Himalaya (see 3.2.2 above).

b) Mountain slope:

More important than the absolute height of the mountain range is the height and steepness of the leeward slope, as it determines the amplitude of the wave motion and its updrafts. Steep and high lee slopes can produce wave updrafts of 10 to 20 m/s a few kilometres downstream of the lee slope, although, 5 m/s is more common.

c) Asymmetry:

An asymmetrical mountain profile with a flat windward slope and a steep leeward slope induces stronger waves than a symmetrical mountain, at least in numerical models. In practice, stagnating winterly airmasses tend to 'level' the windward slope by filling the upstream valleys. Such stagnating air masses may also fill the leeside valleys, before they are driven out by the downslope winds. In this way a difference in level is created between the two cold air reservoirs and the full height of the lee slope is effectively maintained, allowing the wave to reach its maximum development.

d) Length

Mountain ranges of large and uniform length and height produce more intense waves than isolated mountains of equal height because the flow cannot go around them. Nevertheless, three-dimensional mountains also produce lee waves, but they are weaker and resemble the wedge-shaped wake of a ship.

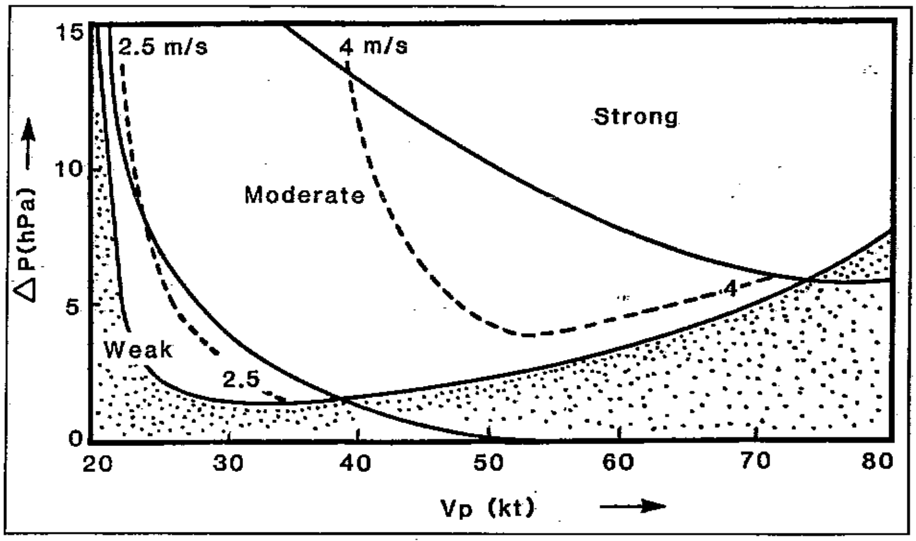


Figure 3.13
Lester-Harrison nomogram for the prediction of wave intensity (weak, moderate, strong) and vertical air speed (dashed, in m/s). Shaded area indicates that the probability of soarable waves is less than 50 percent.

3.3.4 THE LESTER-HARRISON NOMOGRAM

An empirical method to obtain semi-quantitative predictions of wave intensity has been developed by Lester (1975) extending Harrisons's original work. It is based on the forementioned fact that the wave flow across the mountain range is associated with a height difference between the stagnating cold airmasses on the up- and down-wind side resulting in a hydrostatic pressure difference. Only two quantities are used

a) The maximum wind speed (component normal to the mountain range) in a layer 3 km thick above the mountain crest;
b) The pressure difference normal to the ridge between the upwind and down-wind side of the mountain range.

The nomogram (Figure 3.13) has been developed primarily for large mountains, approximately 3 km high, based on numerous wave observations. It predicts the probability that waves will develop, their intensity (weak, moderate, strong) and the approximate updrafts expected. As indicated in the following *procedure of use*, the pressure difference across the mountain range has to be normalized according to the distance between stations used (see step 6). This pressure difference should always be measured approximately normal to the ridge. Provided that the forecast model does not smooth out all troughs, one should use predicted pressure and wind data for prognostic purposes. For small mountains (under 1 km) the nomogram may not be applicable. The intensity of the waves (weak, moderate, strong) refers, in a qualitative way, to both vertical motion and vertical extent of soarable wave flow.

In Figure 3.13 Δp (hPa) is the adjusted, cross-mountain sea-level pressure difference, V_p (kt) the maximum cross-mountain wind component in the 3 km layer above the mountains. The shaded area indicates that the probability of soarable waves is less than 50 percent. The dashed lines are estimates of vertical airspeeds. The heavy solid lines divide the nomogram into areas of wave strength as determined from observations of wave length,amplitude and vertical air speeds.

Procedure for use of the modified Harrison lee-wave nomogram

Step 1 Obtain the closest upstream sounding of windspeed and direction for the layer extending 3 km above the mountain tops;
Step 2 Resolve the windspeeds into components perpendicular to the ridgeline;
Step 3 Select the maximum component in the layer (V_p);
Step 4 Obtain the difference in sea-level pressure between an upstream station (p_u) and a downstream (p_d) to yield $\Delta p_0 = p_u - p_d$;
Step 5 Determine the distance (Δx) in km between the stations perpendicular to the ridgeline;
Step 6 Multiply Δp_0 by the ratio ($320/\Delta x$) to obtain Δp;
Step 7 Enter the nomogram with V_p (step 3) and Δp (step 6) to obtain the probability of wave occurence (> or <50%), the wave strength (weak, moderate or strong), and an estimate of vertical air speed (<2.5 m/s, 2.5—4 m/s, >4 m/s).

CHAPTER 4

FORECASTING THERMAL WAVES

4.1 GENERAL DESCRIPTION

Thermal waves form over thermals or over cumulus clouds when there is vertical wind shear and an inversion over the convective boundary layer. The thermals or cumulus clouds may be randomly distributed (3-dimensional convection) or they may be organized in roll vortices, i.e. in updraft or cloud streets (2-dimensional convection). In the latter case the vertical wind shear must also be directional in order for the upper flow to be directed normal or near-normal to the cloud street axes. The two types of thermal waves are usually called 'cumulus waves' and 'cloud street waves', although the formation of clouds is not required for thermal waves to exist. In the scientific literature thermal waves are called 'convection waves'. Since 1985 they have been systematically explored with the aid of instrumented aircraft, wind profiles and numerical models (Kuettner et al., 1987; Clark et al., 1986; Hauf and Clark, 1989).

4.1.1 CUMULUS WAVES

An individual cumulus cloud that rises into a level of stronger wind will maintain most of its original horizontal momentum which was produced by the wind at the lower level. As a consequence the cumulus forms an obstacle to the surrounding air giving rise to a wave-like flow with very smooth—but weak—updrafts on the windward side of the cumulus (Kuettner, 1972). Soaring pilots can climb in this wave outside the cloud to levels well above its top. A vertical wind shear of more than 3 m/s per 1000 m (approximately 10 kts/5000 ft) without substantial change of the wind direction is required to produce this phenomenon with sufficient intensity to be utilized by sailplane pilots (Figure 4.1).

4.1.2 CLOUD-STREET WAVES

The conditions for the formation of cloud streets are described in section 2.3.4. For cloud-street waves to occur the vertical shear must be such that the wind component normal to the cloud-street axis exceeds 3 m/s per 1000 m both below and above the inversion. The cloud-streets then act in the same way as periodic mountain ranges, and the sailplane pilot can 'slope soar' on and above their upwind side (Figure 4.2; Jaekisch, 1968 and 1972).

4.2 SYNOPTIC AND UPPER AIR FEATURES

Thermal waves exist more frequently than glider pilots think because the shear values mentioned above are quite common. Actually the observed shear values connected with thermal waves can be much higher and sometimes reach 10 m/s per km. A typical synoptic situation favouring thermal waves is shown in Figure 4.3 (a) and (b). Here the area in which thermal waves occur (Kansas, USA) lies in a postfrontal ridge with subsidence and northerly low-level flow along anticyclonically curved isobars, while the WNW flow aloft is cyclonic, increasing strongly with

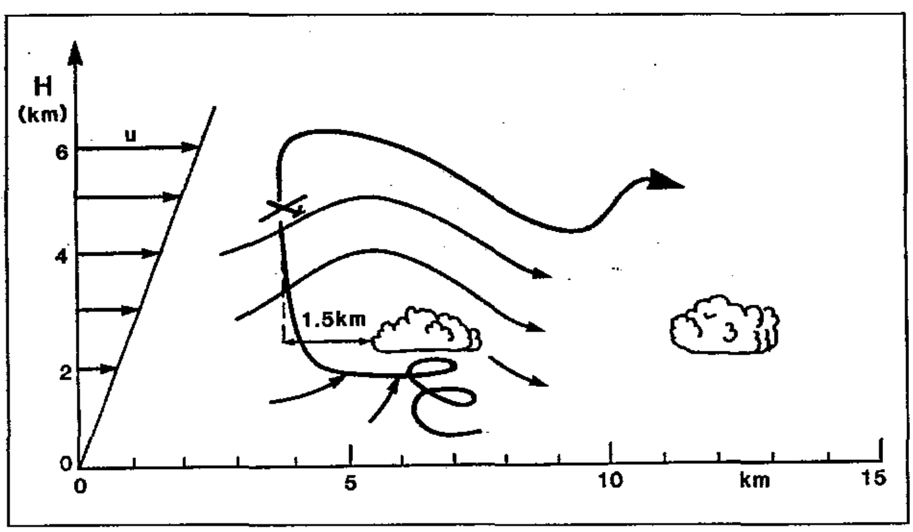


Figure 4.1
Model of cumulus wave. The required vertical wind profile is shown on the left.

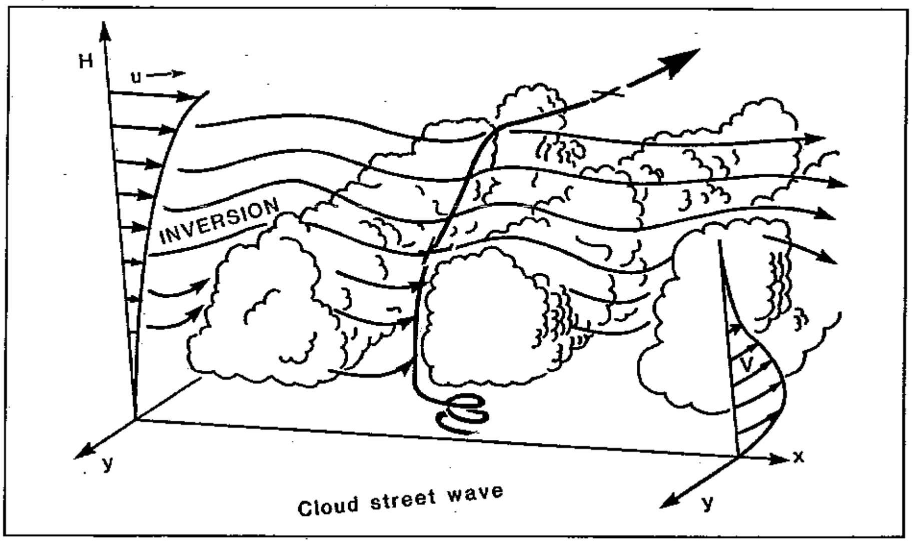


Figure 4.2
Wave above convection streets. The necessary wind conditions are shown by the wind profiles in the perpendicular directions of the lower and upper flow.

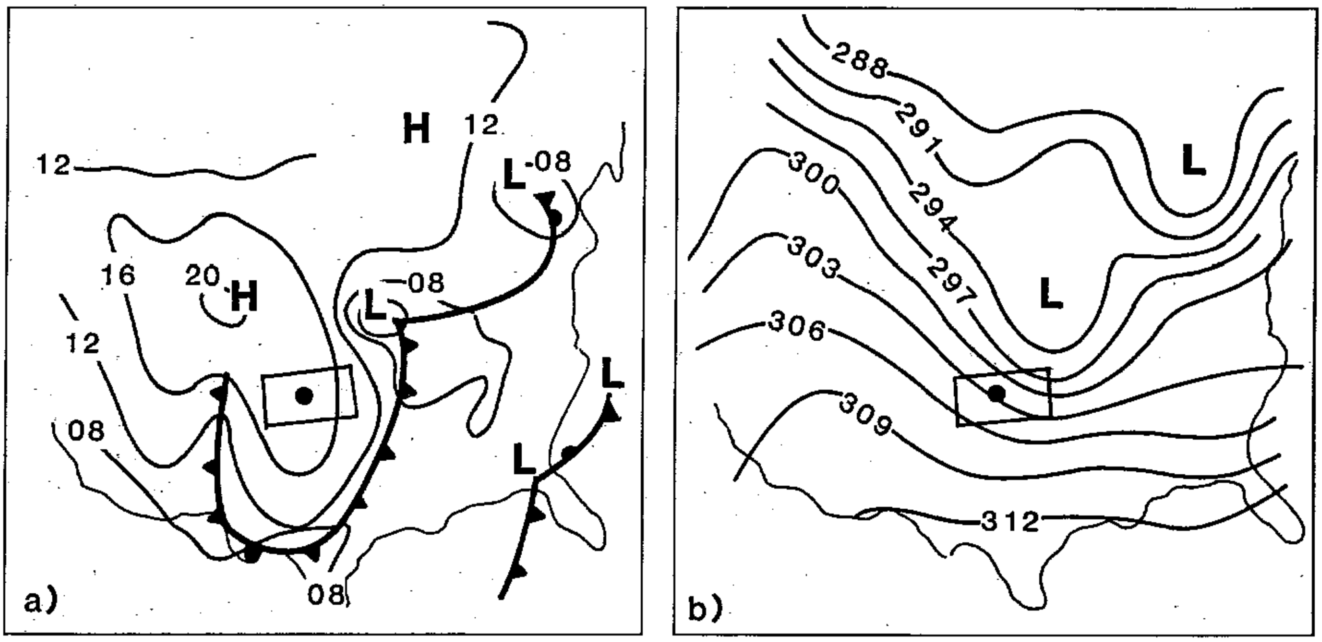
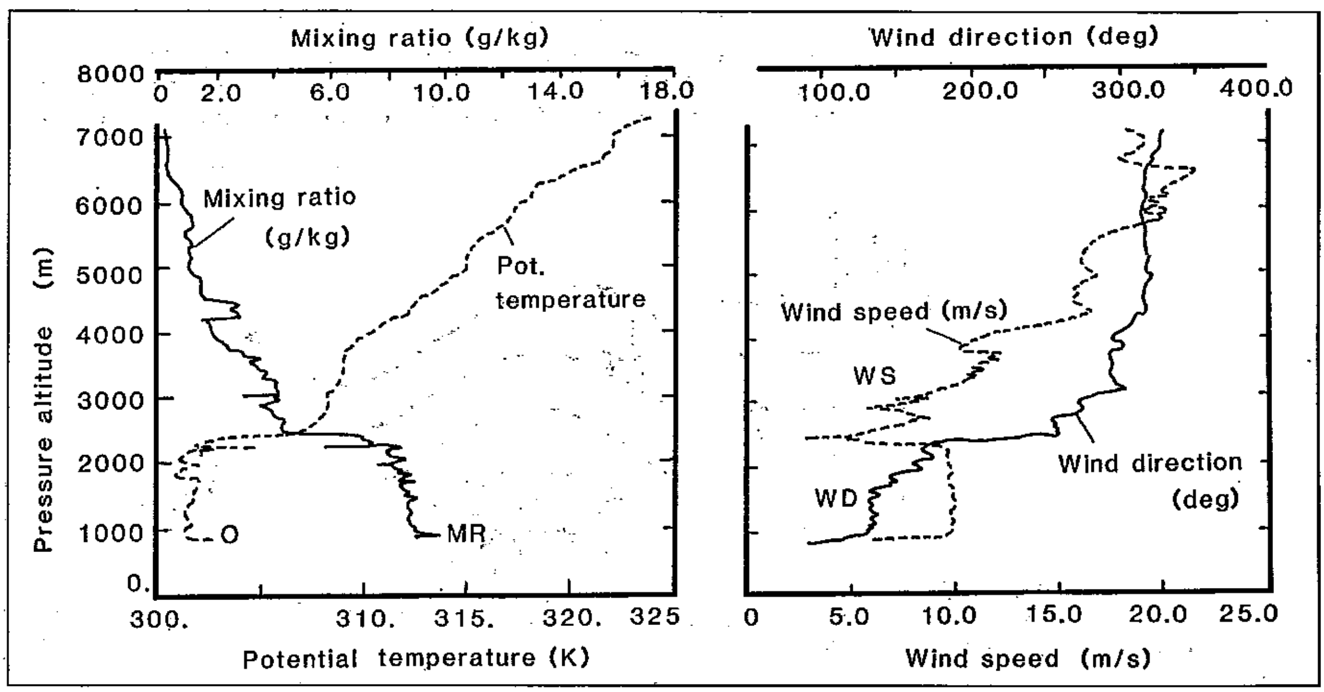


Figure 4.3 *(below)*
Weather maps for thermal waves over Kansas (outlined), USA, during flight missions with NCAR research aircrafts. (a) Surface map 27 April 1988 00 UTC; (b) 700 hPa contour map.



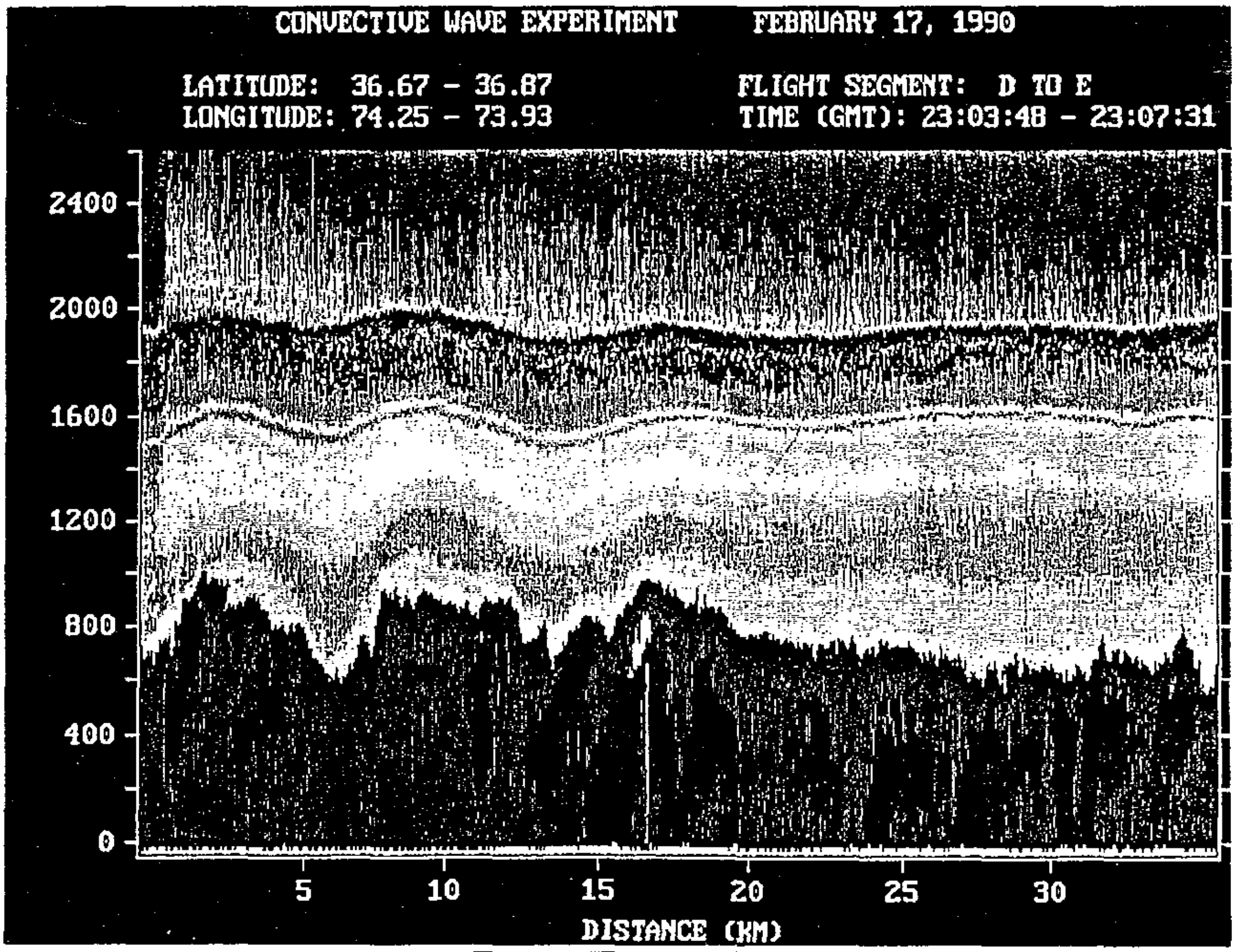


Figure 4.5
Thermal waves over convective boundary layer (dark lower layer) as seen in clear air by Lidar from NASA Electra aircraft.

height on the rearside of an upper trough. This weather situation provides an inversion on top of the convective boundary layer flow and a strong zonal shear (about 10 m/s per km). While these are favorable conditions for the development of thermal waves, the strongly increasing winds have a negative effect on the vertical extension of the waves similar to the 'trapping' of mountain waves discussed in chapter 3, i.e. the waves may exist only in the lower half of the troposphere.

The required upper-air profiles usually show an adiabatic boundary layer (the potential temperature is constant) capped by a sharp inversion with very dry, stable air aloft. This is why clouds seldom form in thermal waves. The wind profile for cumulus waves must contain the aforementioned vertical shear values of about 3 to 10 m/s per 1000 m in the layer below and above the inversion.

Figure 4.4 shows a typical sounding taken in an experimental area where convection waves were observed. A sharp increase of the potential temperature and a sharp decrease of the mixing ratio at the inversion can be seen. Characteristically for cloud-street waves, the change of windspeed and wind direction near the inversion is also seen.

4.3 THE STRUCTURE OF THERMAL WAVES

Figure 4.4 (left)
Vertical sounding of potential temperature, mixing ratio, wind direction and wind speed as a function of pressure altitude obtained from NCAR Sabreliner aircraft in an area of convection waves observed near North Platte, Nebraska, USA, 20 May 1986.

Thermal waves are weaker than mountain waves. Their updrafts range typically from 1 to 3 m/s, their wavelengths from 4 to 15 km (average 9 km). Like mountain lee waves, thermal waves occur both in a high reaching mode and a 'trapped' mode. In the first case they may exist throughout the troposphere to 9 or 10 km. More frequently they are trapped beneath 5 km, depending on the vertical windshear.

Figure 4.5 shows a wave field as seen by a downlooking Lidar. The top of the (dark) convective layer at the bottom of the picture shows the vertical displacements of the inversion by convection which induce the wave motion aloft. The wind in the boundary layer is from the North (out of the picture, towards the reader), the wind in the upper layer is from the West (from left to right). The wavelength is about 7 km and vertical motions of ± 2 m/s were observed by the research aircraft.

4.4 FLIGHT TECHNIQUE

To enter the wave, the glider pilot has to overcome some difficulties. The aircraft has to penetrate from under the cloud base against the prevailing wind to reach the wave updraft at the upwind side of the cloud (Figure 4.1). It is important that the pilot continue the penetration for 1 or 2 km beyond the cloud where the maximum lift occurs. Staying at some distance upwind of the cloud a sailplane may climb against the wind in smooth lift to heights considerably above cloud tops. It can then be flown downwind from cloud to cloud using dolphin techniques as indicated in Figure 4.1. It is easier to find the way into the wave from the top of a cloudless thermal or if coming from above (as during a high-altitude lee wave flight) and to continue a cross-country flight after convection dies out, because thermal waves are known to exist for at least two hours after convection ceases.

In cloud street waves (Figure 4.2) the glider pilot may fly crosswind along and above the streets at high speed without circling. It is equally possible to fly downwind, hopping from one street to the next. Both techniques can be used to extend a cross-country flight. The weather forecaster should call attention to these possibilities.

CHAPTER 5

FORECASTING FOR SLOPE SOARING

Slope soaring is the oldest form of soaring. Pilots soared over windward facing slopes in 1920, six years before thermals were discovered. Slope soaring means the utilization of updrafts which exist at the windward slope of hills or mountains. The updraft results from the deflection of the flow by the obstacle (see Figure 5.1 (a)). Slope updrafts from slopes facing the sun can intensify thermal convection. Pilots still use the updrafts at mountain slopes to soar long distances. An out and return flight of 1633 km has been carried out almost entirely in slopelift (Karl Striedieck, U.S.A., along the Allegheny Mountains, see Chapter 8). At many sites a slope is the main source of updraft for local training.

5.1 WIND CONDITION FOR SLOPE SOARING

For sailplane soaring, the wind speed should be within a range of 15 to 40 kt, blowing from the base to the top of the slope. For hang glider soaring and in exceptional cases for sailplanes, lighter winds may be adequate. The wind estimated from synoptic charts should be at right-angles to the ridge, but a variation of as much as 40 degrees may occur before the slopes cease to be soarable. An increase of wind usually enables the soaring pilot to soar higher above and farther out from slopes. The vertical extent of soarable slope updraft is seldom more than 500 metres (1600 ft) above mountain crests, unless other sources of updraft (thermals or waves) exist in addition. Long-distance flights along mountain ridges are unlikely without thermals or waves to help crossing mountain gaps. Above a certain speed, which depends on the roughness of the slope and the stability of the air, the flow becomes turbulent and a further increase in wind speed does not help pilots to climb higher. Special attention should be paid to the development of vortices (see Figure 5.1 (b),(c)). A different type of slope updraft (Figure 5.1 (d)) at lee slopes may occur as a part of a lee vortex. This is dangerous to fly.

5.2 EFFECT OF STABILITY VARIATION

When the air is unstable, thermals may form and break away from the slopes. This causes marked variation in the updraft. Neutral stability usually gives the best conditions. Very stable air may get blocked and stagnate or may flow parallel to the slope instead of upwards.

5.3 SHAPE OF SLOPE

The angle of the slope should be between 20 and 45 degrees with a smooth profile (Figure 5.1 (a)). As the surface of the slope becomes rougher, small eddies develop, causing turbulence. As the angle steepens, the band of updrafts becomes narrower, and sometimes a vortex forms (Figure 5.1 (b)). Slopes steeper than 60 degrees may be difficult to soar.

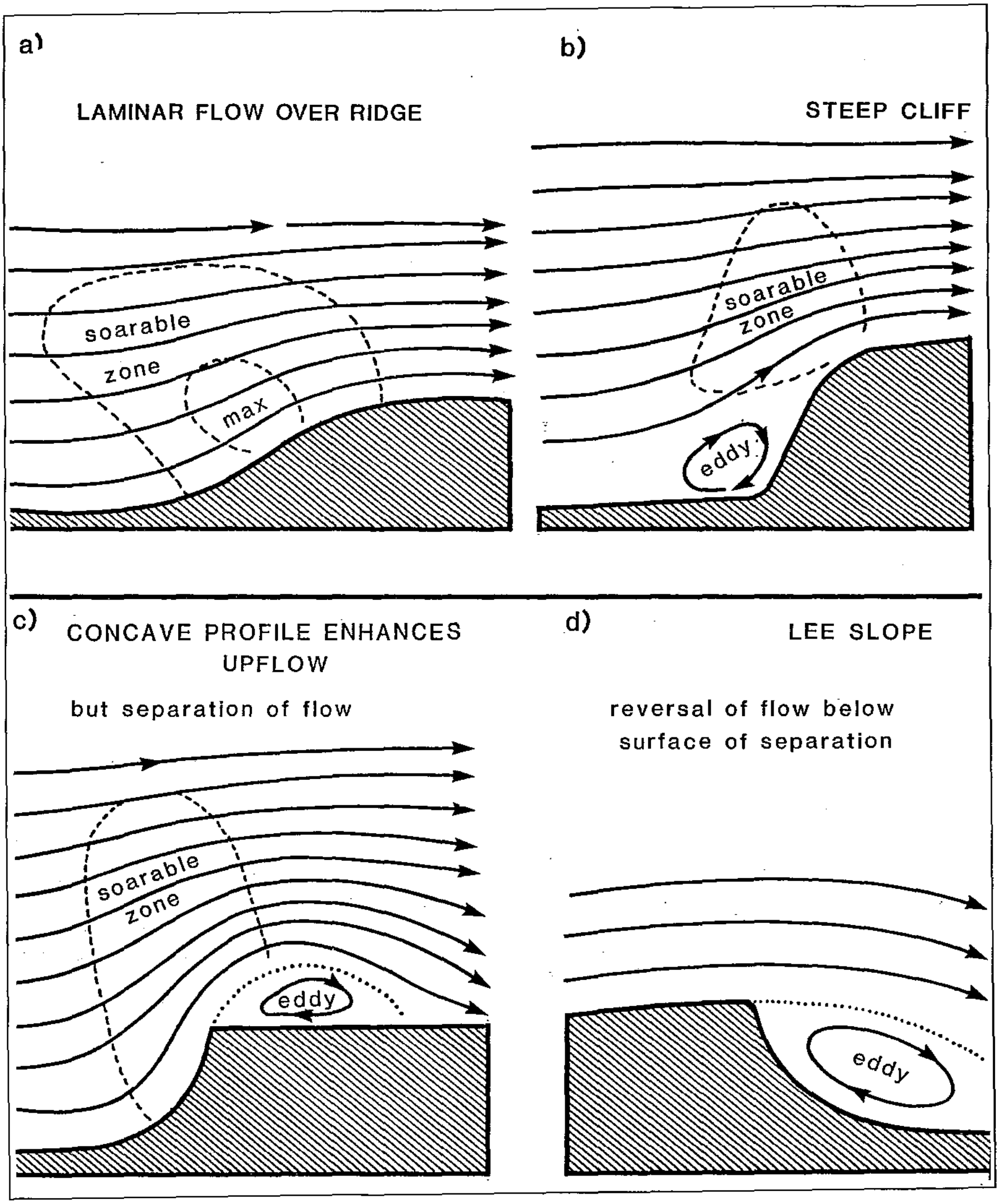


Figure 5.1
Schematic view on the flow field above a hill

CHAPTER 6

ADDITIONAL TOOLS FOR FORECASTING

6.1 NUMERICAL METHODS

6.1.1 NUMERICAL WEATHER PREDICTION

Over the last three decades, numerical weather simulation has become the most powerful tool of synoptic weather forecasting. Numerical models and post-processing of model output show considerable differences from country to country with respect to physics, numerical structure, and spatial resolution. Therefore only a general guideline and outlook can be presented here.

Numerical forecasting has now reached a stage where global models are run by international forecast-centres, such as the European Centre for Medium-Range Weather Forecasting, and by a few major national weather services. These models have a typical spatial resolution of about 100 to 200 km horizontally, and 500 to 1000 m vertically. The forecasts range upto 6 to 10 days. Manifold prognostic fields are sent in digital form to minor national centres or sub-centres via fast data lines. They use these data as boundary or initial conditions to run nested limited-area models covering the area of interest on a regional scale, e.g. Europe. Nested models have a typical resolution of about 25 to 50 km horizontally and 100 to 500 m vertically. They support the regional scale weather forecast on a time scale of up to three days. Again, the model output of limited-area models can be used as initial or boundary conditions in order to run high-resolution mesoscale models (resolution 2 to 20 km horizontally and 10 to 100 m vertically) for local and regional short-range forecasts.

In the future mesoscale models will become more and more operational. Models with a vertical resolution of less than 100 m will enable the prognosis of vertical profiles of temperature, humidity, and wind with sufficient accuracy to be used for the determination of thermal activities by conventional methods or with one-dimensional convection models. This is most easily done if the national weather centers provide forecast profiles in digital format.

6.1.2 ON-SITE USE OF PERSONAL COMPUTERS

The availability of low-cost high-performance personal computers opens the possibility of using numerical evaluations and simulations for the prediction of soaring weather. Computers are now transportable enough to use during competitions even at remote air fields. They are most effective if a direct data link to a numerical forecasting centre is available.

Input data which have to be available are one or several vertical soundings representative for the area of interest. The soundings should either be measured (at an optimal time as recommended in section 2.1.2.1) or synthetically produced by a numerical model. In addition, information about the local topography, especially the terrain elevation, the shape of terrain (flat, hilly, mountainous), and the actual state of the earth's surface (wet, dry, state of albedo) is required. Also the coverage of non-convective clouds (As, Ac, Ci) has to be known to consider the effect of screening solar radiation.

In the case of measured morning-hour soundings, the manual evaluation procedure described in Chapter 2 can be employed to estimate the modification of the representative soundings by the daily heating and possibly by large scale advection. Personal computers may already serve as helpful tools for this purpose, since the manual method of evaluating soundings and determining the rate of heating can be substituted by computer programmes. Computer-aided evaluation schemes have been described by Heimann (1983) and Friedrich (1987). Using personal computers helps to avoid time-consuming graphic constructions and increases accuracy.

Prediction of local thermal activity can be improved by using a numerical dynamic convection model. Simplified one-dimensional models, which can be run on ordinary personal computers have been introduced by Ogura and Takahashi (1971) and Nelson (1979). Local vertical profiles of temperature and humidity are needed as input data. These represent the ambient air of thermals for different times of the day and different locations within the competition area. The model uses these data as boundary conditions. The data can be taken either from a numerical weather forecast model, or from an evaluation scheme as described above. The advantage of a numerical simulation is the consideration of additional effects, which cannot be taken into account by manual methods or have to be estimated quite roughly. These are the effects of buoyancy, friction, lateral entrainment, inertia, and latent heat exchange. The model provides vertical profiles of mean thermal lift velocity, and the height of cumulus cloud base and tops for all day times and locations of the model region. In addition, the model indicates over-developments (cumulonimbus) and spreading out (strato-cumulus).

The use of computer-aided evaluation and simulation depends greatly on the available equipment (capacity and speed of personal computers) and the possible data access. It also requires forecasters who are trained in using numerical methods. The software has to be adapted to the particular equipment, to the data input and output facilities, and also to the requirements of actual sporting events. Possible realizations of computer-aided evaluation and forecasting schemes are given by Heimann (1983 and 1986) and Friedrich (1987). Both include numerical one-dimensional simulation models of thermals and cumulus convection.

6.2 SATELLITE IMAGES

Receiving facilities for weather satellite images are now available at a great number of airfields in some countries and have become an important tool for briefings of glider competitions.

Most of the facilities are cheaper and simpler than those usually available at National Meteorological Service centres for the reception of high-resolution images.

If high resolution images are not available, satellite images are transmitted in the so-called APT (analog picture transmission) or WEFAX (weather facsimile) mode. Small isolated clouds or small gaps in a cloud cover cannot be seen in those images. For example, it is impossible to detect small cumulus clouds during the initial state of convection.

APT images from polar orbiting satellites (such as the NOAA satellites) have a horizontal resolution of 1 km at best, while geostationary satellites (like METEOSAT) infrared images (WEFAX) have a resolution of about 30 km.

The spatial resolution of images from geostationary satellites decreases considerably with increasing distance from the sub-satellite-point (SSP). For example, at 50 degrees latitude from the SSP the resolution decays by a factor 2. The great advantage of images from satellites in geostationary orbit is their availability every 30 minutes. With the presently-available system of two polar orbiting satellites, successive images from the same part of the earth can be provided about every 6 hours.

6.2.1 Hints for interpreting visible channel (VIS) images

VIS images are available only during daylight periods. Their resolution from geostationary satellites is better than that of IR images. Images from the visible channels are most suitable for detecting clouds. A bright or white area is either cloud or a snow- or ice-covered surface. It is mostly very difficult to distinguish clouds from snow. One way to distinguish is with an animation loop: clouds are usually moving whereas a snow-covered surface is fixed.

If some parts of a uniform area at the earth's surface appear darker in VIS images than other parts, we can conclude that the surface at the darker part is wetter.

Ice-clouds appear darker than a snow-covered surface. The albedo of deserts can be higher than that of cumulus clouds, so that some ice-clouds can hardly be recognized in VIS images.

6.2.2 Hints for interpreting infrared (IR) images

IR images are available during the whole day. They may cause a misleading interpretation, if no additional weather information is available.

IR images provide information about cloud top temperatures and hence on cloud top heights. Under cloudless conditions they provide information on surface temperatures. If no special enhancement is applied to IR images, the brighter clouds appear in satellite images the colder they are. Cloud features and cloud top temperatures are revealed in detail more and more precisely if IR images are converted to a colour display.

It is very difficult, sometimes impossible, to detect fog or low stratus in IR images, especially during the night. The temperatures of such clouds are often similar to surface temperatures of a bordering landscape. It is very important to be aware of this problem, as first selections of the area where gliders will fly during a competition are done at times when only IR images are available.

Notice should be taken of so-called split fronts. The first part of such a cold front system appears significantly bright in satellite images. This cloud system is followed by a wide band of low-level clouds which can hardly be seen in IR images. These low-level clouds are being overrun by cold air aloft, whereas the cold front at the surface is located at the rear of these low-level clouds.

Cirrus clouds can be easily observed in IR images as they are very cold. Sometimes cirrus clouds can appear so significant that one can be mislead into thinking that there is bad weather below, especially if no other information is available. In fact, however, solar radiation can penetrate through the cirrus clouds and acceptable soaring conditions may develop. Some information on the thickness of cirrus clouds can be revealed by comparison with VIS images, if they are available. Thin cirrus layers can hardly be seen in VIS images.

6.3 WEATHER RADAR

Weather radar is an excellent tool for nowcasting precipitation systems. Radar pictures show the reflectivity or the estimated precipitation rate of those systems. With a frequent image update (10 to 30 minutes) movement and change of intensity can be observed. If the radar is equipped with Doppler capabilities, additional information on the wind field is available.

Radar information can be obtained by a local weather radar or from a nationwide or international network. Local weather radars have a range of about 200 to 300 km. It is very common to overlay the radar image with a satellite image, as the radar shows only precipitating systems. Shallow showers far away from the radar are not observed due to the curvature of the earth surface. With a high powered or short- wavelength local radar it is also possible to receive the reflectivity of the convective boundary layer and cumulus clouds up to about 100 km. In this case convective cells, cloud rolls, or convection associated with gust fronts can be observed. With a Doppler radar, convergence lines can be located prior to cloud development.

Radar data can be used for the nowcasting of showers, thunderstorms, and fronts. It can show whether thunderstorms or showers are isolated, clustered, or aligned along a squall line. From their movement the forecaster can extrapolate at what time they will approach into the area of flight or the airfield. This information should be used to issue warnings to pilots and their crews (see section 7.3).

CHAPTER 7

PREPARATION AND PRESENTATION OF SOARING FORECASTS

7.1 PREPARATION OF SOARING FORECASTS

7.1.1 OBJECTIVES AND SUITABLE TOOLS

Successful forecasting depends on detailed analysis concentrated upon a relatively small area over which soaring is intended. The necessary work consists mainly of two parts: (a) synoptic analysis, diagnosis and prognosis and (b) interpretation of the representative vertical sounding(s). Here we will address the synoptic part of the work as the latter part has been described in detail in chapter 2.

First of all the forecaster should understand the synoptic situation. Then it is possible to select the proper sounding(s) and to assess the impact of horizontal advection of temperature and/or humidity and large-scale vertical motion on soaring conditions.

The forecaster needs a reliable framework of analysis and prognostic charts for surface and upper levels, into which he can fit his more detailed picture. It is advisable to rely on the charts issued by major meteorological centres. Standard issues will contain the major synoptic features. The more detailed analysis on a smaller scale which is actually needed for soaring purposes has to be carried out on charts of a scale of about one in two million or one in three million (see Figures 7.1 and 7.2). Usually

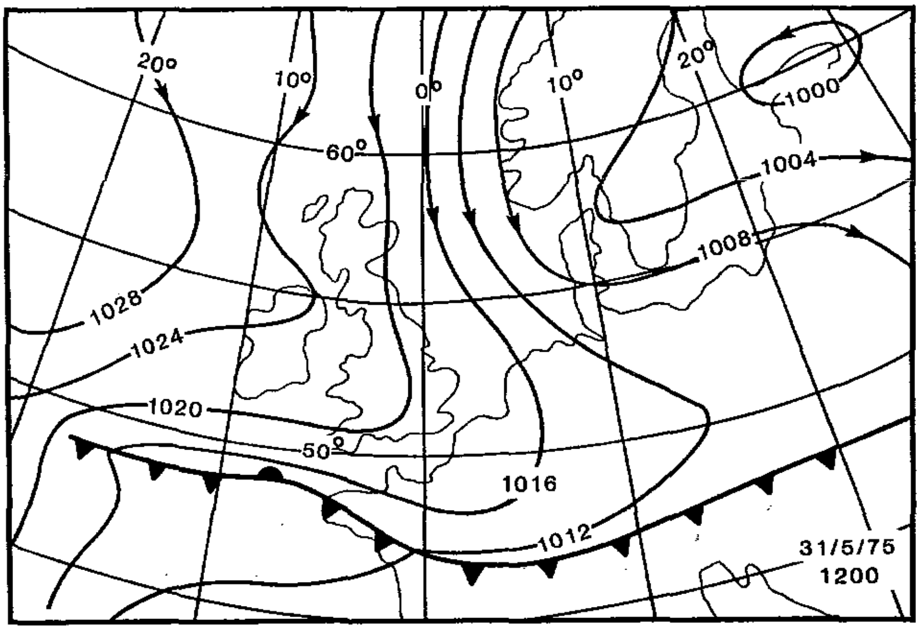


Figure 7.1
Standard issue of a surface weather chart

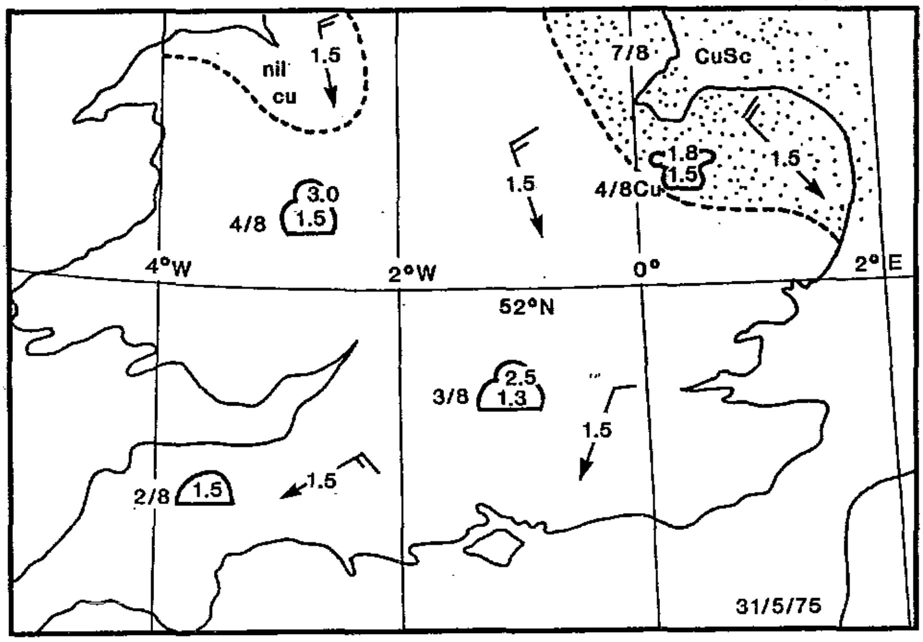


Figure 7.2
Simplified chart for soaring forecast. For symbols used see Figure 7.7.

the main centres will be able to supply the forecaster with a number of special charts, covering items such as divergence, vorticity, temperature and vorticity advection, vertical motion, convection indices, humidity, trajectory and precipitation, which may be very useful.

Aerological diagrams used by most meteorological services are adequate for soaring forecasts. The tephigram is well suited to soaring requirements (see section 2.1). An enlarged version of such diagrams showing the lower layers of the atmosphere in detail enables the forecaster to draw lines representing changes due to insolation without obliterating the shape of the original sounding.

If available, a personal computer and suitable software will successfully perform analytic and prognostic work (see section 6.1).

7.1.2 ROUTINE WORK

A successful interpretation of the available vertical sounding(s) needs a good understanding of the prevailing synoptic situation. Temperature and humidity fields are of special interest because of their considerable impact on soaring conditions (recall the contents of chapter 2.). A tried and tested procedure to handle the synoptic part of the soaring forecast is suggested in the following (if necessary the forecaster is recommended to adjust the following suggestions to his own requirements):

(i) Charts

Obtain the latest analysis and prognostic charts (surface and upper-level charts).

Analyses are needed of:

Surface chart

- pressure field, pressure centres and their movement;
- associated wind field;
- frontal zones, convergence lines and their movement;
- dew-point analysis.

Upper-level charts:

- geopotential field, centres, troughs and ridges;
- wind, temperature and humidity fields;
- horizontal advection of temperature and humidity.

Remark: The technique of superimposing upper-air and surface charts may assist the forecaster to grasp the major features dominating the situation.

(ii) Construction

Use the relevant charts to construct surface and upper-level contour charts showing the synoptic situation to be expected at or soon after the time of local noon.

Remark: If such charts are not already issued routinely try to interpolate between the analysed and prognostic charts.

(iii) Analysis

Draw a detailed analysis using the latest available data plotted on a chart large enough for mesoscale features to be detected (see Fig. 7.3).

What should be analysed are

- the features already mentioned in (i) above;
- surface chart:
  - isopleths of dew-point;
  - significant weather such as rain bands, boundaries of significant cloud systems, areas of poor visibility etc.

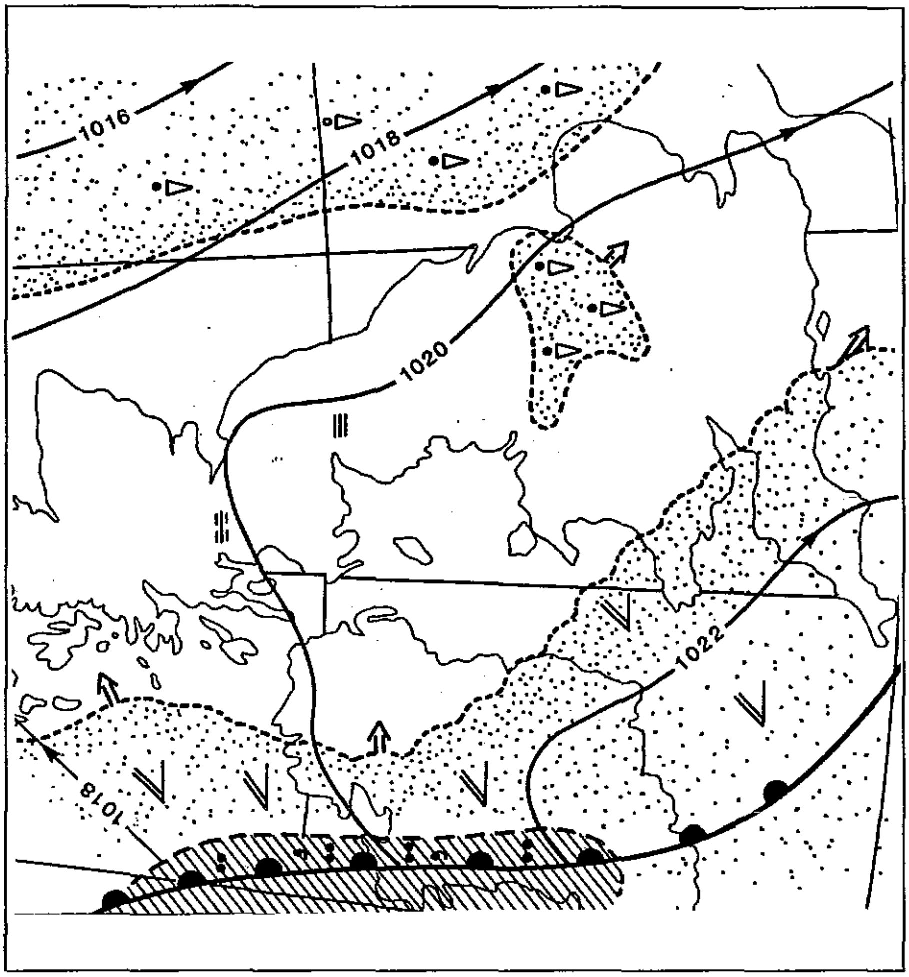
Remark: Such a chart should be of a scale of at least one in two million or one in three million. When available for that time, analyse upper-air charts.

(iv) Forecast

Use the analysed chart (iii) to transfer the significant weather features (in a diagrammatic representation) to the prognostic chart (ii).

Remarks: Complete the chart (ii) using all additional information you can get and absorb (latest satellite pictures, own (ground or airborne) measurements and observations, possibly facsimile reproductions of radar observations, TAFs and METARs, etc.). If the completed chart is used for briefing purposes, pilots can visualize the situation more easily when weather features are shaded in. This prognostic chart should then have a diagrammatic representation of important weather features as well as the standard isobaric pattern.

Figure 7.3
Cloud weather analysis. For symbols used see Figure 7.7.



7.1.3 Further remarks and hints

7.1.3.1 Low level contour charts

In regions such as Europe and North America, where there is a comprehensive network of radiosonde stations, a low-level contour chart is valuable (see Figure 7.4). Where the general level of the terrain is below 500 m, the 850 hPa chart is generally the best layer to study. In higher regions the 700 hPa level may be more important. The choice should be governed by the approximate level where cross-country sailplanes will be likely to fly. For good results the forecaster should construct his own 850 hPa or 700 hPa chart using Part A messages from radiosonde stations. Low-level contour charts issued by main meteorological centres are often derived from computer analyses which smooth out minor irregularities which are important to soaring. The following details are useful:

- Wind direction and velocity plotted as standard arrows;
- Height of the pressure level in metres;
- Height of the 1000 hPa surface in metres;
- The thickness of the layer from 1000 hPa to the upper level chosen;
- The temperature at the standard level chosen, together with isotherms;
- The dewpoint depression (below the dry-bulb temperature);
- The wetbulb potential temperature.

7.1.3.2 Personal computer (PC) with suitable software

At this stage a PC with suitable software will be very useful (see section 6.1). Cross-sections displaying temperature and humidity fields, horizontal fields of calculated stability indices or the interpretation of vertical soundings will successfully support analytic and prognostic work.

7.1.3.3 Additional charts

Additional charts from the meteorological service should be used to complete the detailed picture of the synoptic situation. Special charts displaying (potential) vorticity, advection, vertical velocity, divergence, humidity at certain levels, thickness, trajectories and precipitation may be very helpful.

(i) Precipitation

Charts showing the precipitation over the preceding 24 hours, are important when considering soil moisture and the effect on thermal activity.

(ii) Isochrone charts

Maintaining a chart showing isochrones of the position of centres, fronts or important weather features such as the boundaries of precipitation or cloud masses is a helpful tool when the situation shows mobility. Known positions can be marked in firm inked lines. Predicted positions are sketched more lightly. A series of isochrones showing the leading edge of thick frontal cloud at three or six-shourly intervals is useful when making a forecast. It also gives the forecaster an opportunity to amend his timing if subsequent reports show that the movement differs from the predicted rate.

(ii) Trajectory charts

Charts showing the backward trajectories of the air approaching the forecast area can be very useful in deciding which soundings are most representative. The trajectories should be computed for a level within the convective layer. These backward trajectories show the track of the air towards the flying area, if advection is the dominant factor. Forward trajectories, on the other hand, are a useful tool in assisting long distance flights of gas balloons.

In a situation when there has been little movement of air, the small changes between the charts for the previous day and the present day can help the forecaster. It is rare for situations to be identical on two successive days and the forecaster should be helped to detect the small but important changes which may effect soaring conditions.

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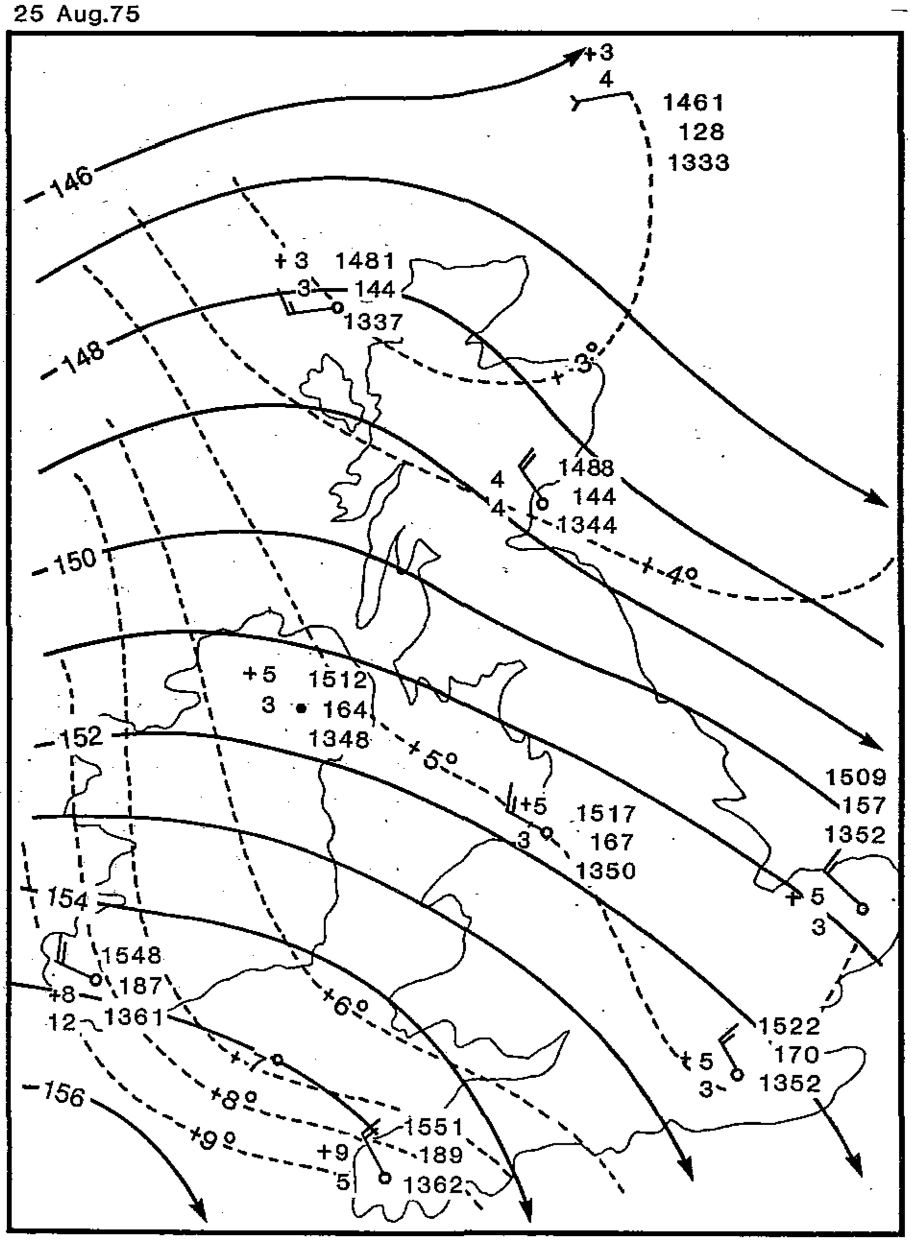


Figure 7.4

Detailed analysis of upper-air chart. Solid lines are 850 hPa heights (gpdm), dashed lines are isotherms. Numbers to the left of the station indicate temperature and dew-point depression, numbers on the right side are: height of 850 hPa level, height of 1000 hPa level and thickness of the layer between the 1000 and 850 hPa level

7.2 PRESENTATION OF SOARING FORECASTS

7.2.1 Daily routine forecasts

In some countries daily routine soaring forecasts are made and recorded on the automatic telephone-answering system and broadcast on some radio stations. The weather services of many countries provide weather forecasts for general aviation on the automatic telephone-answering system or telefax. For a daily forecast for soaring the use of specially-designed forms is recommended.

7.2.1.1 Forecast form for soaring

An example of a form designed specifically for soaring is shown in Figure 7.5. Most of the form is self-evident. It is important that changes expected during the day or the development of showers are announced in the synoptic summary. Warnings are given in the case of expected development of dangerous conditions such as hail, thunderstorm or strong gusts, rotors and other significant turbulence that may cause damage. In the section of thermal activity three columns have to be filled. 'When first formed' describes the conditions when cumulus first appear. At this time the cloud base may be too low for soaring or the strength and distribution of thermals too poor for cross-country flight. 'At.........hours' should indicate that thermals are strong enough and extend high enough for good soaring. This level will be at least 600 m but, in agreement with users, another level may be chosen. 'Character of thermals' should mention details such as the development of lines of thermals, (cloud streets), distortion of thermals by wind shear or modification of thermals by wave flow. 'Special phenomena' could include items of interest such as slope and wave soaring, thermal waves, sea breezes or other convergence lines.

Obscuration of the ground due to closing cloud gaps (also called wave slots or windows) and lowering of the cloud base also have to be predicted on the form as conditions such as these may make it impossible to return to the airfield.

7.2.1.2 Forecast form for ballooning

An example of a form designed specifically for ballooning is shown in Fig. 7.6. An accurate wind profile should be measured at the take off area with a theodolite as close as possible before take off.

7.2.2 Forecasting for contests

After having studied the weather situation, the possibilities for different tasks have first to be discussed with the director of the contest or the task setter. After this meeting, when the task has been chosen, the maps to be displayed and the documentation for the pilots can be prepared. To overcome the language barrier at international contests it is desirable to employ symbols in the display and the documentation (Figure 7.7). Besides the ICAO symbols already used in civil aviation, a few additional symbols are suggested for phenomena of particular importance for soaring (example: Figure 7.9).

7.2.2.1 Symbols

Cloud symbols are the same as those internationally agreed upon. The symbols are drawn large enough to give space to enter the heights of base and top of clouds (generally in km). Thermals are represented by the letter T. The strength of thermals is shown by the number of vertical strokes. Thermal streets are shown by a series of small rings, representing the plan view of thermals, joined by a line to show the orientation of the streets. Thermal waves are represented by the symbol for thermal streets with a wavy line on top. A number in the shaft of wind arrows shows the height concerned. Weather regions are outlined and the area concerned is shaded as needed. Symbols inside this area denote the phenomenon (usually precipitation or thick cloud layers). An arrow showing direction of movement is added to indicate changes with time.

7.2.2.2 Documentation

Whenever there are copying facilities, available pilots should be supplied with a copy of a vertical cross section or a forecast illustrated with the symbols outlined in 7.2.2.1.

In the time-height cross-section (Figure 7.8) heights are marked on the left-hand side. The winds at each level are shown on the right-hand side of the diagram. The cross section represents the changes with time over the area of flight. The time is marked along the top of the diagram. At the foot of the diagram the temperatures are given at hourly intervals. A sloping double line

***Figure 7.5** (next page)*
Forecast form for soaring
***Figure 7.6** (following page)*
Forecast form for ballooning

Valid from: .... **to** ....
Area: ....
Synoptic summary: ....
....
....
Warnings: ....
....

WINDS AND TEMPERATURES

Height	**In the morning**	**Changes during the day**
... m		
... m		
... m		
Surface		
Visibility		

THERMAL ACTIVITY

Duration of soarable thermals	Starting at	with surface temp. of
	Ending at	Sunset at
	Intensity	

	When first formed	**at .... hours**	**maximum**
Top of dry thermals			
Amount of Cu clouds			
Base of Cu clouds			
Top of Cu clouds			
Other clouds			
Mean rates of climb			
Character of thermals			

Maximum Temperature:

Base of significant inversion or stable layer:

Height of 0°C isotherm:

QNH: Tendency:

Special phenomena:

Outlook:

Date/Time of origin:

Valid from: .... **to:** ....

Area: ....

Synoptic summary: ....

....

....

Warnings: ....

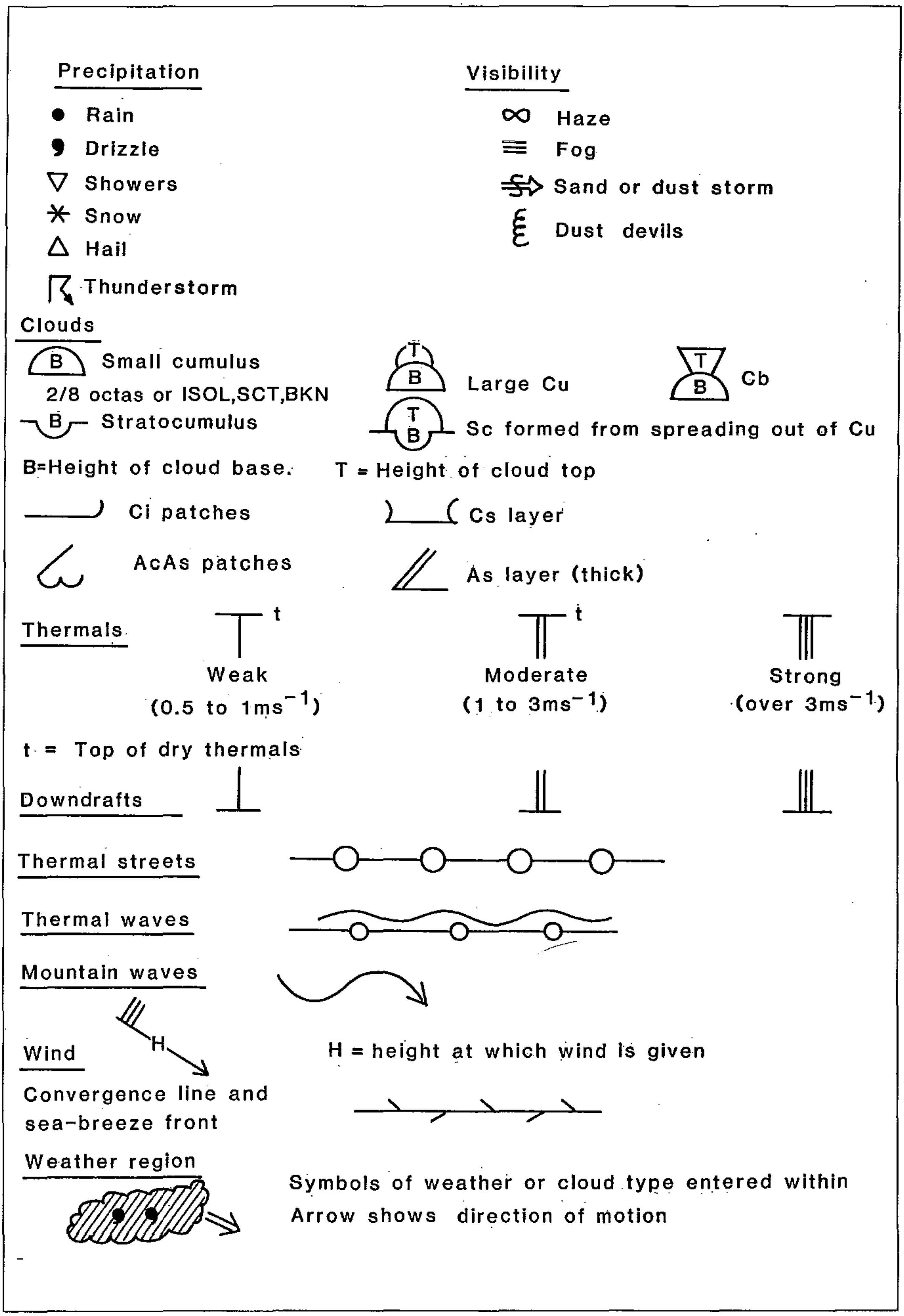
....

WINDS AND TEMPERATURES

Height	In the morning	Changes during the forecast period
Surface		
100 m		
200 m		
300 m		
400 m		
500 m		
m		
m		
m		
m		

CLOUDS AND OTHER WEATHER PHENOMENA

Amount of low cloud:	
Base of low cloud:	
Top of low cloud:	
Other clouds:	
Visibility:	
Significant weather:	
QNH:	Tendency:
Height of 0°C isotherm:	
Inversion:	
Special phenomena influencing ballooning:	
Is thermal activity expected ?	Start: End:
Outlook:	
Date/time of origin:	


Precipitation
Rain
Drizzle
Showers
Snow
Hail
Thunderstorm
Visibility
Haze
Fog
Sand or dust storm
Dust devils
Clouds
B
Small cumulus
2/8 octas or ISOL,SCT,BKN
B
Stratocumulus
T
B
Large Cu
T
B
Cb
T
B
Sc formed from spreading out of Cu
B=Height of cloud base.
T = Height of cloud top
Ci patches
Cs layer
AcAs patches
As layer (thick)
Thermals
t
Weak
(0.5 to 1ms⁻¹)
t
Moderate
(1 to 3ms⁻¹)
Strong
(over 3ms⁻¹)
t = Top of dry thermals
Downdrafts
Thermal streets
Thermal waves
Mountain waves
Wind
H
H = height at which wind is given
Convergence line and sea-breeze front
Weather region
Symbols of weather or cloud type entered within
Arrow shows direction of motion

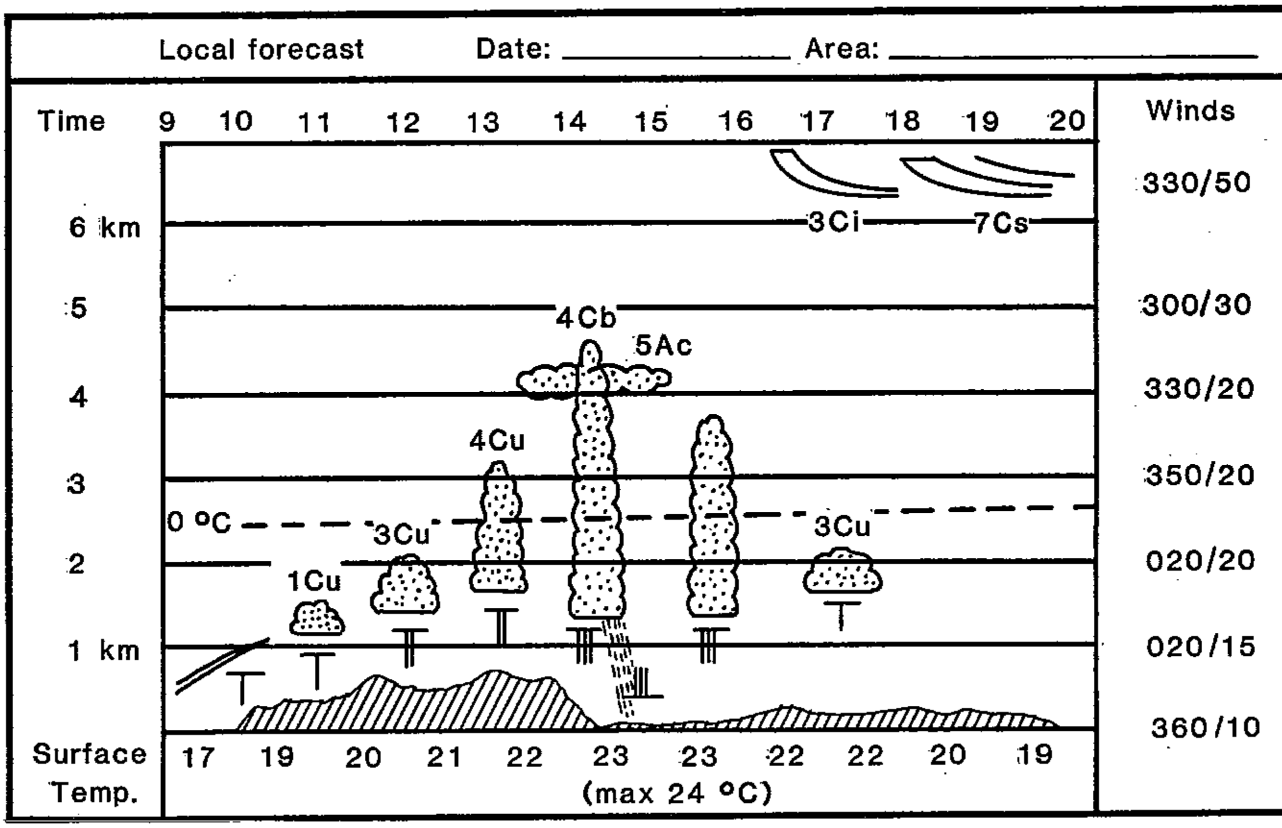


Figure 7.8
Vertical cross-section of convection development during the day.

represents the upper limit of cloudless thermals. Cumulus development is shown by pictures of cloud showing the vertical extent. The cloud cover is given as 4 Cu, indicating 4/8 cumulus. Showers are shown by sketching precipitation falling from cloud. Forecast winds refer to the mid-time of flight. This type of presentation should preferably be used for tasks with specified courses or in homogeneous weather situations regarding the area of contest. For flights with a specified course the elevation of the terrain might be sketched at the bottom of the diagram.

Forecast map (Figure 7.9): This map shows the weather in symbolic form. Clouds are drawn large enough to enter the height of base and tops. The wind is shown by arrows at different heights. A shaded area in the north-west corner of the map marks a zone where thick altocumulus expands and may reduce or even stop convection. When pilots are aware of spreading high cloud they can plan to circumnavigate this area or to complete the course earlier to avoid being brought down by a premature end of convection activity. This fixed time prognostic chart should be preferably used for pilots selected course tasks where indication of regional development should be given.

7.3 NOWCASTING FOR SOARING PURPOSES

Nowcasting can be used to forecast the optimum time of start during a contest and to issue weather hazard warnings. Different methods have to be applied and are available for very short range forecasting (2–12 hours). Nowcasting includes weather watch and weather observation by the means of the assimilation of all available information including satellite and weather radar pictures. A simple nowcasting procedure is the extrapolation of these data up to a time-scale of two hours.

7.3.1 Weather information for nowcasting

The current weather data of all available meteorological stations in the neighbourhood should be continously collected. Additionally, all data referring to aeronautical meteorology like METAR (meteorological aerodrome routine report), SIGMET (significant weather), and especially upper air soundings should be gathered.

Technical aids like radar and satellite information should be used if available. All data enable the forecaster to monitor the current weather and extrapolate it for the next two hours.

Figure 7.7
Briefing symbols.

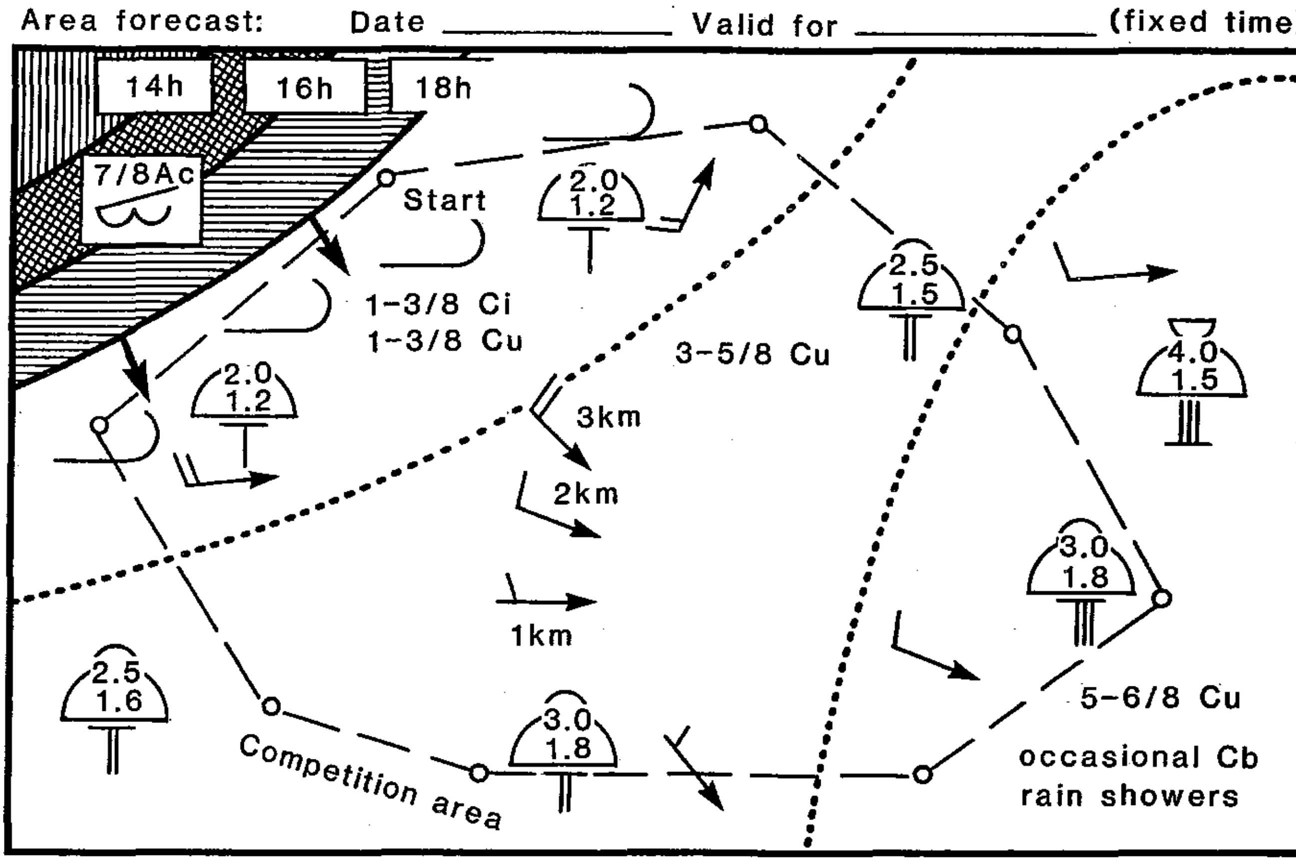


Figure 7.9
Fixed time forecast chart for a specified competition area.

All meteorological parameters must be checked for any indication of favourable events, e.g. onset of thermals, formation of cloud streets, approach of sea-breeze front, or atmospheric hazards, e.g. development or approach of thunderstorms or squall-lines, formation or advection of fog, spreading clouds in mountainous areas.

7.3.2 Real time weather hazard warning

Hazard alerts must be issued as soon as possible and at the latest twenty minutes prior to the hazardous event. Remember that the area of interest during a soaring contest can be large (300 to 500 km from the point of start). Warnings and information should be distributed to the crew and to the pilots by radio. If strong wind or hail is expected, warnings for ground operations are also necessary.

CHAPTER 8

EXAMPLES OF OUTSTANDING SOARING FLIGHTS

To give an overall impression of the extreme results achieved in long distance, high speed and high altitude soaring, this chapter outlines a few outstanding record flights most of which gained world records, some still valid although they date back several years. All the flights involved highly skilled pilots using the most suitable sailplanes for each type of record attempt and making the best use of unusually favourable weather conditions.

The following examples have been chosen as representative:

- Distance in a straight line (Hans W. Grosse, Germany), 25 April 1972, 1460 km;
- Out-and-return course (Karl Striedieck, USA), 19 May 1976, 1633 km;
- Polygon course (Ray Lynskey, New Zealand), 14 Dec. 1990, 2026 km;
- Triangular course (Hans W. Grosse and Hans-Heinrich Kohlmeier, Germany), 10 Jan. 1987, 1379 km;
- Altitude (Robert R. Harris, USA), 17 Feb. 1985, absolute altitude 14938 m.

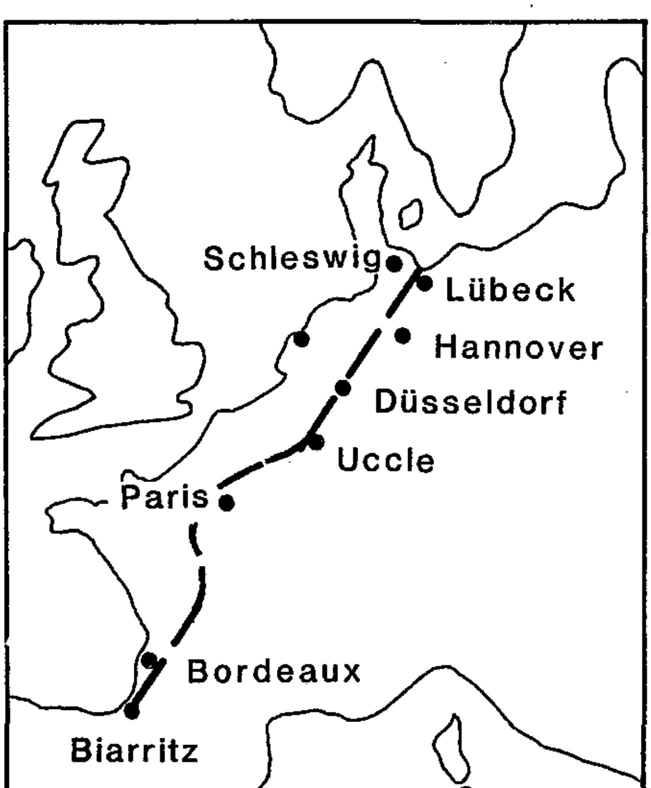
8.1 DISTANCE IN A STRAIGHT LINE

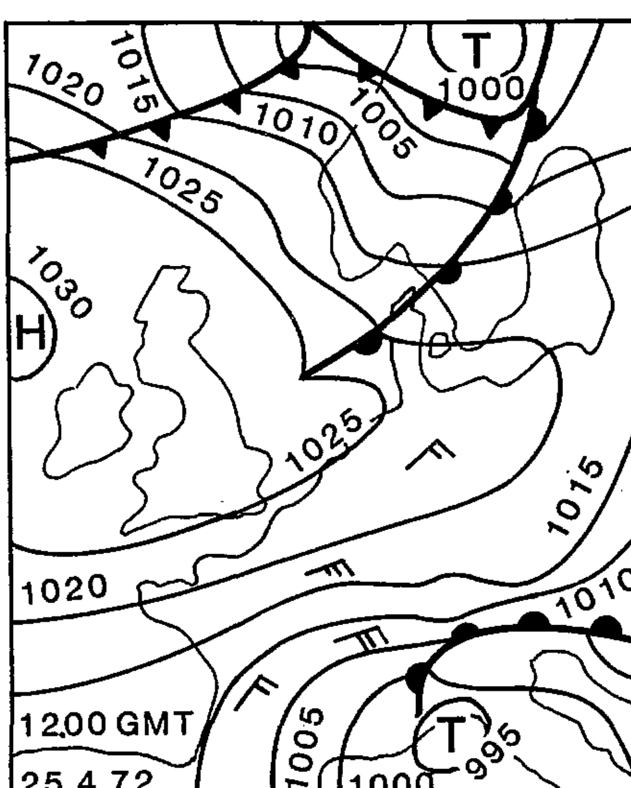
Flights along a straight line are the oldest record category in soaring. Starting with distances of a few hundred meters in the 1920's, the world record now stands at 1460.6 km set by Hans-Werner Grosse in 1972 (Figure 8.1.1). Briefly, his flight can be summarised as follows:

Date of flight:	25 April 1972
Pilot:	Hans Werner Grosse
Sailplane:	ASW 12
Take off:	Lübeck Airfield at 8.30 LT
Landing:	Biarritz Airfield at 20.23 LT
Distance:	1460.6 km
Average speed:	123 km/h

Figure 8.1.1 *(below)* *Free Distance world record flight of Hans Werner Grosse with 1460.6 km from Lübeck to Biarritz on 25 April 1972.*

Figure 8.1.2 *(right)* *Surface weather situation on 25 April 1972, 12.00 UTC*





8.1.1 WEATHER SITUATION

A cold air outflow from Scandinavia had entered northern Germany in a band about 800 km wide progressing over more than 1000 km in a south-westerly direction at about 10 kt (Figure 8.1.2). The dry air of this cold air outbreak was steadily moving along a line from the northern part of Germany through Belgium and France to the Pyrenees leading to nearly perfect conditions for the formation of convection along the whole route of the flight. Near dry adiabatic lapse rates with temperatures about 10° to 15° below April averages and a dew-point depression of about 10° led to frequent and strong updrafts in the convection layer which eventually grew to a depth of 2500 m.

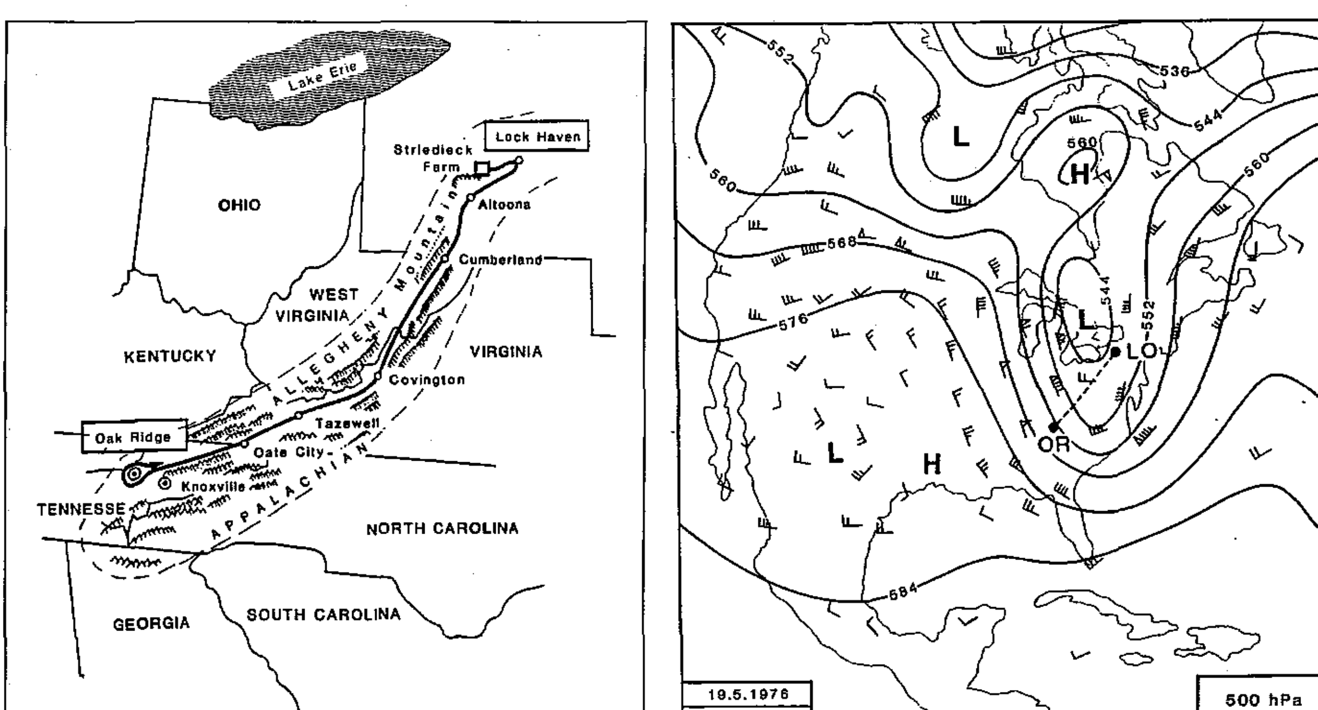
8.1.2 PILOT'S REPORT

"On the 23 and 24 April, a cold air outbreak from Scandinavia had led to showers over Belgium and France. During the night of April 24, drier air followed behind the initial body of cold and moist air. I decided to declare a flight to a goal in a straight line from Lübeck to Nantes (1150 km). On the morning of the 25th, the first small cumuli appeared as early as 8.30 LT at about 900 m producing lift of around 1 m/s for the first hour of my flight. A rapidly lifting cloud base and increasing tailwinds together with streeting made for easy progress. Over Belgium, I encountered a region with strong low level winds and less cumulus clouds. The strong turbulence connected with it made centring in thermals nearly impossible below about 800 m AGL. At about 16.00, I was on final glide to Nantes, my original record goal. I decided at that time to continue onward to beat the world record for a flight in a straight line which at that time stood at 1250 km. Leaving the area of strong tailwinds near Bordeaux, the thermals became more organized again and I twice reached about 2500 m under well developed cumuli. I arrived overhead Biarritz at 600 m and landed there at 20.23 LT after a flight of 1460.6 km."

8.2 OUT-AND-RETURN COURSE

Naturally, out-and-return records soon followed those for distance flight along a straight line. Of course, such flights have the advantage that sailplanes do not have to be brought back on the road or by an aerotow. Today's world record mark lies at a distance of 1645.6 km out and return. Distances of this magnitude can be achieved only by using strong continuous lift over almost the complete distance of flight. Such conditions are restricted to slope lift with upwind soaring conditions generated by strong and nearly constant airflow over extended areas perpendicular to long mountain ridges.

Figure 8.2.1
Out and Return flight pattern of Karl Striedieck's 1633 km flight along the mountain ranges of the Alleghenies and Appalachies on 19 May 1976.



The Allegheny and Appalachian Mountains are probably the most favourable mountain chains for performing outstanding flights of this type.

Date of flight:	19 May 1976
Pilot:	Karl Striedieck
Sailplane:	ASW 17
Take off:	Striedieck Farm (Eagle Field) at 05.35 LT
Landing:	Striedieck Farm (Eagle Field) at 19.00 LT
Distance:	1633 km (1015 miles)
Average speed:	122 km/h

8.2.1 Weather situation

A well-developed northwesterly flow directed southeastwards from the Great Lakes area between a meridional elongated low with its centre just over the Lakes and a high over Kansas, Oklahoma and Colorado had been established in an almost perpendicular direction towards the mountain ranges of the Alleghenys and Appalachians. The surface trough with a front passed the mountain range and then the slopes to the west with increasing altitude. The flow field at 500 hPa crossed with windspeeds of 60 to 80 kt exactly at the right time and the right place over the ranges (Figure 8.2.1). The 750 and 850 hPa levels also showed favourable conditions and, at the surface, prevailing winds with 15 to 45 kt from 320 degrees persisted over the whole day of flight.

8.2.2 Summary from Pilot's Report

It was a good forecast that Karl Striedieck received on May 18th by Penn State University's Weather Station to try the 1000 miles Out-and-Return flight along the 'Allegheny and Appalachian Skyway'. It promised northwest winds (290°–330°) of 30–80 km/h. The lows and highs were positioned at the right place and the higher levels at 500, 750 and 850 hPa showed a suitable vertical structure of the windfield. After making a final decision in the early morning at 04.15 LT, Striedieck was auto-towed and airborne at 05.35 LT picking up the slope current and heading north to his starting point at Lock Haven, where observers on the ground verified his crossing over the starting line. Starting the flight to the southwest (Figure 8.2.2) it was difficult at the beginning to stay above the crests; the lift was not strong, but when the ridge curved more southerly the lift became stronger and he could penetrate along the hills with speeds of 180 km/h, later increasing it to 210 km/h. The gaps between the ridges could be crossed safely but with no more than 200 m above the ridges. Luckily enough Striedieck had to make his first 360° circle at Cumberland, 160 miles from his take off point. Further down where the hills rise to about 1000 m, the lift kept strong, but the extreme turbulence could only be avoided when flying more than 60 m away from the crest. Lift was reduced when the direction of the ridges changed to a more westerly direction, but thermal lift, although very weak at 0.5 m/s, helped to bridge unlandable areas and gaps between the ridges. At the end of the 'Allegheny Expressway' with the end of mountain ridges he arrived over flat country with still another 40 km to go to his turning point — only thermals helped him to reach it. The time at the turning point was 13.30 LT; a distance of 817 km has been flown.

Hunting back to catch the mountain lift again, 3 black vultures circling in 200 m above ground helped him to avoid dropping seriously low. When reaching the ranges, lift returned to normal; occasionally slope flying had to be mixed with thermal circling, but the cumulus development grew better and better, so that Striedieck spoke of that part as 'Texan soaring conditions'. But further on on the flight back, the conditions became very difficult with increasing cloud coverage cutting out the heating and thickening to a solid overcast. Finally on the last part of the flight, rain further reduced sailplane performance and brought the flight level down to the crests or even below them. But choosing the speed range to give the best gliding angle and also dumping his water ballast enabled him to reach the starting point safely and he landed at 19.00 LT after a flight of 1633 km and 13.5 hours in the air.

Figure 8.2.2 (left)
Weather situation at 500 hPa responsible for the favourable wind conditions at the surface persisting throughout the whole day of Karl Striedieck's Out-and-Return-flight along the Allegheny and Appalachian Mountains. (OR = Oak Ridge as southern turning point, LO = Lock Haven as northern turning point)

8.3 POLYGON COURSE FLIGHT

To cater for areas with reduced soaring possibilities because of specific topographic features, the International Sporting Commission has introduced a special type of distance flight over a Polygonal course. Pilots can select specified courses with predetermined turning points. A recent and spectacular flight in which, for the first time a soaring flight exceeded 2000 km took place in New Zealand, piloted by wave specialist Ray Lynskey (Figure 8.3.1).

Date of flight:	14 December 1990
Pilot:	Ray W. Lynskey
Sailplane:	Nimbus 2b
Take off:	Woodbourne Airfield at 06.00 LT
1st turning point:	Five Rivers Garage at 12.00 LT
2nd turning point:	Willow Flat Bridge at 17.20 LT
Landing:	Woodbourne Airfield at 21.00 LT
Distance:	2026 km
Average speed:	135 km/h

8.3.1 Weather situation

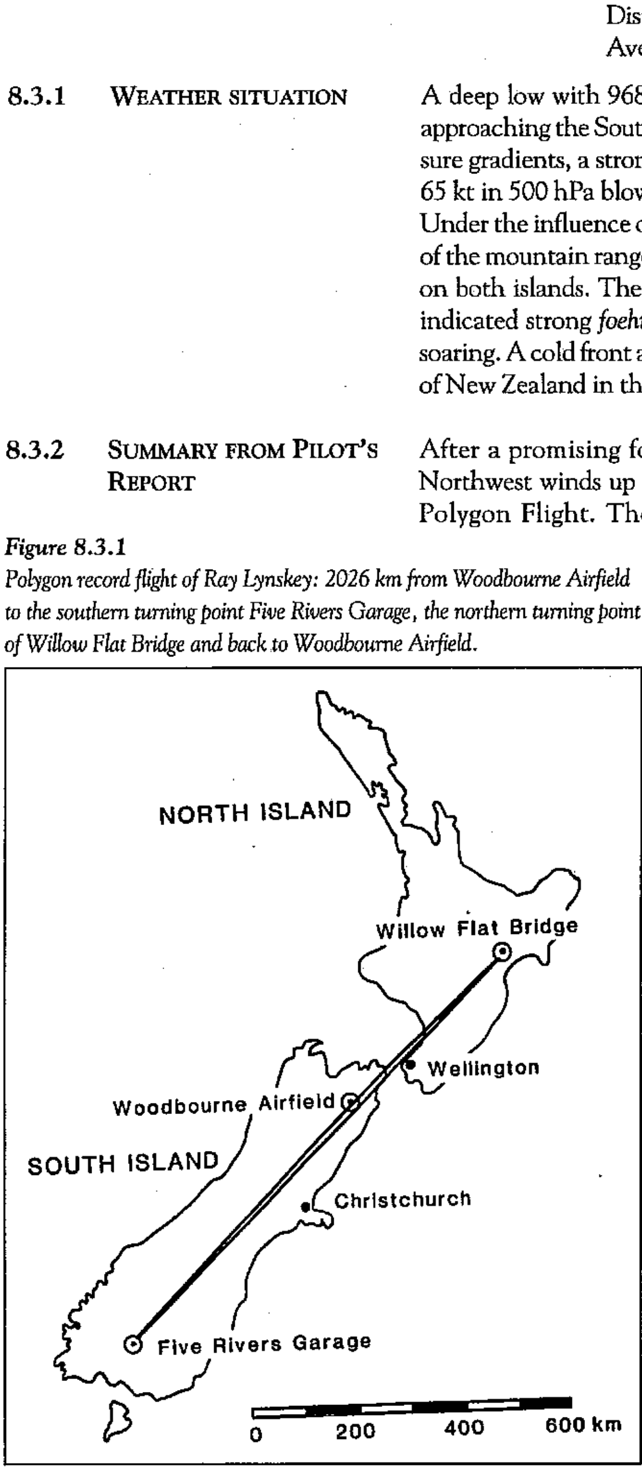
A deep low with 968 hPa centered at 150°E 50°S moved eastward on 14 Dec. 1990 approaching the South Island with its northeastern edge (Figure 8.3.2). With high pressure gradients, a strong windfield established over both islands with windspeeds up to 65 kt in 500 hPa blowing nearly perpendicular to the mountain ranges (Figure 8.3.3). Under the influence of the colder and more humid air mass, heavy rain on the west side of the mountain ranges could be expected as could wave formations along the east side on both islands. The typical pressure deformation along the entire mountain ranges indicated strong *foehn* effects in the downwind region and good conditions for wave soaring. A cold front approaching from the southwest was expected at the southern end of New Zealand in the evening.

8.3.2 Summary from Pilot's Report

After a promising forecast on the evening of 13th December 1990 with strong Northwest winds up to 500 hPa, Ray Lynskey decided for an attempt of a 2000 km Polygon Flight. The early morning conditions confirmed his decision and so he started at 06.00 LT from Woodbourne Airfield. Due to New Zealand's geographical position, its shape and its orography, most long distances flights use waves most of the time. Lynskey's flight was nearly completely on waves, assisted a few times by ridge lift and wave-induced thermals established along the mountain ranges of the South and North Islands under the favourable weather conditions of the 14th December 1990 (Figure 8.3.4).

Figure 8.3.1

Polygon record flight of Ray Lynskey: 2026 km from Woodbourne Airfield to the southern turning point Five Rivers Garage, the northern turning point of Willow Flat Bridge and back to Woodbourne Airfield.



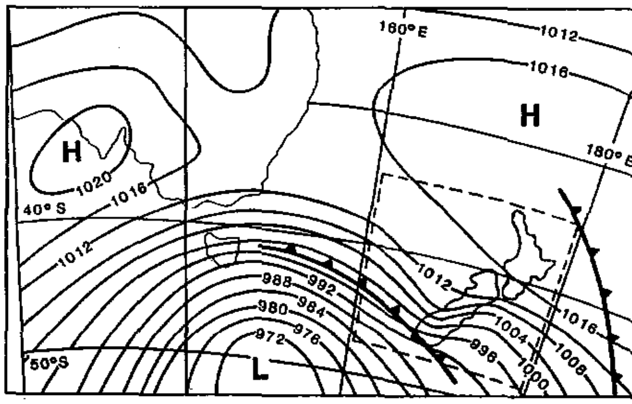
Five Rivers Garage at the far end of the South Island mountain range was selected by Lynskey as the southern turning point and Willow Flat Bridge in the Northeast corner of North Island's mountain range the northern turning point. He decided to do the southern leg first because of the cold front approaching from the southwest forecast for the evening. Most of the flight was performed on the downwind side of the mountains.

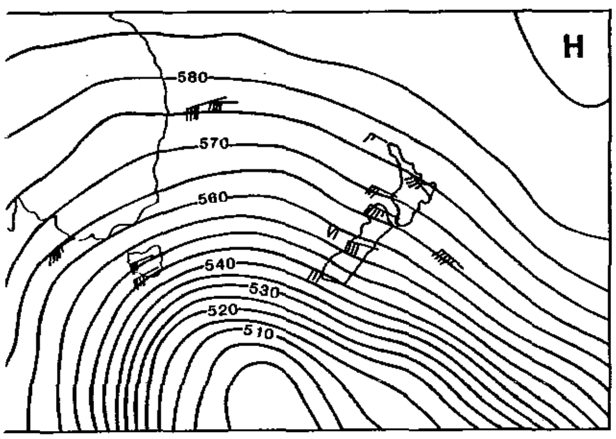
Airborne at 06.00 LT, the first good wave contact with updrafts of 4 m/s was made after 1 hour at 1900 m using ridge lift and wave-induced thermals. When reaching and using waves, the operational height in this part was between 4 and 6.5 km, not allowing a fast cruising speed in steady lift for long periods. It was necessary to stop and climb frequently. Fairly unpleasant clear air turbulence was met by Lynskey half way down to the south, in his opinion due to shear between two layers with different wind velocities or interference between a higher and a lower wave system. But generally clouds and often only what he called 'wisps' of wave- or roll-clouds or even shadows of clouds at the ground were portents of potential updrafts.

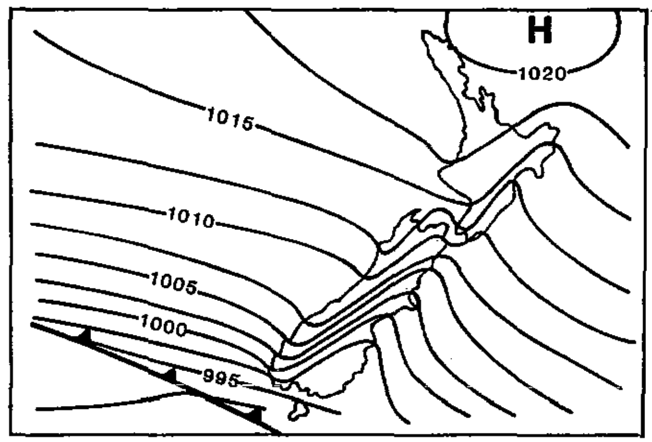
Figure 8.3.2 (right)
Synoptic weather situation on 14 December 1990, 00 UTC, 12.00 LT, surface chart. Dashed box shows area of Figure 8.3.4

Figure 8.3.3 (below)
500 hPa weather chart on 14 December 1990, 00 UTC.

Figure 8.3.4 (below right)
haracteristic surface pressure distribution over New Zealand during the record flight on 14. December 1990.







With one low point of 2300 m MSL the second half of the flight to the turning point was up and down between 4 km and 7.6 km. Lynskey reached Five Rivers Garage at 12.00 LT after 6 hours of flight and a distance of 650 km.

For the flight back north, Lynskey needed only about 3 hours to reach his starting point in the Blenheim area flying between 4.5 km and 6.1 km altitude again with a dip down to 2.5 km in between. As 6.5 hours of daylight remained, the general weather situation was good and a number of pilots reported favourable conditions on the North Island, Lynskey decided to attempt to cover the remaining 700 km of his planned flight. He began flying across Cook Strait to the North Island always in contact with air traffic services at Wellington and keeping his altitude so to be able to return to the South if needed or to land at Masterton on the North Island. Again the flight altitudes were relatively low and did not exceed 5 km all the way up to the northern turning point Willow Flat Bridge, which he reached at 17.20 LT.

With four hours of daylight remaining, Lynskey decided that the flight was still possible. Carefully observing the development of wave clouds, he was able to locate usable and sometimes strong updrafts on his way back to the Southwest. The height band of this part of flight was in average 4.9 to 6.6 km reaching one peak with a maximum altitude of 8.7 km about 150 km northeast of Wellington when climbing upwind of a well developed lenticular formation right over the east coast.

It needed all the experience of six double crossings to decide on the return flight over the Cook Strait, but starting from a height of 6.6 km and with the shining Lake Grassmere on the South Island in sight, he decided to go. Sinking at times heavily and even climbing a little at times at a moderate speed of 120 km/h Lynskey reached the southern coastline. The rest of the flight was not too difficult and Lynskey made his final approach to Woodbourne Airfield and landed at 21.00 local time after 15 hours of flight with a total distance of 2026 km at an average speed of 135 km/h.

8.4 FLIGHT AROUND A TRIANGULAR COURSE

A triangular flight is a flight around three turn points, of which one may, but need not be the starting and end point. The shortest leg must not be shorter than 25 % of the total distance, the longest one not longer than 45 % of it. At present, the F.A.I. recognizes speed records around triangles of lengths of 100 km, 300 km, 500 km, 750 km, 1000 km and 1250 km. In addition, the longest triangular flight is a separate record category.

At the time of writing, Hans-Werner Grosse holds the world record for the longest triangle and the fastest speed around a triangle over 1250 km or more with a flight in Australia in 1987. The description of the weather situation and the flight is illustrated in the accompanying diagrams.

Date of flight:	10 January 1987
Pilot:	Hans-Werner Grosse
Co-Pilot:	Dr. Hans-Heinrich Kohlmeier
Sailplane:	ASH 25
Take off:	Alice Springs Airport, crossing startline at 09.46 LT
1st turning point:	Mt. Unapproachable
2nd turning point:	Wintinna
Landing:	Alice Springs Airport, crossing finish line at 19.23 LT
Total Distance:	1379.3 km
Average speed:	143 km/h

Figure 8.4.1
Surface weather situation on 10th Jan. 1987, 09.00 LT (Dotted lines = Triangular course route).

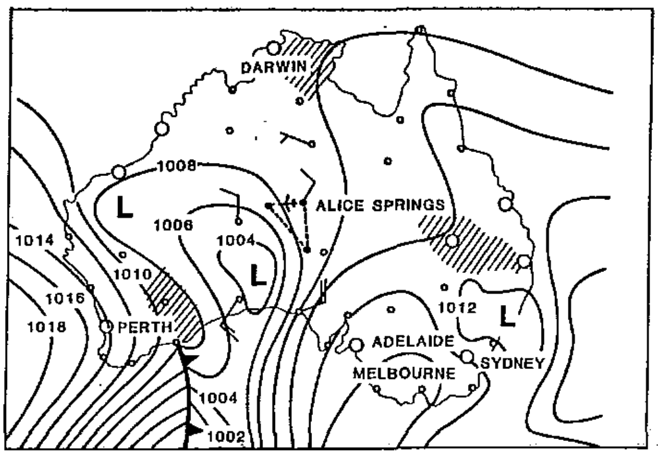


Figure 8.4.2 (a)
Pressure lines in 850 hPa on 10th Jan. 1987, 13.30 LT. Wavy lines are cool changes.

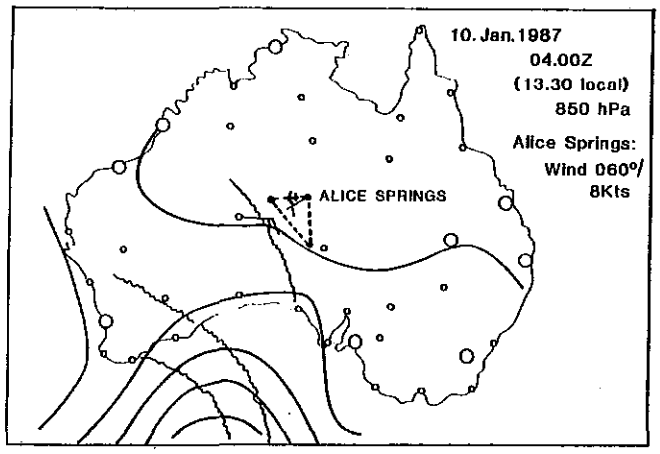


Figure 8.4.2 (b)
Pressure distribution in 700 hPa on 10th Jan. 1987, 13.30 LT.

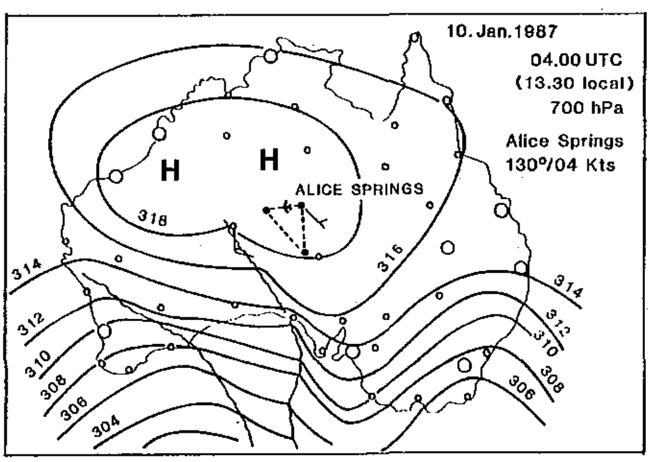
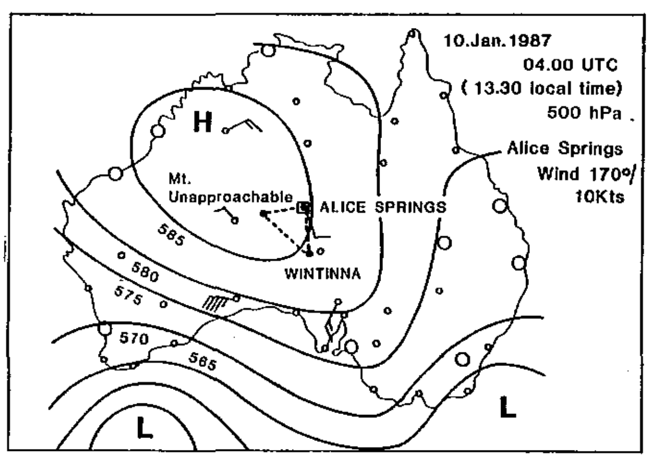


Figure 8.4.2 (c)
Pressure distribution in 500 hPa on 10th Jan. 1987, 13.30 LT.



8.4.1 Weather Situation

On 10 January 1987, an upper trough in the Great Australian Bight connected with a cold front moved from 123°E (23 UTC on 9 January) to 145°E (23 UTC on 10 January). During the same period, a low pressure system situated to the southeast of Tasmania moved approximately 500 km southwards. Another low pressure system developed behind the cold front in the Bight and moved to 44°S 136°E by the end of this period. The low at the northern end of the front weakened and its centre shifted to the northwest while a ridge of high pressure extended across the western half of Australia eastwards with its axis along 32°S. Over Central Australia there was little change in the 700 hPa pattern throughout the day.

The passage of a weak upper level disturbance was expected for the southern part of the Northern Territory, especially in the Alice Springs area. Maximum temperatures of 40°C and more with dewpoints of around 0°C were forecast, indicating the development of cumulus with high cloud bases and a relatively low probability of extended showers.

8.4.2 Pilot's Report

"Based on the favourable forecast for the area to the southwest of Alice Springs, I decided together with my co-pilot Dr. Hans-Heinrich Kohlmeier to declare a 1379 km triangle with the turning points at Mt. Unapproachable (390 km west of Alice Springs) and Wintinna (437 km south of Alice Springs) and a distance between these two points of 552 km. For the first 90 minutes after take-off at 09.46 local time, we found only weak thermal activity up to 1000 m above ground without cumulus development. Near the approaching trough, increasing wind shear made centring in thermals difficult. Only after 300 km on the first leg, did we find cumulus development with a base of 4000 m MSL. A thin cirrus cover extended to the west from the first turning point, Mt. Unapproachable, but as our track continued from there to the southeast it did not affect our good progress underneath 3/8 cumulus at an average speed of more than 160 km/h for the next 3 hours. Passing Ayers Rock, a few light showers near the axis of the trough decreased our speed slightly, but reaching the second turning point brought us back onto the dry side of the trough. We occasionally failed to locate the best lift directly underneath promising clouds, until my co-pilot observed that the updraft had its origin about 3 km to the southwest of the cloud. This helped us to repeatedly locate extremely good thermals with lift up to 6 m/s.

We finally reached Alice Springs shortly after sunset and landed at 19.23 after 1379.35 km. Our average speed for the whole flight was 143.46 km/h."

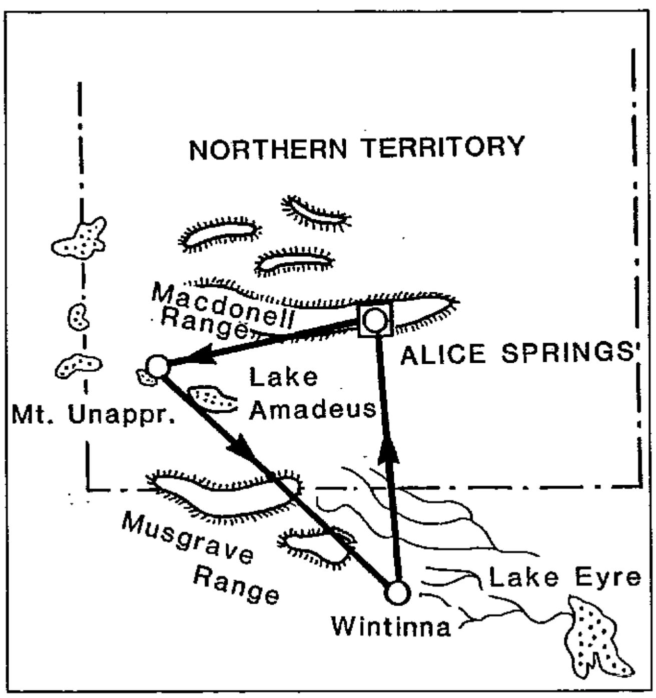


Figure 8.4.3
Area of the Triangular Courseworld record flight of Hans Werner Grosse with Dr. HansHeinrich Kohlmeier in Inner Australia on 10th Jan. 1987 over a distance of 1379.3 km with an average speed of 143 km/h (□ = Start and finish point at Alice Springs)

8.5 ALTITUDE FLIGHT

'Absolute altitude' and 'Gain of Altitude' are also world record categories in soaring. Except in thunderstorms in tropical areas the valid altitude record heights of today can only be reached by using mountain waves. The present world record in 'Absolute Altitude' was set in 1986 over the Sierra Nevada, USA, (see Figure 8.5.1).

Date of flight:	17 February 1986
Pilot:	Robert R. Harris
Sailplane:	Grob G 102
Take off:	California City Airport (Elev. 743 m MSL) at 12.50 LT
Landing:	Inyokern Airfield at 16.33 LT
Lowest point:	2776 m MSL
Highest point:	14 938 m MSL

8.5.1 WEATHER SITUATION

A subtropical jet stream embedded in a general zonal flow developed from the West towards California (Figure 8.5.3) with warm air masses ahead of it. The tropopause reached heights up to 45000 ft (150 hPa) with temperatures around -65°C and windspeeds of 80 to 100 kt at that height (Figure 8.5.4). According to observations made by the American meteorologist Doug Armstrong (1987) and his colleagues as well as the pilot himself, such a high tropopause establishes itself only once or twice in several years at this season. An important fact was the weak transition to the

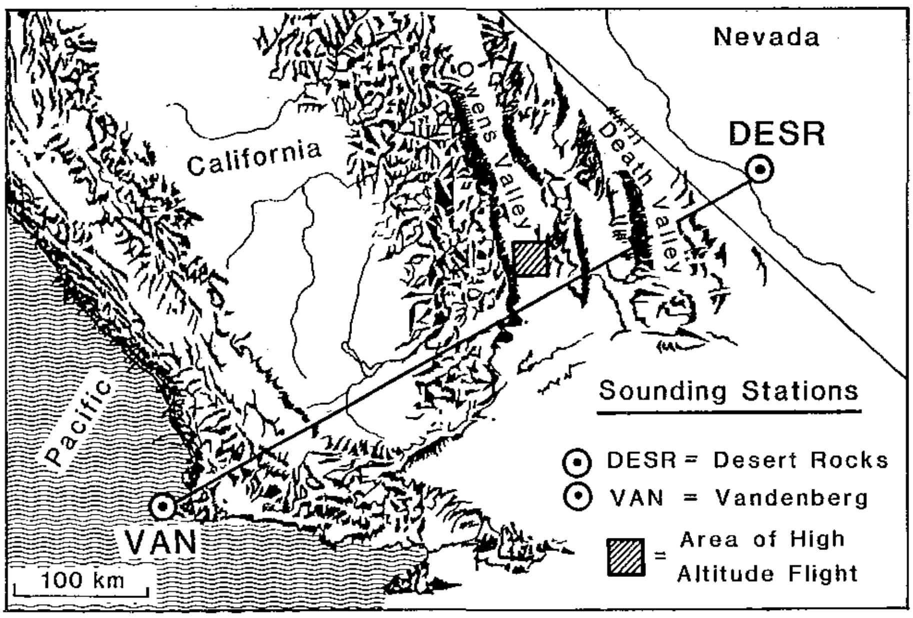


Figure 8.5.1
The Sierra Nevada area, where Robert Harris achieved the world altitude record of 14938 m MSL on the 17 Februar 1986.

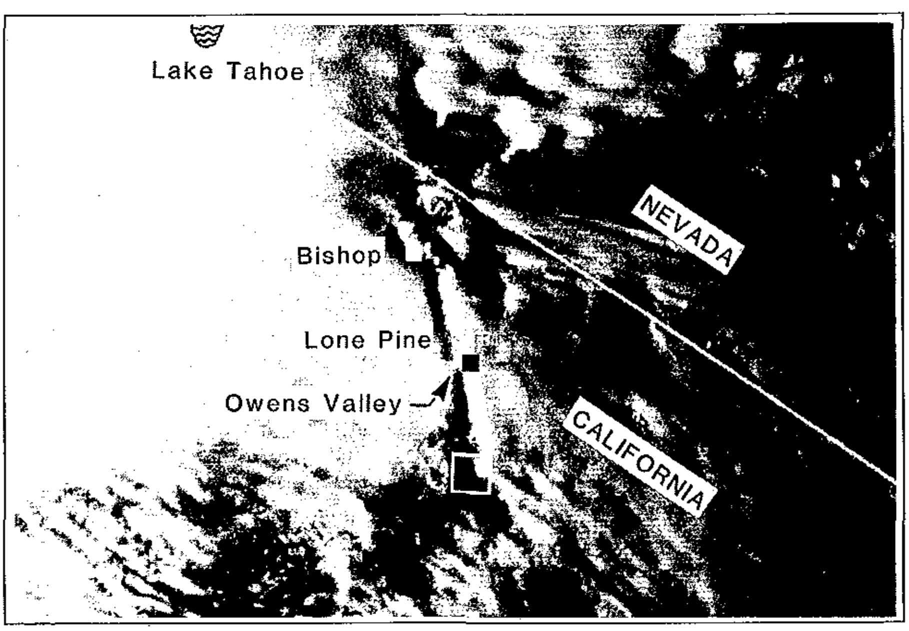


Figure 8.5.2
The GOES-6 satellite picture shows the closed cloud deck in the west, followed by the foehn gap along the Owens Valley and the elevated wave cloud area north and south of Long Pine.

tropopause, which prevented the generation of breaking waves at that altitude. Flight observations of cloud type and coverage showed also very humid air with high, staggered lenticularis formations along the Sierra Nevada Mountain Range.

The satellite picture (Figure 8.5.2) offers an impressive view on the completely closed cloud deck west of the Owens Valley, reaching to the Pacific coast. The Owens Valley is cleared by foehn effect. Then follows the eastern cloud wall formed through the elevated airmass over the hydraulic jump in front of the mountain range of the White and Inyo Mountains.

8.5.2 Extract from Pilot's Report

"...On 17 February 1986 we observed the best set of wave condition parameters we had seen in four years of watching. Characterized by almost perfect zonal flow across California with the jet stream crossing the state near the northern border, strong mountain waves should be generated over the High Sierras in the Owens Valley, especially when the jetstream crossed California somewhere between San Francisco and the California Oregon border. The Vandenberg sounding confirmed a high tropopause at 128 hPa with winds in the vicinity of 80 to 100 kt.

Take off was from California City airport with no wave indications. But 150 km north, a powerful wave cloud was observed over Owens Valley. After flying through the roughest rotor I ever encountered, I found wave contact in 10000 ft. Drifting north after release, over Little Lake 18000 ft; arriving over Owens Lake 35000 ft. At 38000 ft canopy totally frosted up. At 42000 ft lift increased to 300 to 500 ft/min. Electronic vario froze. Oxygen regulator No. 1 failed, No. 2 was operating normally. After reaching highest point, starting descent drifting southward using needle-ball, VOR and compass to stay clear of clouds; freezing up of canopy at 35000 ft with improvement of vision; freezing up also from dump system for exhaled air. After two trials to reach take-off airport California City landing after 3 hours 43 minutes flight at Inyokern and towed back through even more turbulent rotor as before to final landing at California City."

Remark: This flight reached the absolute biological limit without pressurization. It was performed after prolonged training in a pressure chamber.

Figure 8.5.3
Pressure and wind distribution at 200 hPa (≈ 12 km MSL) on 18 Feb. 1986, 00 UTC shortly after Robert Harris' record flight.

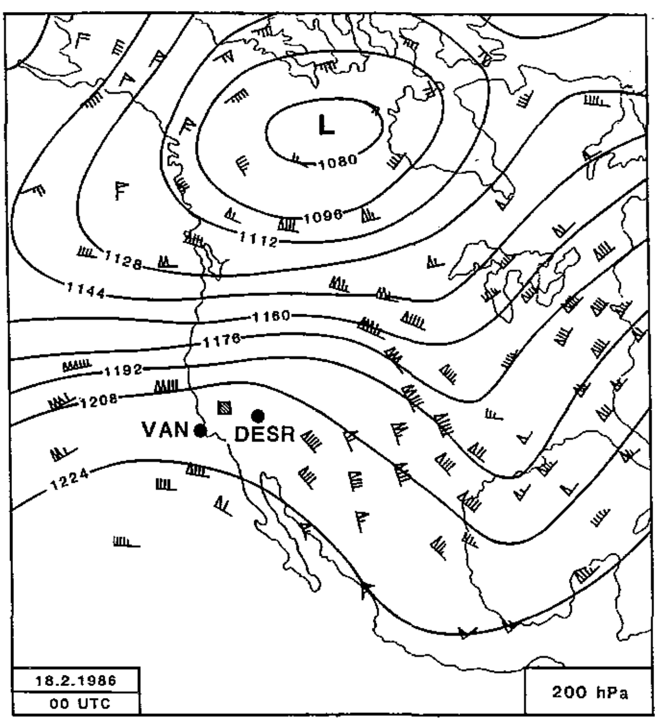
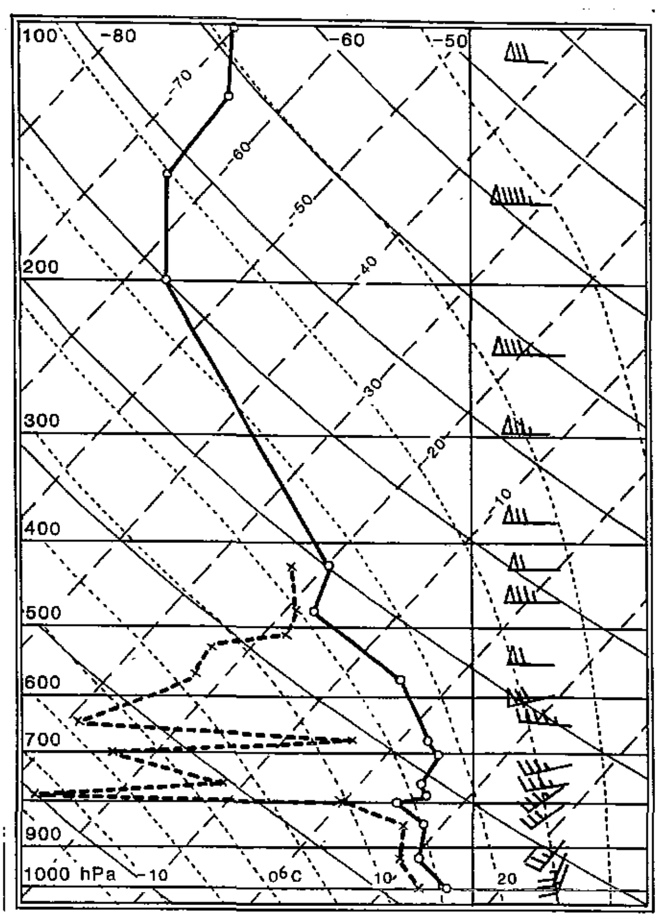


Figure 8.5.4
Upper air sounding from Vandenberg station during the record flight of Robert Harris on 18th February 1986.



CHAPTER 9

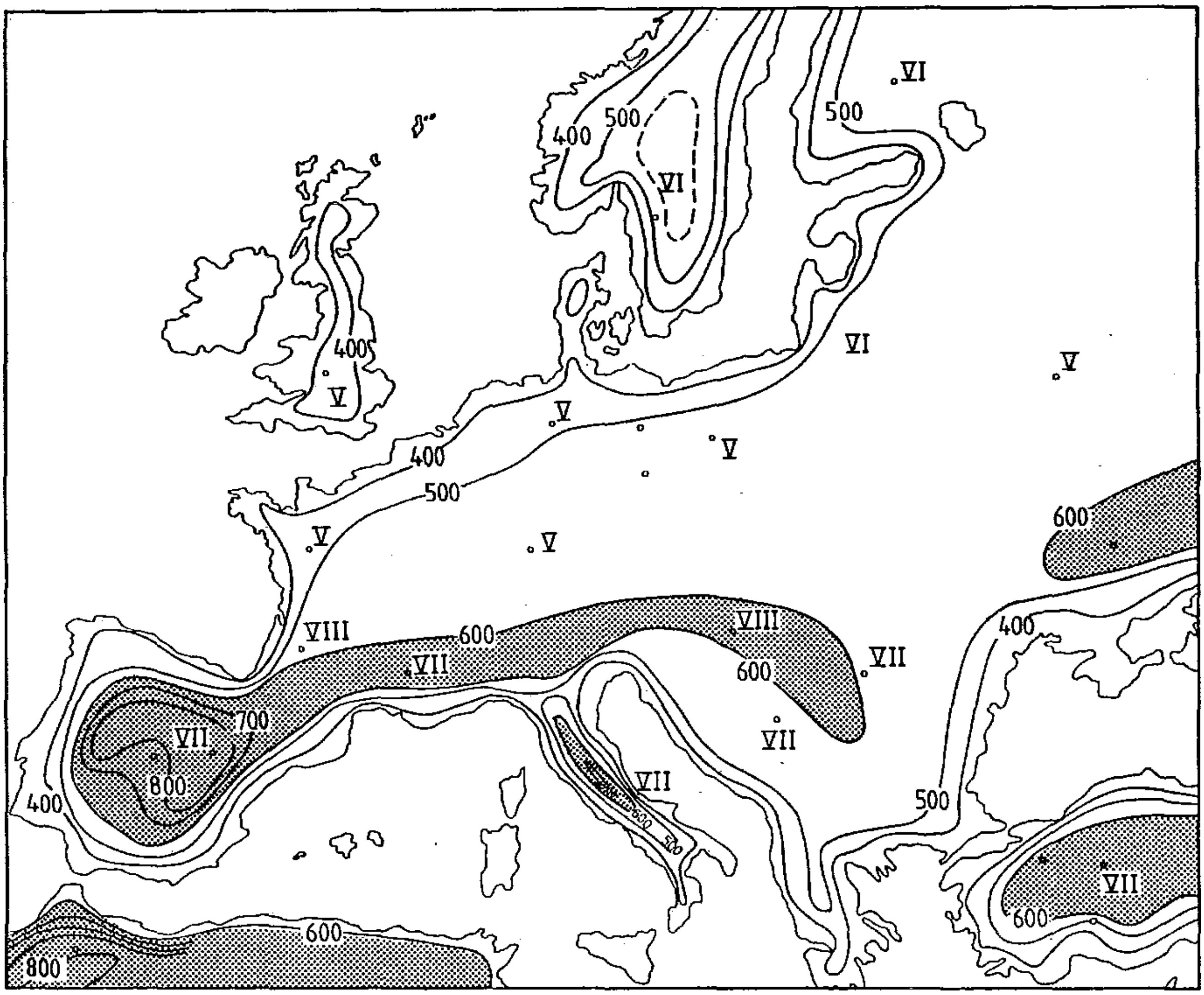
SOARING CLIMATOLOGY

Soaring climatology allows assessment of the probability of favourable weather conditions for soaring for a given landscape and season. It should combine effects of the local climate (insolation, cloudiness, temperature, humidity, and static stability of the air masses) and topographical parameters (sun exposure, soil quality, soil humidity, vegetation, land use). Basically all meteorological features which are used for soaring, i.e. thermals, mountain waves, and thermal waves, are associated with particular meteorological and topographical conditions, which, in turn, can be compiled into a soaring climatology after statistical evaluation. However, up to now, soaring climatologies are rather incomplete and were published more or less sporadically for selected regions and consider only particular phenomena.

The first attempts to get an idea of soaring capabilities in Central Europe were promoted by Müller and Kottmeier (1982), Lindemann (1981) and others. These approaches mainly used soil characteristics and vegetation cover. As a result, detailed maps of surface influences on the development of thermals were compiled for Central Europe which, of course, do not consider atmospheric climatology. Nevertheless, such maps are of special interest for route planning on days with thermal activity.

Another approach (Lindemann, 1988) introduced a thermal convection index (TCI) on the base of monthly average values of the vertical temperature gradient, monthly sunshine, and cumulus condensation level. A special correction factor accounts for precipitation frequency. The TCI was deduced for months April to August at selected places throughout Europe and Asia Minor. Figure 9.1 depicts isolines of maximum monthly TCI.

Figure 9.1
Isoplothes of the maximum monthly TCI over Europe. Areas with TCI exceeding 600 are shaded. Roman numerals indicate the month with the highest TCI at selected places



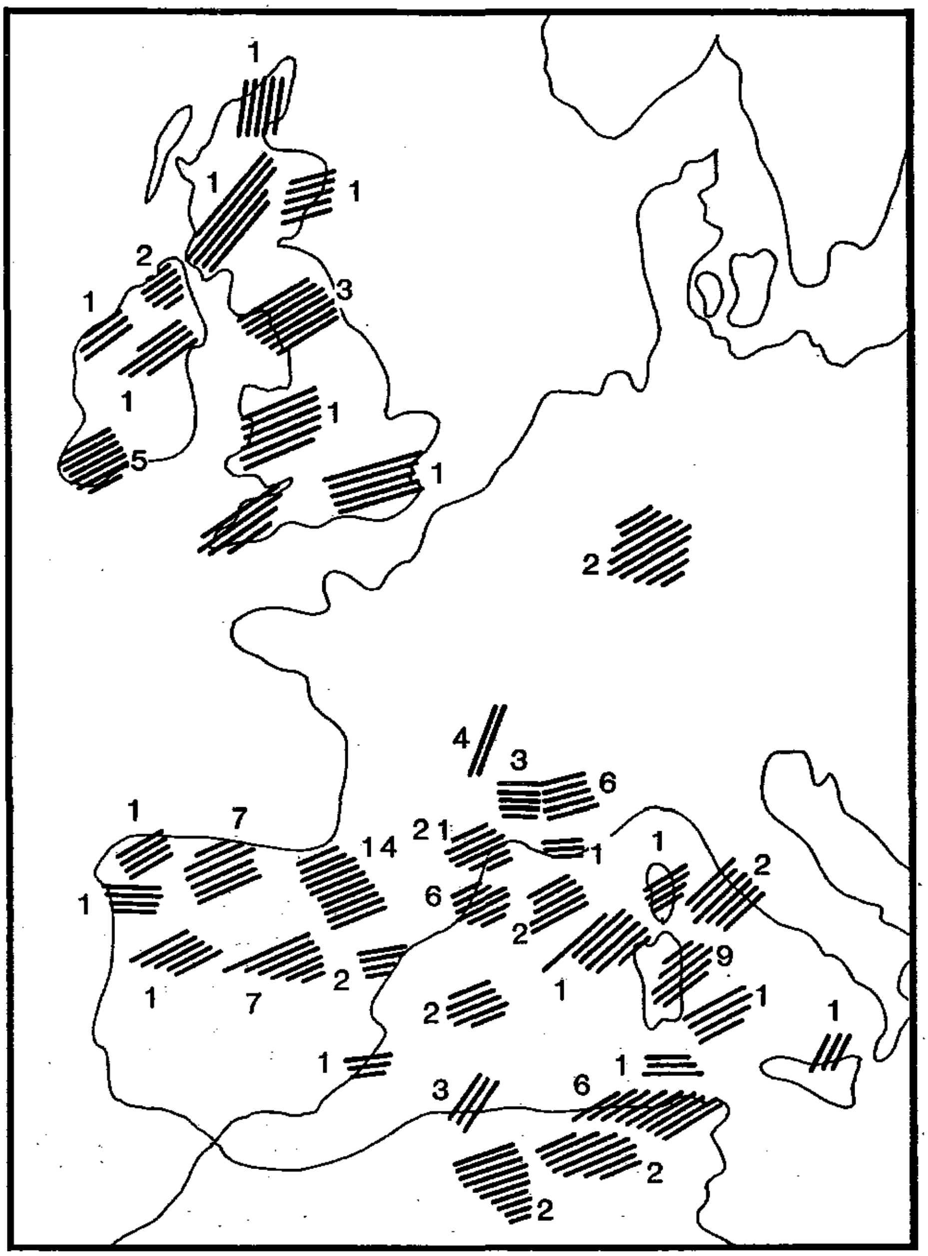


Figure 9.2
Wave climatology of Western Europe under conditions of northwesterly flow as derived from satellite pictures from 1966 to 1968. Numbers indicate how often these wave systems were observed in the various locations; parallel lines indicate aerial extension of systems and orientation of waves (but not wave length). After Cruette (1973).

Numbers give the month in which the maximum TCI is expected. For comparison the maximum TCI values for three notable locations are given: 861 for Alice Springs, Central Australia; 821, for Bagdad, Iraq, and 843 for Libya. The map shows that similar high values are found in Spain and Turkey. However, the TCI method does not consider topographic influences (soil and vegetation). It is valuable for the planning of contests and gives useful hints which places and times of the year promise the best chance for excellent meteorological conditions.

A wave climatology for Western Europe was derived by Cruette (1973) from satellite pictures of the period 1966 to 1968. It shows where waves are likely to occur in Great Britain, northern Spain, southern France and over the Mediterranean islands (Figure 9.2). Cruette's wave map provides the frequency of occurence and the main orientation of waves in these areas. Wave situations which were not associated with visible wave clouds in the satellite images are, of course, not included in Cruette's climatology. Moreover, the short period (only three years) during which the cases were sampled does not actually allow a climatological interpretation of these statistics.

New methods of soaring climatology are still in development. It is hoped that in future climatological maps will be published which join atmospheric and topographical influences on thermal activities. Wave climatologies should be based on long-term statistics of observations and should consider static stability and vertical wind shear.

REFERENCES

Amstrong, D., Harns, R., 1987: Paper presented on the XX. OSTIV-Congress, Benalla, Australia.

Buz, A.I., 1975: *Meteorological conditions for soaring flight*. Transactions of the U.S.S.R. Hydrometeorological Centre, Vol. 162, 6973.

Clark, T.L., Hauf, T., Kuettner, J.P., 1986: *Convectively forced internal gravity waves: Results from two-dimensional numerical experiments*. Quart. J. R. Meteorol. Soc., Vol. 112, 899925.

Corby, J.A., 1954: *The airflow over mountains*. Quart. J. R. Meteorol. Soc., Vol. 80, 491521.

Cruette, D., 1976: *Experimental study of mountain lee-waves by means of satellite photographs and aircraft measurements*. Tellus, Vol. 28, 499523.

Friedrich, A., 1987: *Wetterüberwachung und Unterstützung der Kürzestfristprognose mit einem Personal Computer Eine Pilotstudie*. Deutscher Wetterdienst, Offenbach a.M.

Gold, E., 1933: *Maximum day temperatures and the tephigram*. Prof. Notes Met. Office, London, No. 63.

Hauf, T., Clark, T.L., 1989: *Three-dimensional numerical experiments on convectively forced internal gravity waves*. Quart. J. R. Meteorol. So., Vol. 115, 309333.

Heimann, D., 1983: *A Thermal activity forecasting scheme suitable for personal computers*. OSTIV-Publication, XVII, 173174.

Heimann, D., 1985: *A simple numerical model of thermals and cumulus convection*. OSTIV-Publication, XVIII, 117121.

Jaeckisch, H., 1968: *Waveflow above convective streets*. OSTIV-Publication, X, originaly published in Aero Revue.

Jaeckisch, H., 1972: *Synoptic conditions of wave formation above convection streets*. OSTIV-Publication, XII, originaly published in Aero Revue (651653).

Klemp, J.B. and Lilly, D.K., 1975:*The dynamics of wave-induced downslope wind*. J. Atmos. Sci., Vol. 32, 320-339.

Konovalov, D.A., 1976: *Thermals in the sub-cloud layer of the atmosphere*. OSTIV-Publication, XIV,

Kuettner, J.P., 1952: *On the possibility of soaring on traveling waves in the jetstream*. Aeronaut. Engin. Rev., Vol. 11, p. 1.

Kuettner, J.P., 1958: *Rotorflow in the lee of mountains*. Aero Revue, 208215.

Kuettner, J.P., 1971: *Cloudbands in the earth's atmosphere*. Tellus, Vol. 23, 404426.

Kuettner, J.P., Hildebrand, P.A., Clark, T.L., 1987: *Convection waves: Observations of gravity wave systems over convectively active boundary layers*. Quart. J. R. Meteorol. Soc., Vol. 113, 445467.

Lester, P.F., 1975: *An evaluation of a lee wave forecasting nomogramme*. Technical Soaring, Vol. 3, 110.

Lindemann, C., 1973: *Thermal waves*. Aero Revue, No. 12 (1973) and No. 1 (1974).

Lindemann, C., 1981: *Parameters of thermal convection as measured by a powered glider*, OSTIV-Publication, XVI, 256-259.

Lindemann, C., 1988: *Soaring climatology of thermal convection*, Technical Soaring, Vol. 12, 95-100.

Lindsay, C.V., 1965: *Satellite wave observations used as an aid to wave soaring*. Aero Revue, 733734, cont. 1966, p. 444.

Müller, D., Kottmeier, C., 1982: *Die Auswirkung von Bodeneigenschaften auf die regionalen Konvektionsunterschiede über Norddeutschland*. Met. Rundsch., Vol. 35, 84-91.

Nelson L.D., 1979: *Observations and numerical simulations of precipitation mechanisms in natural and seeded convective clouds*. The Univ. of Chicago, Dept. Geoph. Sc., Cloud Phys. Lab., Techn. Note 54.

Ogura Y., Takahashi, T., 1971: *Numerical Simulation of the Life Cycle of a Thunderstorm Cell*. Mon. Wea. Rev.,Vol. 99, 895911.

Reinhardt, M.E., 1971: *Aerologische Strukturen am Alpennordrand nach Flugzeugsondierungen*. Annalen d. Meteorologie, No. 5, 8191.

Rovesti, P., 1970: *Thermal wave (termoondo) soaring in Italy and Argentina*. OSTIV Publication, XI, originaly published in Aero Revue.

Schmidt, H., Schumann, U., 1989: *Coherent structure of the convective boundary layer derived from large eddy simulations*. J. Fluid Mech., Vol. 200, 511562.

Smith, R.B., 1979: *The influence of mountains on the atmosphere*. In: Advances in Geophysics, Vol. 21, 87-230.

Trimmel, H., 1987: *Meteorological support for gliding, hang gliding and hot-air balloon championships*, Benella, XX. OSTIV- Congress 1987.

Trimmel, H., 1991: *Report on OSTIMET 2* (Wiener Neustadt), Uvalde, XXII. OSTIV-Congress 1991

Wallington, C.E., 1977: *Meteorology for glider pilots*. Third edition, J. Murray, London.

Vieweg-Pielsticker, U., 1956: in W.Georgii: Flugmeteorologie. Akad. Verlagsges., Frankfurt a.M.

WMO, 1960: *The airflow over mountains*.WMO Technical Note 34.

WMO, 1973: *The airflow over mountains, research 1958–1972*. WMO Technical Note 127.

RECOMMENDED BIBLIOGRAPHY

Bessemoulin, J., Viaut, A., 1967: *Manuel de météorologie du vol à voile.* editions Blondel la Rougery, Paris.

Bradbury, T., 1989: *Meteorology and flight.* A&C Black, London.

Kalckreuth, J., 1973: *Segeln über den Alpen.* 2nd edition, Motorbuch Verlag, Stuttgart, 1973.

Lindsay, C.A., Lacy, S.J., 1972: *Soaring meteorology for forecasters*, National Weather Service, USA.

Piggott, A.D., 1986: *Gliding (Fifth Edition)*, A&C Black, London

Reichmann, H., 1988: *Cross-country soaring.* Motorbuch Verlag, Stuttgart.

Scorer, R.S., 1978: *Environmental aerodynamics.* Ellis Horwood, Chichester.

APPENDIX

CONVERSION FORMULAS

In general international standard units are used throughout this manual. In practice, and in some figures in this manual, other units are still used. Some basic conversion formulas shall be given here:

Nautical miles (nm):
1 nm = 1.853 km
1 km = 0.540 nm

Knots (kt):
1 kt = 1.853 km/h
1 km/h = 0.540 kt

1 kt = 0.514 m/s
1 m/s = 1.942 kt

Feet (ft):
1 ft = 0.3048 m
1 m = 3.2808 ft

Feet per minute (ft/min):
100 ft/min = 0.508 m/s
1 m/s = 196.9 ft/min

Degree Fahrenheit (°F):
Temperature (°C) = (Temperature (°F) 32) • 5/9
Temperature (°F) = Temperature (°C) • 9/5 + 32

Kelvin (K):
Temperature (°C) = Temperature (K) 273.15

Note: In this handbook Kelvins are only used to indicate temperature differences.

Hectopascal (hPa):
1 hPa = 1 mbar