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This text book has been written and published as a reference work for student pilots with the aims of helping them prepare for the PPL theoretical knowledge examinations, and to provide them with the aviation knowledge they require to become safe and competent pilots of light aeroplanes. The book is not a flying training manual and nothing in this book should be regarded as constituting practical flying instruction. In practical flying matters, students must always be guided by their instructor.

This book has been produced by CAE Oxford Aviation Academy.

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FOREWORD TO THE SECOND EDITION.

INTRODUCTION.

Whether you are planning to fly microlights, space shuttles, gliders, combat aircraft, airliners or light aircraft, it is essential that you have a firm grasp of the theoretical knowledge which underpins practical piloting skills. This Oxford Aviation Academy "Skills for Flight" series of text books covers the fundamental theory with which all pilots must come to grips from the very beginning of their pilot training, and which must remain with them throughout their flying career, if they are to be masters of the art and science of flight.

JOINT AVIATION AUTHORITIES PILOTS' LICENCES.

Joint Aviation Authorities (JAA) pilot licences were first introduced in Europe in 1999. By 2006, almost every JAA member state, including all the major countries of Europe, had adopted this new, pan-European licensing system at Air Transport Pilot's Licence, Commercial Pilot's Licence and Private Pilot's Licence levels, and many other countries, world-wide, had expressed interest in aligning their training with the JAA pilot training syllabi.

These syllabi, and the regulations governing the award and the renewal of licences, are defined by the JAA's licensing agency, 'Joint Aviation Requirements - Flight Crew Licensing', (JAR-FCL). JAR-FCL training syllabi are published in a document known as 'JAR-FCL 1.'

The United Kingdom Civil Aviation Authority (UK CAA) is one of the founder authorities within the JAA. The UK CAA has been administering examinations and skills tests for the issue of JAA licences since the year 2000, on behalf of JAR-FCL.

The Private Pilot's Licence (PPL), then, issued by the UK CAA, is a JAA licence which is accepted as proof of a pilot's qualifications throughout all JAA member states.

Currently, the JAA member states are: *United Kingdom, Denmark, Iceland, Switzerland, France, Sweden, Netherlands, Belgium, Romania, Spain, Finland, Ireland, Malta, Norway, Czech Republic, Slovenia, Germany, Portugal, Greece, Italy, Turkey, Croatia, Poland, Austria, Estonia, Lithuania, Cyprus, Hungary, Luxembourg, Monaco, Slovakia.*

As a licence which is also fully compliant with the licensing recommendations of the International Civil Aviation Organisation (ICAO), the JAA PPL is also valid in most other parts of the world.

The JAA PPL in the UK has replaced the full UK PPL, formerly issued solely under the authority of the UK CAA.

Issue of the JAA PPL is dependent on the student pilot having completed the requisite training and passed the appropriate theoretical knowledge and practical flying skills tests detailed in 'JAR-FCL 1'. In the UK, the CAA is responsible for ensuring that these requirements are met before any licence is issued.

EUROPEAN AVIATION SAFETY AGENCY.

With the establishment of the European Aviation Safety Agency (EASA), it is envisaged that JAA flight crew licensing and examining competency will be absorbed into the EASA organisation. It is possible that, when this change has taken place, the PPL may even change its title again, with the words "EASA" replacing "JAA". However, we do not yet know this for certain. In the UK, such a step would require the British Government to review and, where necessary, revise the Civil Aviation Act. But, whatever the future of the title of the PPL, the JAA pilot's licence syllabi are unlikely to change fundamentally, in the short term. So, for the moment, the JAA Licence remains, and any change in nomenclature is likely to be just that: a change in name only.

OXFORD AVIATION ACADEMY AND OAAMEDIA.

Oxford Aviation Academy (OAA) is one of the world's leading professional pilot schools. It has been in operation for over forty years and has trained more than 15 000 professional pilots for over 80 airlines, world-wide.

OAA was the first pilot school in the United Kingdom to be granted approval to train for the JAA ATPL. OAA led and coordinated the joint-European effort to produce the JAR-FCL ATPL Learning Objectives which are now published by the JAA itself as a guide to the theoretical knowledge requirements of ATPL training.

OAA's experience in European licensing, at all levels, and in the use of advanced training technologies, led OAA's training material production unit, OAAmedia, to conceive, create and produce multimedia, computer-based training for ATPL students preparing for JAA theoretical knowledge examinations by distance learning. Subsequently, OAAmedia extended its range of computer-based training CD-ROMs to cover PPL and post-PPL studies.

This present series of text books is designed to complement OAAmedia's successful PPL CD-ROMs in helping student pilots prepare for the theoretical knowledge examinations of the JAA PPL and beyond, as well as to provide students with the aviation knowledge they require to become safe and competent pilots.

The OAA expertise embodied in this series of books means that students working towards the JAA PPL have access to top-quality, up-to-date, study material at an affordable cost. Those students who aspire to becoming professional pilots will find that this series of PPL books takes them some way beyond PPL towards the knowledge required for professional pilot licences.

THE JAA PRIVATE PILOT'S LICENCE (AEROPLANES).

The following information on the Joint Aviation Authorities Private Pilot's Licence (Aeroplanes); (JAA PPL(A)) is for your guidance only. Full details of flying training, theoretical knowledge training and the corresponding tests and examinations are contained in the JAA document: **JAR–FCL 1, SUBPART C – PRIVATE PILOT LICENCE (Aeroplanes) – PPL(A).**

The privileges of the JAA PPL (A) allow you to fly as pilot-in-command, or co-pilot, of any aircraft for which an appropriate rating is held, but not for remuneration, or on revenue-earning flights.

For United Kingdom based students, full details of JAA PPL (A) training and examinations can be found in the CAA publication, **Licensing Administration Standards Operating Requirements Safety (LASORS),** copies of which can be accessed through the CAA's Flight Crew Licensing website.

Flying Training.

The JAA PPL (A) can be gained by completing a course of a minimum of 45 hours flying training with a training organisation registered with the appropriate National Aviation Authority (the Civil Aviation Authority, in the case of the United Kingdom).

Flying instruction must normally include:

- **25 hours** dual Instruction on aeroplanes.

- **10 hours** supervised solo flight time on aeroplanes, which must include **5 hours** solo cross-country flight time, including one cross-country flight of at least 150 nautical miles (270km), during which full-stop landings at two different aerodromes, different from the aerodrome of departure, are to be made.

The required flying-instructional time may be reduced by a maximum of 10 hours for those students with appropriate flying experience on other types of aircraft.

The flying test (Skills Test), comprising navigation and general skills tests, is to be taken within 6 months of completing flying instruction. All sections of the Skills Test must be taken within a period of 6 months. A successfully completed Skills Test has a period of validity of 12 months for the purposes of licence issue.

Theoretical Knowledge Examinations.

The procedures for the conduct of the JAA PPL (A) theoretical knowledge examinations will be determined by the National Aviation Authority of the state concerned, (the Civil Aviation Authority, in the case of the United Kingdom).

The JAA theoretical knowledge examination must comprise the following 9 subjects: *Air Law, Aircraft General Knowledge, Flight Performance and Planning, Human Performance and Limitations, Meteorology, Navigation, Operational Procedures, Principles of Flight, Communication.*

A single examination paper may cover several subjects.

The combination of subjects and the examination paper titles, as administered by the UK CAA, are, at present:

1. Air Law and Operational Procedures.
2. Human Performance and Limitations.
3. Navigation & Radio Aids.
4. Meteorology.
5. Aircraft (General) & Principles of Flight.
6. Flight Performance and Planning.
7. JAR-FCL Communications (PPL) (i.e. Radiotelephony Communications).

The majority of the questions are multiple choice. In the United Kingdom, examinations are normally conducted by the Flying Training Organisation or Registered Facility at which a student pilot carries out his training.

The pass mark in all subjects is 75%.

For the purpose of the issue of a JAA PPL(A), a pass in the theoretical knowledge examinations will be accepted during the 24 month period immediately following the date of successfully completing all of the theoretical knowledge examinations.

Medical Requirements.
An applicant for a JAR-FCL PPL(A) must hold a valid JAR-FCL Class 1 or Class 2 Medical Certificate.

THE UNITED KINGDOM NATIONAL PRIVATE PILOT'S LICENCE (AEROPLANES).

One of the aims of the United Kingdom National Private Pilot's Licence (UK NPPL) is to make it easier for the recreational flyer to obtain a PPL than it would be if the requirements of the standard JAA-PPL had to be met. The regulations governing medical fitness are also different between the UK NPPL and the JAA PPL.

Full details of the regulations governing the training for, issue of, and privileges of the UK NPPL may be found by consulting LASORS and the Air Navigation Order. Most UK flying club websites also give details of this licence.

Basically, the holder of a UK NPPL is restricted to flight in a simple, UK-registered, single piston-engine aeroplane (including motor gliders and microlights) whose Maximum Authorized Take-off Weight does not exceed 2000 kg. Flight is normally permitted in UK airspace only, by day, and in accordance with the Visual Flight Rules.

Flying Training.
Currently, 32 hours of flying training is required for the issue of a UK NPPL (A), of which 22 hours are to be dual instruction, and 10 hours to be supervised solo flying time.

There are separate general and navigation skills tests.

Theoretical Knowledge Examinations.
The UK NPPL theoretical knowledge syllabus and ground examinations are the same as for the JAA PPL (A). This series of books, therefore, is also suitable for student pilots preparing for the UK NPPL.

THE UNITED KINGDOM FLIGHT RADIOTELEPHONY OPERATOR'S LICENCE.

Although there is a written paper on Radiotelephony Communications in the JAA PPL theoretical knowledge examinations, pilots in the United Kingdom, and in most other countries, who wish to operate airborne radio equipment will need to take a separate practical test for the award of a Flight Radiotelephony Operators Licence (FRTOL). For United Kingdom based students, full details of the FRTOL are contained in LASORS.

NOTES ON CONTENT AND TEXT.

Technical Content.

The technical content of this OAA series of pilot training text books aims to reach the standard required by the theoretical knowledge syllabus of the JAA Private Pilot's Licence (Aeroplanes), (JAA PPL(A)). This is the minimum standard that has been aimed at. The subject content of several of the volumes in the series exceeds PPL standard. However, all questions and their answers, as well as the margin notes, are aimed specifically at the JAA PPL (A) ground examinations.

An indication of the technical level covered by each text book is given on the rear cover and in individual subject prefaces. The books deal predominantly with single piston-engine aeroplane operations.

Questions and Answers.

Questions appear at the end of each chapter in order that readers may test themselves on the individual subtopics of the main subject(s) covered by each book. The questions are of the same format as the questions asked in the JAA PPL (A) theoretical knowledge examinations, as administered by the UK CAA. All questions are multiple-choice, containing four answer options, one of which is the correct answer, with the remaining three options being incorrect “distracters”.

Students Working for a Non-JAA PPL.

JAA licence training syllabi follow the basic structure of ICAO-recommended training, so even if the national PPL you are working towards is not issued by a JAA member state, this series of text books should provide virtually all the training material you need. Theoretical knowledge examinations for the JAA PPL are, however, administered nationally, so there will always be country-specific aspects to JAA PPL examinations. ‘Air Law’ is the most obvious subject where country-specific content is likely to remain; the other subject is ‘Navigation’, where charts will most probably depict the terrain of the country concerned.

As mentioned elsewhere in this Foreword, this series of books is also suitable for student pilots preparing for the United Kingdom National Private Pilot's Licence (UK NPPL). The theoretical examination syllabus and examinations for the UK NPPL are currently identical to those for the JAA PPL.

Student Helicopter Pilots.

Of the seven book in this series, the following are suitable for student helicopters pilots working towards the JAA PPL (H), the UK NPPL (H) or the equivalent national licence:

Volume 1: ‘Air Law & Operational Procedures’; Volume 2: ‘Human Performance’; Volume 3: ‘Navigation & Radio Aids’; Volume 4: ‘Meteorology’, and Volume 7: ‘Radiotelephony’.

The OAAmedia Website.

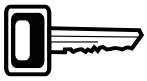
If any errors of content are identified in these books, or if there are any JAA PPL (A) theoretical knowledge syllabus changes, Oxford Aviation Academy's aim is to record those changes on the product support pages of the OAAmedia website, at:
www.oaamedia.com

Grammatical Note.

It is standard grammatical convention in the English language, as well as in most other languages of Indo-European origin, that a single person of unspecified gender should be referred to by the appropriate form of the masculine singular pronoun, *he*, *him*, or *his*. This convention has been used throughout this series of books in order to avoid the pitfalls of usage that have crept into some modern works which contain frequent and distracting repetitions of *he or she*, *him or her*, *etc*, or where the ungrammatical use of *they*, and related pronouns, is resorted to. In accordance with the teachings of English grammar, the use, in this series of books, of a masculine pronoun to refer to a single person of unspecified gender does not imply that the person is of the male sex.

Margin Notes.

You will notice that margin notes appear on some pages in these books, identified by one of two icons:

a key  or a set of wings .

The key icon identifies a note which the authors judge to be a key point in the understanding of a subject; the wings identify what the authors judge to be a point of airmanship.

The UK Theoretical Knowledge Examination Papers.

The UK CAA sets examination papers to test JAA PPL (A) theoretical knowledge either as single-subject papers or as papers in which two subjects are combined.

Two examination papers currently cover two subjects each:

- **Aircraft (General) & Principles of Flight**: The 'Aircraft (General) & Principles of Flight' examination paper, as its title suggests, covers 'Principles of Flight' and those subjects which deal with the aeroplane as a machine, 'Airframes', 'Engines', 'Propellers' and 'Instrumentation', which JAR-FCL groups under the title 'Aircraft General Knowledge'.

- **Flight Performance & Planning:** The examination paper entitled 'Flight Performance & Planning' covers both 'Aeroplane Performance, and 'Mass & Balance'.

When preparing for the two examinations named above, using this Oxford series of text books, you will need **Volume 5, 'Principles of Flight'**, which includes 'Aeroplane Performance', and **Volume 6, 'Aeroplanes'**, which includes 'Mass & Balance' as well as 'Airframes', 'Engines', 'Propellers', and 'Instrumentation'. So to prepare for the 'Aircraft (General) & Principles of Flight' examination, you need to take the **'Aeroplanes'** infomation from **Volume 6** and the **'Principles of Flight'** information from **Volume 5**. When you are preparing for the 'Flight Performance & Planning' examination you need to take the **'Aeroplane Performance'** information from **Volume 5** and the **'Mass & Balance'** information from **Volume 6**.

It has been necessary to arrange the books in this way for reasons of space and subject logic. The titles of the rest of the volumes in the series correspond with the titles of the examinations. The situation is summed up for you in the table on the following page:

JAA Theoretical Examination Papers	Corresponding Oxford Book Title
Air Law and Operational Procedures	Volume 1: Air Law
Human Performance and Limitations	Volume 2: Human Performance
Navigation and Radio Aids	Volume 3: Navigation
Meteorology	Volume 4: Meteorology
Aircraft (General) and Principles of Flight	Volume 5: Principles of Flight Volume 6: Aeroplanes
Flight Performance and Planning	Volume 5: Aeroplane Performance Volume 6: Mass and Balance
JAR-FCL Communications (PPL)	Volume 7: Radiotelephony

Regulatory Changes.

Finally, so that you may stay abreast of any changes in the flying and ground training requirements pertaining to pilot licences which may be introduced by your national aviation authority, be sure to consult, from time to time, the relevant publications issued by the authority. In the United Kingdom, the Civil Aviation Publication, LASORS, is worth looking at regularly. It is currently accessible, on-line, on the CAA website at **www.caa.co.uk**.

Oxford,
England

August 2011

TO THE PILOT.

A pilot is required by law, before he goes flying, to obtain an appropriate aviation weather forecast, either for the local area or for his route and destination airfield, and to assure himself that, given the weather conditions, his qualifications, and his aircraft's performance and equipment, the planned flight can be carried out safely.

From the earliest days of aviation, pilots have needed to acquire a deep knowledge of the winds and weather in order to fly safely.

In the days before specialised aviation forecasts, it was crucial that pilots should know how to assess the present and developing weather situation by analysing variations in atmospheric pressure and reports from meteorological observation posts, before getting airborne. Once in the air, pilots had to be capable of interpreting changes in the wind, and cloud formations, in order to judge whether or not it was prudent to continue with their flight. It should not, therefore, be in any way surprising that, since the very beginnings of manned-flight, Meteorology has been a core groundschool subject in pilot training.

Even in today's world of advanced technology where aircraft can almost fly and navigate themselves, and where accurate weather forecasts are available to all pilots, amateur as well as professional, a thorough understanding of the weather phenomena that an aircraft may encounter in flight is no less important to the pilot than it was at the dawn of aviation.

Advances in weather forecasting, and their increasing availability to all pilots, should have almost eliminated aircraft accidents occurring because pilots fly, unawares, into deteriorating weather conditions. But this has not been the case. The factor that has not changed over the passing years is, of course, that of human fallibility, and so, despite increasingly accurate and available weather forecasts, between 15% and 20% of all aircraft accidents and fatalities, in general aviation, are weather related. This proportion of weather-related accidents has remained constant over very many years, and suggests that it is the pilot's understanding of weather phenomena and interpretation of the developing meteorological situation which have not kept pace with advances in weather forecasting.

General aviation pilots operating light aircraft remain particularly vulnerable to adverse weather conditions, because of a combination of factors. There is the light structure and basic instrumentation of the aeroplane, the probable lack of formal, programmed training of the pilot, and the sometimes basic nature of any operational support from air traffic control and meteorological services.

Pilot error is, however, by far the most significant factor in aircraft accidents. Pilot error accounts for almost 75% of all aircraft accidents, world-wide, and, within that category, the proportion of accidents caused by weather-related pilot error is high.

A study of general aviation accidents in the USA, conducted by the Aircraft Operators' and Pilots' Association (AOPA), over a period of 11 years, found that the four most common causes of weather-related accident were connected with the pilot's inadequate appreciation of, or handling of, wind, visibility, airframe and induction icing, and thunderstorms. Over the period, in the USA, there were 5 894 fixed-wing light aircraft accidents related to the weather categories just mentioned, of which more than 1 700 were fatal. Of the fatal accidents, the unplanned passage of VFR flight into Instrument Meteorological Conditions (IMC) was the leading cause. Most accidents occurred between 9 am and 6 pm on Saturdays and Sundays, which points to the heavy toll borne by the recreational pilot.

Perhaps the most telling aspect of the VFR into IMC accidents was that two thirds of the pilots involved had had access to weather briefings which indicated that the weather was unsuitable for VFR flight.

It would seem, then, that the determination of some pilots to get airborne despite adequate warning of unsuitable weather conditions must be added to lack of understanding of the subject of Meteorology as a major cause of weather-related accidents.

It should, therefore, go without saying that all pilots need to strive to acquire a deep understanding of, and respect for, the weather, if they are to be confident of planning and conducting their flying in a safe and expeditious manner.

This book has been written with that aim in mind by instructors of CAE Oxford Aviation Academy, one of the world's leading professional flying training schools.

The book's primary aim is to provide both student and qualified general aviation pilots with pilot-oriented instruction in the theory of Aviation Meteorology and to teach them how to use their knowledge of weather theory to interpret meteorological forecasts and reports in order to carry out effective flight planning.

A further important aim of the book is to help student pilots prepare for the theoretical knowledge examination of the Part-FCL/EASA Private Pilot's Licence (PPL) in the subject of Meteorology.

It is hoped, too, that this book will constitute a sound introduction to the subject of Aviation Meteorology for those students preparing for professional pilot examinations.

A wise man once said that whereas aviation, in itself, is not inherently dangerous, it is, to an even greater extent than the sea, terribly unforgiving of any carelessness, incapacity or neglect. There is no aspect of flying to which this truth is more applicable than to that of the pilot's need to acquire a thorough understanding of the weather.

CHAPTER 1
THE ATMOSPHERE

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INTRODUCTION.

An understanding of the Earth's Atmosphere is fundamental to a pilot's training. The atmosphere is not just the air he breathes, but also the environment in which he flies. This environment can be benign, but may also be very hazardous.

The total depth of the atmosphere is difficult to determine. As altitude increases, the atmosphere becomes slowly thinner and thinner, gradually merging with inter-planetary space. What may be stated with some certainty, though, is that spacecraft, returning to Earth, begin to experience atmospheric effect at an altitude of approximately 120 kilometres (400 000 feet).

Figure 1.1 The Earth is surrounded by a gaseous envelope which we call the "atmosphere".

An atmosphere, in planetary terms, is defined as being "the gaseous envelope surrounding a celestial body". The Earth's atmosphere is the collection of gases which is held around the Earth by gravity. There are over twenty gases making up the Earth's atmosphere, some of which are much more abundant than others.

THE COMPOSITION OF THE ATMOSPHERE.

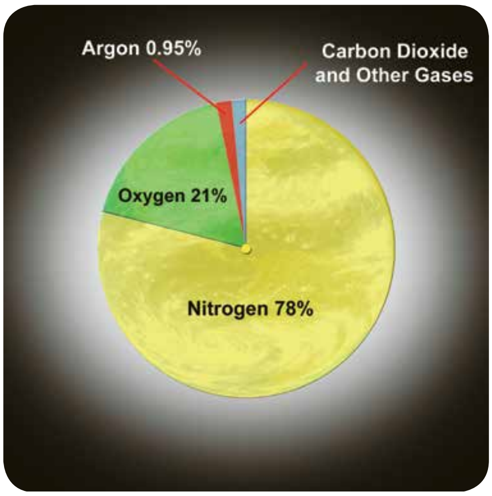

Figure 1.2 The composition of the Earth's atmosphere.

By far the most common gas in the Earth's atmosphere is Nitrogen, which accounts for about 78% of the atmospheric gases. Oxygen, which is essential to sustaining life and the proper functioning of internal combustion engines, makes up just 21% of the atmosphere. Argon makes up less than 1% of the atmosphere. Carbon Dioxide and trace gases are the remaining gases. Trace gases include Carbon Monoxide, Helium, Methane, Ozone and Hydrogen.

The atmosphere consists of 78% Nitrogen, 21% Oxygen, with 1% of other gases, including Carbon Dioxide and Argon.

One of the gases present in the atmosphere in variable concentrations is water vapour (H_2O), a combination of the gases Hydrogen and Oxygen. By volume, water vapour can make up between 0% and 7% of the atmosphere. Water vapour has by far the greatest effect on our weather. Without water vapour, there would be no clouds or precipitation. Water vapour is invisible as a gas; however, it becomes visible when it is in the liquid (water) or solid (ice) state. Most of the atmosphere's water vapour is contained in its lowest layer (the Troposphere), near the Earth's surface.

Water vapour can make up between 0% and 7% of the atmosphere. Water vapour is mainly found in the Troposphere. Without water vapour, there would be no weather.

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Clouds and rain are examples of water vapour's liquid state; snow and hail are examples of its solid state.

The proportions of the atmospheric gases are fairly constant up to about 60 km above the Earth; thereafter, gravitational separation alters the proportions of these gases. However, further explanation of this phenomenon is beyond the scope of this book.

The atmosphere is composed of various layers, which have discrete properties. In order to define the structure of the atmosphere, a property which varies with height must be identified. Though several properties of the atmosphere vary with height, the defining property, for meteorologists, is temperature.

STRUCTURE OF THE ATMOSPHERE.

The atmosphere has a layered structure, as depicted in *Figure 1.3*. Generally speaking, the light aircraft pilot is concerned only with the Troposphere because of the limit to the operating altitude of his aircraft; but brief mention, too, will be made of the Stratosphere, the layer above the Troposphere.

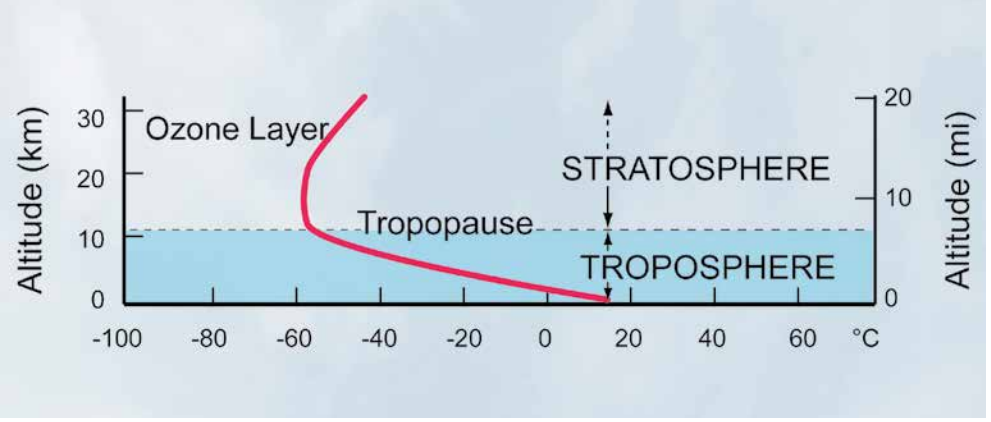
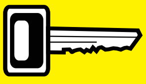


Figure 1.3 In the Troposphere, temperature decreases with height.

The Troposphere.



Almost all of the Earth's weather occurs in the Troposphere.

The lowest layer of the atmosphere is known as the Troposphere, from the Greek word tropos meaning mixing or turning, which undoubtedly refers to the fact that it is in the Troposphere that temperature and pressure changes cause the meeting and mixing of air which gives rise to our weather. Almost all of the Earth's weather occurs in the Troposphere.

The troposphere has two defining characteristics.

Firstly, the troposphere exhibits a marked decrease in temperature with height, throughout its vertical extent. This variation of temperature within the Troposphere, together with the fact that the Troposphere contains the major part of the atmosphere's water vapour, causes instability within the lower atmosphere, resulting in clouds, precipitation (e.g. rainfall or snowfall) and weather systems. Atmospheric instability is explained further in Chapter 8.

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Secondly, the Troposphere contains over 70% of the total mass of the atmosphere. This is because air is compressible, and has mass. Air is subject to the effects of the Earth's gravitational field, with most of the air mass being held close to the Earth's surface where the force of gravity is greatest. Furthermore, the air near the Earth's surface is compressed by the weight of the air above it. This means that air pressure and air density are greatest near the surface of the Earth and decrease with increasing altitude.

The upper limit of the Troposphere is defined as the point where temperature no longer decreases with height. This upper boundary is called the Tropopause.

The height of the Tropopause varies from 16 km over the Equator to 8 km over the poles. The average height of the Tropopause is 11 km at 45º of latitude. 11 km is the height of the tropopause assumed in the ICAO Standard Atmosphere.

The thickness of the Troposphere, and therefore the height of the Tropopause, is not constant around the Earth. (*See Figure 1.4.*) Above the Earth's geographical North and South Poles, the height of the Tropopause is about 8 km, whereas over the Equator the Tropopause can be twice that height, at around 16 km. This height difference in the Tropopause is caused by variations in the surface temperature of the Earth. Where the Earth is warmest, near the Equator, the Tropopause is at its highest. Over the poles, where the air is very cold, the Tropopause is at its lowest. The mechanisms for these variations in temperature are explained in greater detail in Chapter 4.

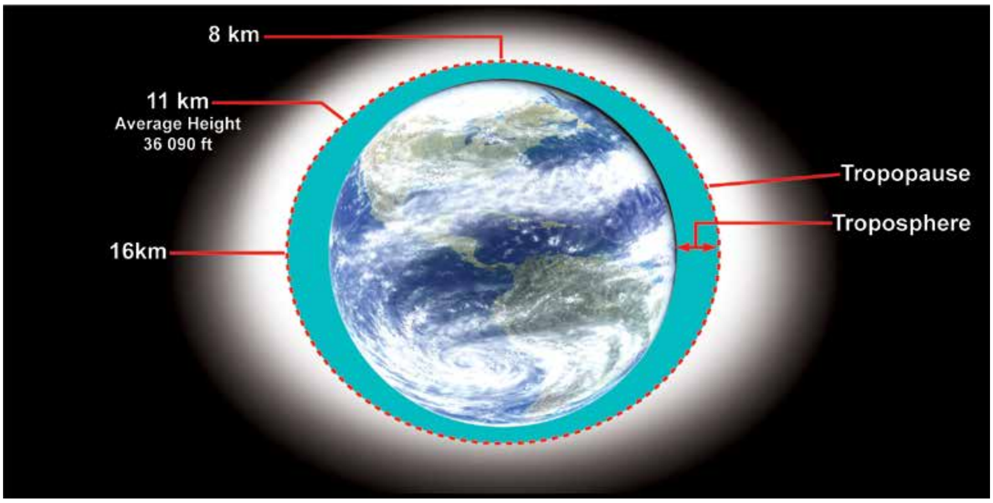

Figure 1.4 The Troposphere is thicker over the Equator than over the Poles.

The average height of the Tropopause, is around 11 km, or 36 090 feet. This is the height of the Tropopause at about 45° latitude, and is also the average height assumed in the ICAO Standard Atmosphere (ISA) which will be described later in this chapter.

The higher the Tropopause, the lower is its temperature. Over the Equator, the Tropopause temperature can be -80°C, whereas over the Poles its temperature is about -40°C. The average temperature of the Tropopause is approximately -56°C. This temperature prevails in the mid-latitudes, where, as previously mentioned, the height of the Tropopause is approximately 11 km.

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The Stratosphere.

The atmospheric layer above the Tropopause is called the Stratosphere. *(See Figure 1.5).* The Stratosphere, unlike the Troposphere, is characterised by the lack of any significant change in temperature with height, especially in its lower layer. *(See Figure 1.3).*

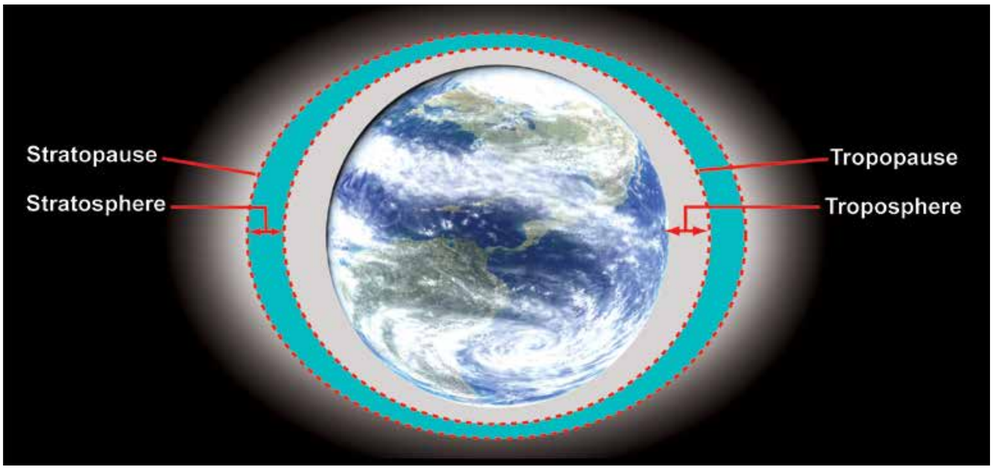

Figure 1.5 The Stratosphere is the layer above the tropopause.

The Tropopause generally marks the upper limit of the Earth's weather. Most of the Earth's weather occurs in the Troposphere.

This absence of any significant temperature variation within the lower Stratosphere gives the air of the Stratosphere stability. In other words, vertical movement of air within the Stratosphere is severely restricted, because temperature variation, which is the mechanism for this vertical movement, is no longer present. Cloud development, therefore, is curtailed, and so the Tropopause marks the upper limit of the majority of weather phenomena experienced within the atmosphere.

The temperature of the Stratosphere, in fact, rises a little in the upper levels, due to the presence of Ozone. Further explanation of this phenomenon, however, is outside the scope of this book.

The upper boundary to the Stratosphere is called the Stratopause. Above the Stratopause, temperature begins to increase with height. The Stratopause is usually found around 50 km above the surface of the Earth.

At altitudes greater than **50 km**, we enter the realms of the atmosphere reserved for rocket-propelled craft and astronauts. So we will end our account of temperature variation with altitude at the Stratopause.

THE ICAO STANDARD ATMOSPHERE.

Changes of air pressure, air density, air temperature and humidity within the atmosphere greatly affect the performance of an aircraft in flight, as well as the readings of certain flight instruments. In the real atmosphere, of course, these properties are changing continuously with altitude, with passing time, and from place to place. In order, therefore, that aerodynamicists, aircraft manufacturers and engineers might have a set of standard values for pressure, density, temperature etc, against which to measure aircraft performance and to calibrate instruments, a so-called standard atmosphere has been defined by the International Civil Aviation Organisation (ICAO).

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In 1964, the International Civil Aviation Organisation, ICAO, defined the properties of an average, or "standard" atmosphere. This is known as the ICAO Standard Atmosphere (ISA). This model of the ISA is limited to a height of 32 km, or about 105 000 feet above mean sea-level; however, this height is well above the maximum ceiling attainable by any current conventional aircraft.

ISA is one of several types of standard atmosphere devised over the years. However, it is the most widely recognised model and the only one of relevance to light aircraft pilots. The variations of temperature, pressure and density within the ISA are depicted in *Figure 1.6.*

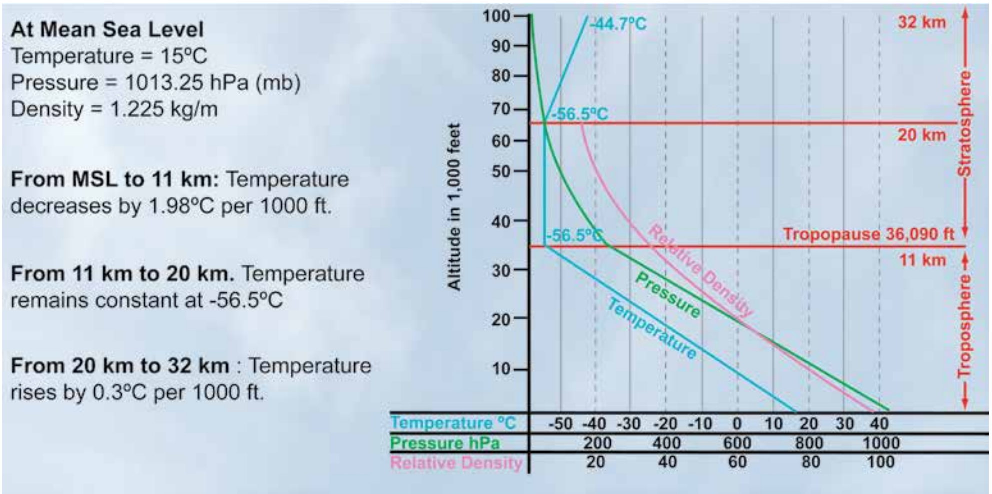

Figure 1.6. Graph showing the ICAO Standard Atmosphere.

ISA assumes that, at mean sea-level, air temperature is 15°C, air pressure is 1013.25 hectopascals (millibars) and air density is 1.225 kg/m³.

ISA assumes that, at mean sea-level, air temperature is 15°C, air pressure is 1013.25 hectopascals (millibars), and air density is 1.225 kg/m³.

From mean sea-level to 11 km, or 36 090 feet, the temperature decreases by 0.65°C per 100 m, or 1.98°C per 1 000 feet. This is known as the environmental lapse rate. Above 11 km, the average height of the Tropopause, temperature no longer falls with height, until beyond the upper limit of the Stratosphere.

From mean sea-level to 11 km or 36 090 feet, the temperature decreases by 1.98°C per 1 000 feet or 0.65°C per 100 m. This is known as the ***environmental lapse rate****. Above 11 km, the Tropopause, the temperature remains constant in the lower part of the Stratosphere, up to an altitude of 20 km.*

Within the Stratosphere, above 11 km and up to 20 km, the temperature remains constant at -56.5°C. Above 20 km and up to 32 km, however, the temperature increases very slowly at a rate of 0.3°C per 1 000 feet or 0.1°C per 100 m.

Deviations of Actual Atmospheric Conditions from ISA.

Since all aircraft instruments are calibrated in accordance with ISA, it is essential to know by how much actual atmospheric conditions, on a given day, differ from the ISA model.

Comparing ISA with the actual atmospheric conditions helps quantify errors in flight instrument readings, and, thereby permits those errors to be corrected.

An ISA deviation example is depicted in *Figure 1.7.* An airfield is 1 000 feet above sea-level. In the ISA, the mean sea-level temperature of the atmosphere is 15°C, which then falls by 1.98°C for every 1 000 feet increase in altitude, up to 11 km. (In examinations, for simplicity of calculation, an ISA environmental lapse rate of 2°C per 1 000 feet is assumed).

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Therefore, the temperature at 1 000 feet should be approximately 13°C. However, in the example depicted in *Figure 1.7*, the actual temperature at 1 000 feet is 20°C, which is much higher than the ISA temperature. A simple calculation reveals that the real atmosphere is 7°C warmer than ISA; so the temperature at 1 000 feet is described as ISA +7°C.

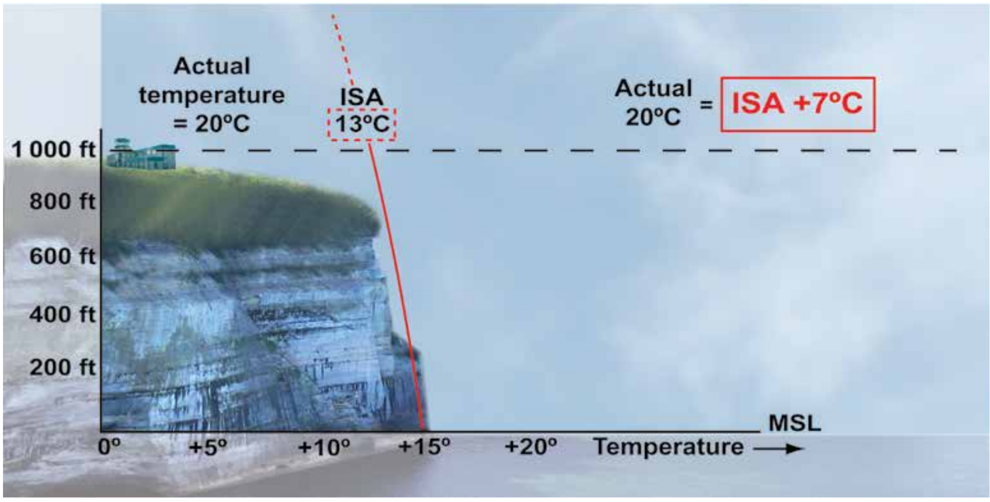

*Figure 1.7 At 1 000 feet AMSL, the ISA temperature is 13°C, but, here, the actual temperature is 20°C. The ISA deviation is written as **ISA+7°C**.*

A further ISA deviation example is illustrated in *Figure 1.8.* In this example, the actual temperature at 10 000 feet is -15°C. What, then, is the ISA deviation?

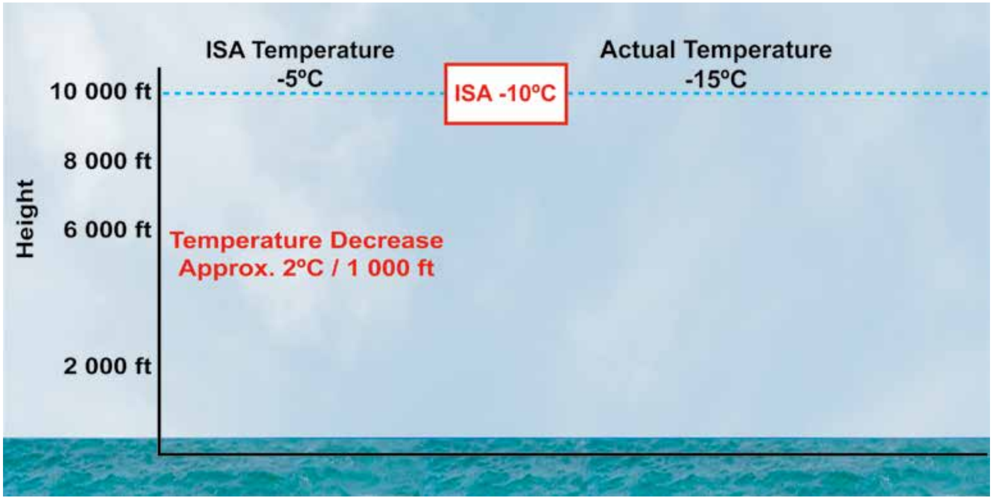

*Figure 1.8 At 10 000 feet AMSL, the ISA temperature is -5ºC. But the actual temperature is -15ºC. ISA deviation is, therefore, **ISA -10°C**.*

For ease of calculation, an ISA lapse rate of 2°C per 1 000 feet , rather than 1.98°C per 1 000 feet, is generally assumed.

In the ISA, temperature falls by approximately 2°C per 1 000 feet and, so, temperature should decrease from sea-level to 10 000 feet by 20°C. The ISA temperature of the air at sea-level is 15°C, and so 15°C minus 20°C would give an ISA temperature at 10 000 feet of -5°C. If the actual temperature, however, is -15°C, a simple calculation shows that the real atmosphere is 10°C colder than ISA; therefore, the deviation is given as ISA -10°C.

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Representative PPL - type questions to test your theoretical knowledge of The Atmosphere.

1. What is the value of the environmental temperature lapse rate assumed by the ICAO Standard Atmosphere?

   a. 1°C / 1 000 feet
   b. 1.5°C / 1 000 feet
   c. 3°C / 1 000 feet
   d. 1.98°C / 1 000 feet

2. In which atmospheric layer is most of the water vapour contained?

   a. Tropopause
   b. Stratosphere
   c. Troposphere
   d. Stratopause

3. On a given day, the air temperature at 2000 feet above mean sea-level is forecast to be 5°C. Compared to the ICAO Standard Atmosphere this is:

   a. ISA -6
   b. ISA +6
   c. ISA +5
   d. ISA -5

4. Below the Tropopause, the ICAO Standard Atmosphere assumes:

   a. A mean sea-level pressure of 1013.25 hPa and a mean sea-level temperature of 15°C, decreasing at a rate of 3°C per 1 000 feet until it reaches -65.6°C at 36 090 feet
   b. A mean sea-level pressure of 1013.25 hPA and a sea-level temperature of 15°C, decreasing at a rate of 1.98°C per 1 000 feet until it reaches absolute zero
   c. A mean sea-level pressure of 1013.25 hPA and a sea-level temperature of 15°C, decreasing by 1.98°C per 1 000 feet up to 36 090 feet
   d. A mean sea-level pressure of 1225 gm/m³ a mean sea-level temperature of 15°C, decreasing at a rate of 1.5°C per 1 000 feet up to 36 090 feet

5. Which of the following statements gives the most correct and complete description of ISA?

   a. The mean sea-level (MSL) pressure is 1013.25 hPa and the temperature is +15°C
   b. The MSL pressure is 1013.25 hPa and the temperature is +15°C with a lapse rate of 1.98°C per 1000 feet
   c. The MSL pressure is 1013.25 mb and the temperature is +15°C with a lapse rate of 1.98°C per 1000 feet up to 36,090 feet above which there is frequently an inversion
   d. The MSL pressure is 1013.25 hPa and the temperature is +15°C with a lapse rate of 1.98°C per 1000 feet up to 36,090 feet

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6. Which of the following options gives the most accurate description of the constituent gases of the Earth's atmosphere? (Ignore the variable concentration of water vapour in the atmosphere.)

   a. Oxygen 21%, Nitrogen 78%, other gases 1%
   b. Oxygen 21%, Hydrogen 78%, other gases 1%
   c. Nitrogen 78%, Argon 21%, Oxygen 1%
   d. Nitrogen 78%, Oxygen 21%, Hydrogen 1%

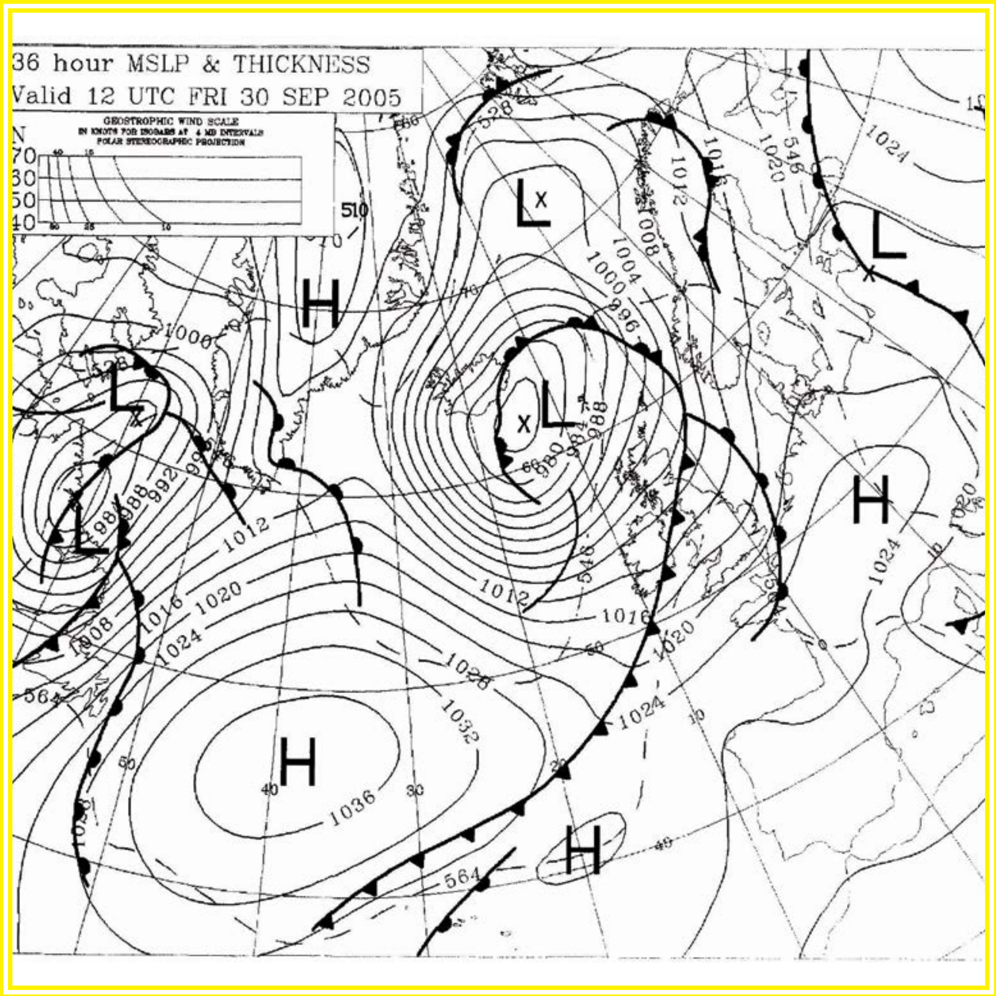
7. The layer of the atmosphere closest to the Earth's surface where the majority of the weather is found is called the:

   a. Tropopause
   b. Troposphere
   c. Stratosphere
   d. Mesosphere

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Answer							

The answers to these questions can be found at the end of the book.

CHAPTER 2
ATMOSPHERIC PRESSURE



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INTRODUCTION.

Understanding the variations in atmospheric pressure across the Earth's surface is fundamental to an understanding of the weather, itself. But what is the fundamental cause of atmospheric pressure?

Atmospheric pressure is caused by the weight of the overlying air, and acts in all directions.

Expressed simply, atmospheric pressure, which acts on any object immersed in the atmosphere, is caused by the weight of air above that object. Atmospheric pressure acts in all directions.

The forces generated by horizontal pressure differences across the Earth's surface give rise to both horizontal, and vertical air movement, creating winds and clouds.

Variations in atmospheric pressure, both vertical and horizontal, are fundamental to the formation of weather patterns.

The variation of atmospheric pressure with altitude allows us to measure the vertical separation of an aircraft from the Earth's surface, using an instrument called an altimeter.

The Fundamental Cause of Atmospheric Pressure.

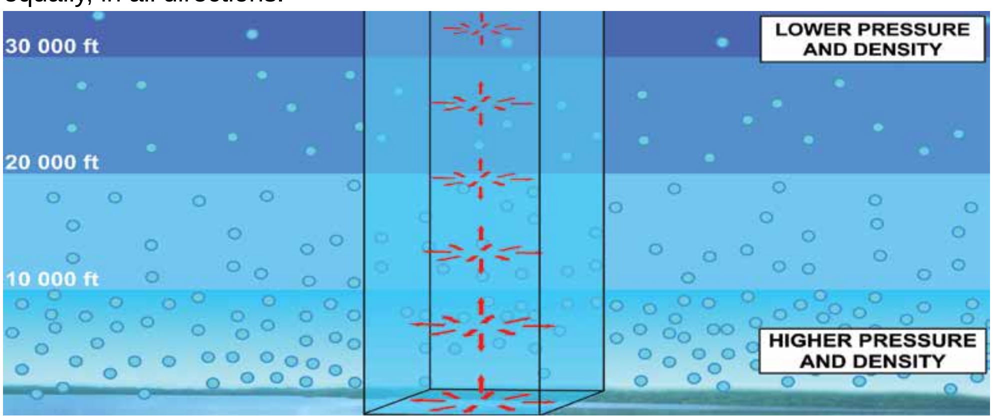
The air which constitutes our atmosphere is made up of billions of molecules. The atmosphere, therefore, has mass, and, as a result of the Earth's gravitational field pulling the mass of the atmosphere towards the centre of the Earth, air possesses weight.

The pressure of the atmosphere at any point is caused by the weight of the column of air overlying that point. Atmospheric pressure (sometimes, in other branches of aeronautics, called static pressure) acts in all directions on any object contained within the atmosphere.

Most of the mass of the atmosphere is contained in its lower layers near the Earth's surface. This is because of the action of the Earth's gravitational field on the air molecules (the force of gravity being greater near the surface), combined with the fact that air is compressible. The air in the lower layers of the atmosphere is compressed by the weight of the air above it. Consequently, air is denser, and atmospheric pressure is greater, at the Earth's surface than at altitude.

Air has mass. Air exerts pressure because of gravity and the compressibility of air. Most of the total mass of the atmosphere is concentrated in its lower layers.

Figure 2.1 represents the relative distribution of molecules within the atmosphere, with more molecules in the lower part of the atmosphere than at altitude. The red arrows within the column of air illustrate that the atmosphere exerts its pressure equally, in all directions.



Atmospheric pressure (and density) reduces with increasing altitude.

Figure 2.1 Atmospheric Pressure is the force or weight exerted on any object by the column of air above that object. Atmospheric (or static) pressure acts in all directions and reduces with increasing altitude.

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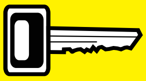
UNITS OF ATMOSPHERIC PRESSURE.



In the United Kingdom, the millibar is the standard unit of atmospheric pressure. In Europe, it is the hectopascal. In the USA, it is inches of Mercury.

In meteorology, the units commonly used to represent atmospheric pressure are inches of mercury, and millibars or hectopascals. The ICAO Standard Atmosphere (ISA) unit of pressure is the hectopascal, but, currently, the millibar is still used in the United Kingdom. The millibar and the hectopascal are identical in value. For instance, ISA sea-level pressure can be expressed as 1013.25 millibars or 1013.25 hectopascals.

In the United States of America, atmospheric pressure is expressed in inches of Mercury. In inches of Mercury, ISA sea-level pressure is 29.92 inches Hg.

The instrument used to measure atmospheric pressure is the barometer (from Greek “baros” meaning weight and “metron” meaning measure). A barometer can be one of two distinct types: the aneroid barometer or the mercury barometer.

The Mercury Barometer.

The mercury barometer consists of a glass tube, sealed at one end, containing Mercury, with the open end immersed in an open mercury reservoir, in the form of a dish *(Figure 2.2)*.

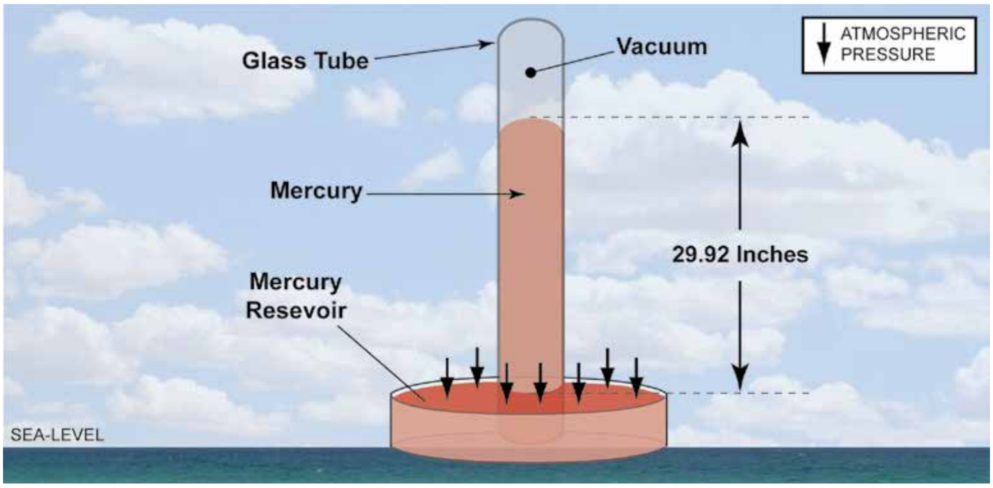


Figure 2.2 A simple Mercury Barometer. In ISA sea-level conditions, atmospheric pressure will support a column of Mercury 29.92 inches in height.

The weight of the column of Mercury in the glass tube is balanced by atmospheric pressure exerted on the Mercury in the dish. In ISA sea-level conditions, the height of the Mercury column would be 29.92 inches. Changes in atmospheric pressure will either depress the Mercury in the open reservoir, forcing more of the Mercury up into the tube, or will allow the level of Mercury in the reservoir to rise, permitting the height of the Mercury in the glass tube to fall. The space above the column of Mercury in the tube is almost a vacuum.

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The Aneroid Barometer.

The aneroid barometer does not contain mercury or liquid, but measures the effect of air pressure on a partially evacuated metal capsule. *(See Figure 2.3.)*

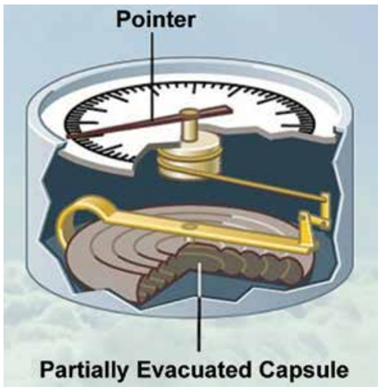

Figure 2.3 An Aneroid Barometer.

The aneroid barometer (from Greek "an" meaning no or none, and "aeras", meaning air) is less accurate overall than the mercury barometer, but is more sensitive to small changes in air pressure. Changes in air pressure cause the metal capsule to expand or contract; a mechanism connected to the capsule causes a needle or pointer to move around a calibrated scale. An aneroid barometer may be calibrated in inches of mercury or in millibars. However, an aneroid barometer can also be calibrated in feet or metres to indicate height above the Earth's surface; the instrument is then known as an altimeter.

Atmospheric pressure may be measured by a mercury barometer or an aneroid barometer. The barograph is a particular kind of aneroid barometer which records pressure change against time.

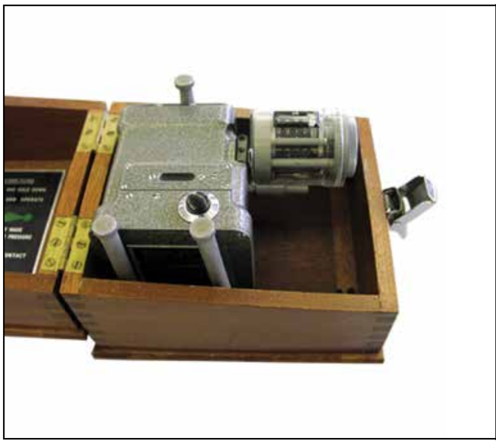
Figure 2.4 A typical aneroid barometer used by Air Traffic Service Units to measure atmospheric pressure at an aerodrome.


Figure 2.5 A barograph, used to record the variation of air pressure with time, on a cylindrical pressure chart.

An example of a portable aneroid barometer used widely by Air Traffic Service Units to measure pressure at the Earth's surface is shown in *Figure 2.4.*

A barograph is an aneroid barometer which records pressure against time on a cylindrical chart. The barograph is usually driven by clockwork. *(See Figure 2.5.)*

PRESSURE VARIATIONS AT THE EARTH'S SURFACE.

Horizontal variations in surface pressure arise because of the differences in weight of different columns of air overlying different locations on the Earth's surface.

Comparatively speaking, if there is a greater mass of air above a given area on the Earth's surface, then the atmosphere will be exerting more pressure on that area. If, in another location, there is less air above the Earth's surface, the atmosphere will be exerting less pressure on the surface. Therefore, high or low surface pressures are a direct consequence of the weight of the mass of the air overlying a given locality, as depicted in *Figure 2.6*.

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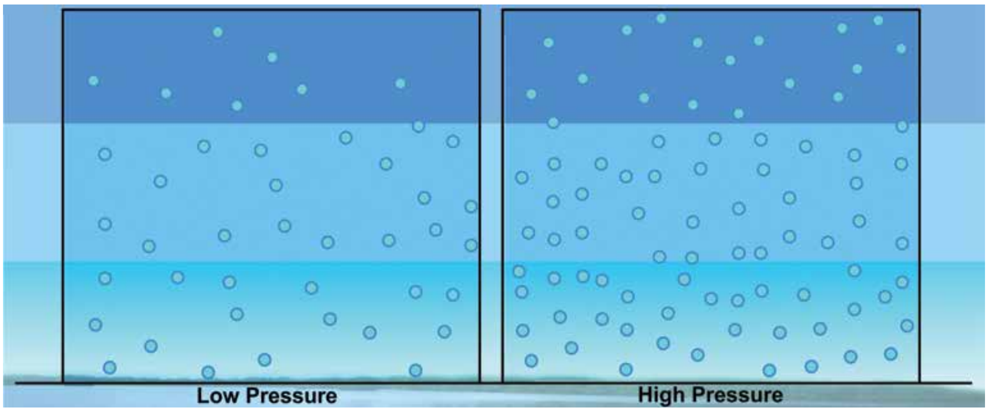

Figure 2.6 Surface pressure at a given location on the Earth depends on the weight of the air above that location.

Surface pressure is a function of the weight of the column of air above any given point on the Earth's surface.

The mechanisms which give rise to these differences in surface pressure are described below. Diagrammatic representations of variations in surface pressure allow us to identify areas of high and low pressure on the Earth's surface. By mapping these pressure variations, it is possible to analyse and, therefore, predict the weather. Diagrams of variations in surface pressure are called surface pressure charts, or, sometimes, synoptic charts (from synopsis meaning a general view).

MEAN SEA-LEVEL SURFACE PRESSURE CHARTS.

Figure 2.7 shows a typical surface pressure chart. Its interpretation and main features will be explained in the following paragraphs.

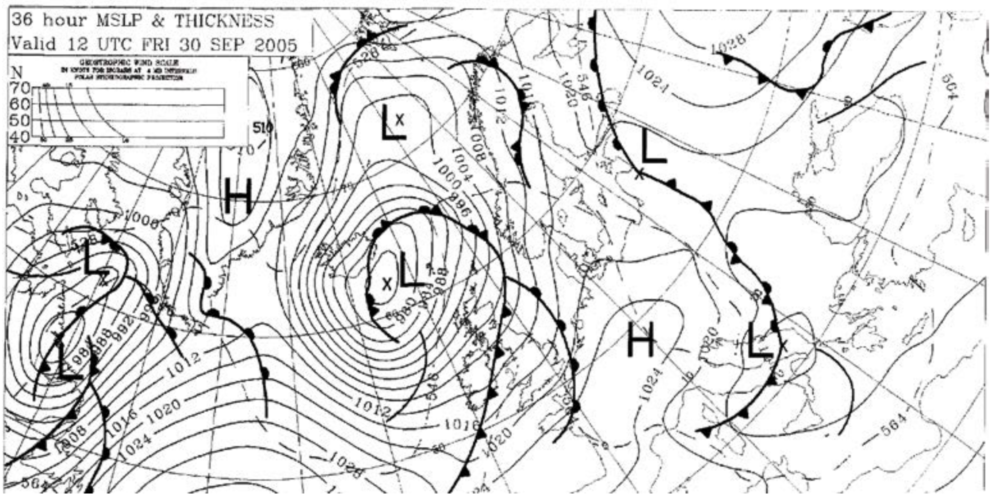

Figure 2.7 A Mean Sea-Level Surface Pressure Chart.

The Earth's surface is made up of plains, mountains, lakes and oceans, and, so, over the Earth's surface, there are wide variations in the elevation of terrain. Consequently, in order to obtain an accurate surface pressure chart, surface pressure readings need to be made with respect to a common vertical datum.

Mean sea-level is the usual datum from which pressures are measured.

The chart at *Figure 2.7* shows the actual horizontal variation in pressure on a given day (30 Sep 2005). The chart is made up of the individual observations taken at different reporting stations.

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Figure 2.8, on the other hand, shows a fictional example of reported mean sea level pressures from meteorological stations across the Earth's surface.

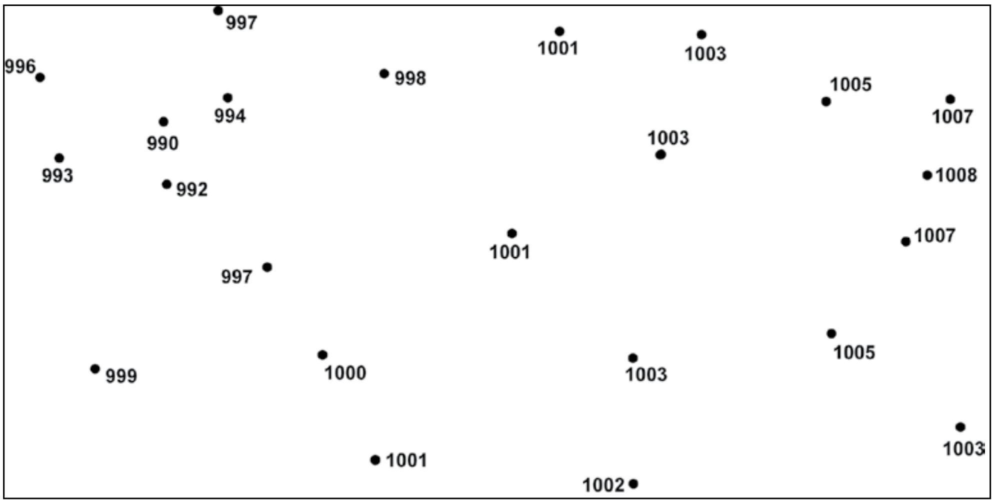

Figure 2.8 Pressure values at different locations, referenced to Mean Sea-Level.

To produce a Mean Sea Level Pressure Chart from the figures given in *Figure 2.8,* lines are drawn connecting all the stations with the same pressure readings. *(See Figure 2.9.)* These lines are called isobars (from Greek isos meaning equal and baros meaning weight).

An isobar is a line drawn on a chart joining points of equal atmospheric pressure at a given level.

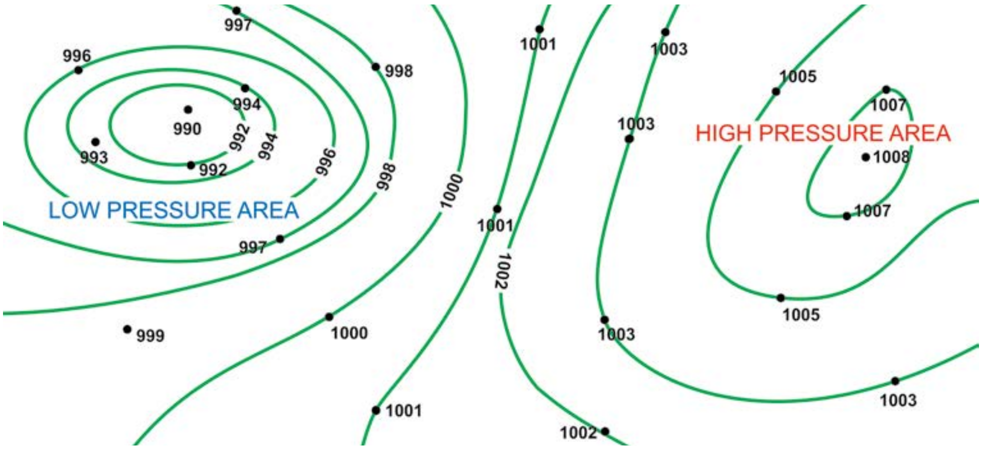

Figure 2.9 Lines connecting locations of equal atmospheric pressure are called isobars.

From the pressure values and isobars, relative areas of low and high atmospheric pressure can be identified. Isobars centred on an area of low pressure values indicate a low pressure area, and isobars centred on an area of relatively higher pressure values indicate an area of high pressure. The dimensions of these high and low pressure area systems can range from tens of nautical miles wide to hundreds, and sometimes a thousand miles wide.

*Low pressure areas are also called **depressions.** High pressure areas are also known as **anticyclones.***

Low pressure areas are known as depressions. High pressure areas are known as anticyclones.

Around the British Isles, the pressure at mean sea-level fluctuates between extremes of 950 millibars and 1050 millibars, but is usually around 1 000 millibars.

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THE PRESSURE GRADIENT FORCE.

The isobars themselves can reveal a great deal of useful information. Air will always tend to move from an area of high pressure to an area of low pressure. Consequently, a force exists which acts from the high pressure regions to the low pressure regions. This force is called the pressure gradient force. The direction of action of the pressure gradient force is shown in *Figure 2.10*.

Tightly spaced isobars indicate strong winds. Widely spaced isobars indicate light winds.

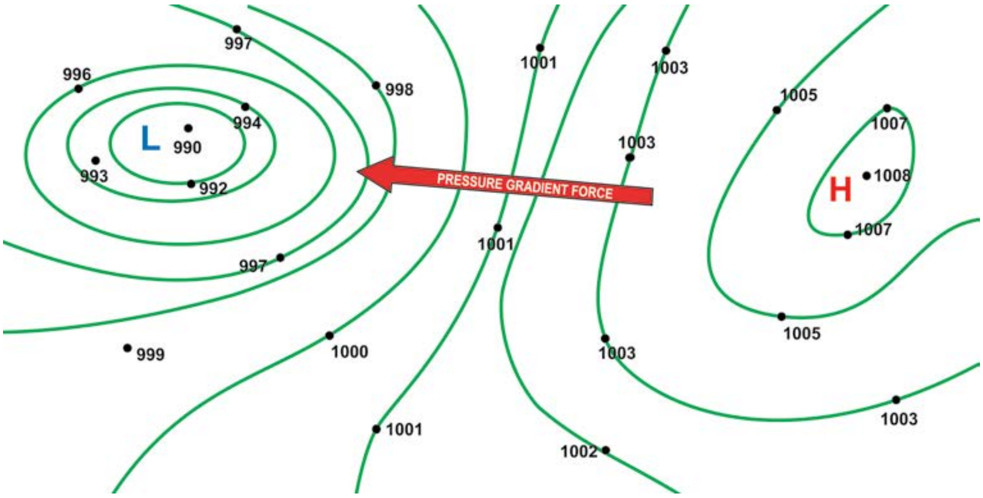

Figure 2.10 The force acting from the high pressure area (H) to the low pressure area (L) is called the ***Pressure Gradient Force****.*

The spacing between isobars is indicative of the relative strength of the pressure gradient force.

Isobars may be compared to contour lines on a topographical map, where the contour line spacing indicates the gradient of a slope. Closely spaced isobars show a large change in the pressure over a short distance, indicating the presence of a large pressure gradient force; this is common within low pressure areas. Widely spaced isobars show a small change in the pressure over a large distance, indicating a small pressure gradient force; this is common within high pressure areas. Wind speed and direction will be discussed in greater detail in Chapter 12.

VERTICAL PRESSURE VARIATION.

The relative number and distribution of air molecules shown in *Figure 2.11, opposite,* indicates that the higher an aircraft climbs in the atmosphere, the smaller will be the mass of air above the aircraft, and, therefore, the lower will be the atmospheric pressure exerted on the aircraft. So, as we have already mentioned, atmospheric pressure decreases with increasing altitude.

Atmospheric pressure falls very quickly with altitude near the Earth's surface, but, at high altitude, the rate of pressure reduction with height is much less marked. This is because most of the air is located close to the Earth's surface.

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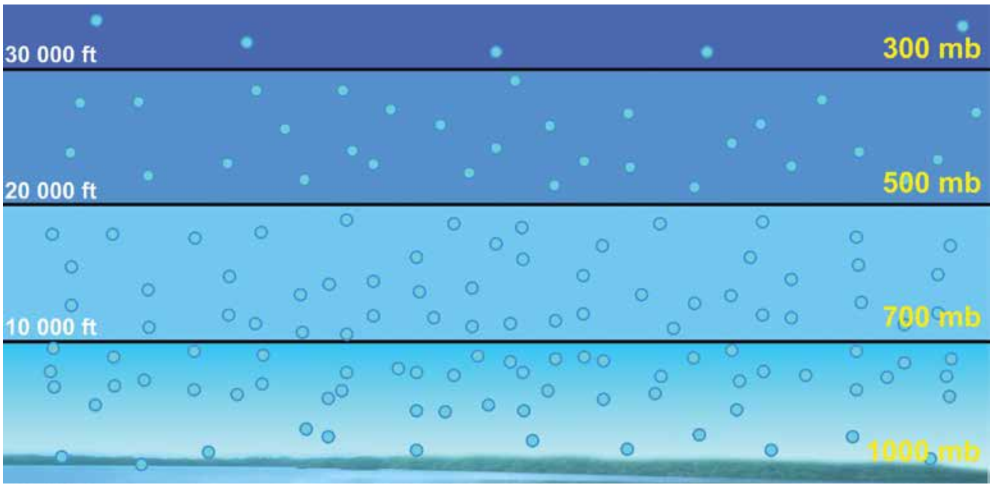

Figure 2.11 Pressure decreases with altitude. The rate at which pressure decreases with altitude also falls as altitude increases.

Pressure decreases with increasing height but the rate of pressure decrease with height is lower at higher altitudes.

In the ICAO Standard Atmosphere (ISA), the fall in pressure with height, close to sea-level, is approximately 1 millibar for every 27 feet. However, at 10 000 feet the rate of pressure decrease with altitude is less, being approximately 1 millibar for every 36 feet gain of height.

For the purposes of pressure versus height calculations, it is assumed that the average change of pressure with height, below the Tropopause, is 1 millibar for every 30 feet.

For calculations involving pressure versus height, assume that 1 mb = 30 ft, in the lower atmosphere.

The significance of pressure variations horizontally and vertically, will be covered in detail in the chapters on Pressure Systems, Wind, and Altimetry.

The Effect of Temperature on Vertical Pressure Variation.

However, even in identical atmospheric layers, the rate of pressure change with altitude is not always constant. Sometimes, pressure falls more rapidly with increasing altitude than at other times. The reason for this is the variations in temperature over the Earth's surface. In *Figure 2.12* you will see three different columns of air. For simplicity, we have included only six molecules of air per column.

Temperature affects the rate at which pressure decreases with altitude. In cold air, the rate of pressure decrease with altitude is greater than in warm air.

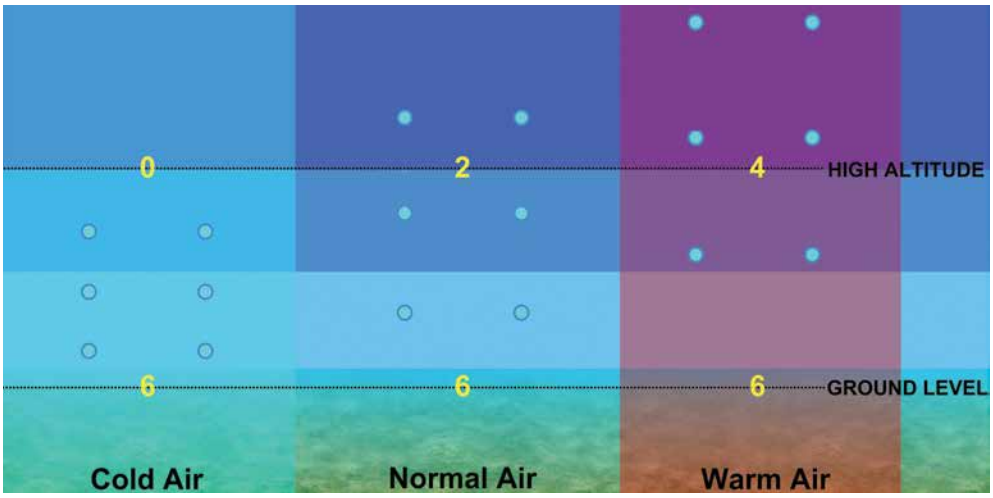

Figure 2.12 Cold air causes pressure to fall more rapidly with height. Warm air causes pressure to fall more slowly with height.

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Examine the column in the middle of *Figure 2.12*, which we will assume represents a "normal" atmosphere. As there are six molecules represented in each column, we will express the pressure at the Earth's surface, caused by the column of air, as six units. However, at high altitude, there are only two molecules, so we will express the atmospheric pressure at high altitude, in this column, as two units.

Now, look at the left hand column of air in *Figure 2.12*. Here, the air is colder, and, as a result, the air has become denser, with the air molecules collecting at the bottom of the column. Surface pressure is still six units, because there are still six molecules bearing down on the surface. However, because the air in this column is cold, there are no molecules at all at altitude; so pressure at altitude in this column, is approaching zero units. You can now see that cold air has caused the pressure to decrease much more rapidly with height than in the warmer air of the "normal" atmosphere. You will not be surprised to find that the opposite is true when the air is warmer than normal.

Examine the column of air on the right. Since this column represents warmer than normal air, the molecules have risen to the top of the column. There are still six molecules above the surface, so the pressure at the surface is still six units, but at altitude there are now four molecules; so pressure at altitude, in this column is 'four units'.

Notice how the warm air has caused the pressure to decrease with altitude much more slowly than normal.

In cold air, the rate of pressure decrease with altitude is higher than in warm air.

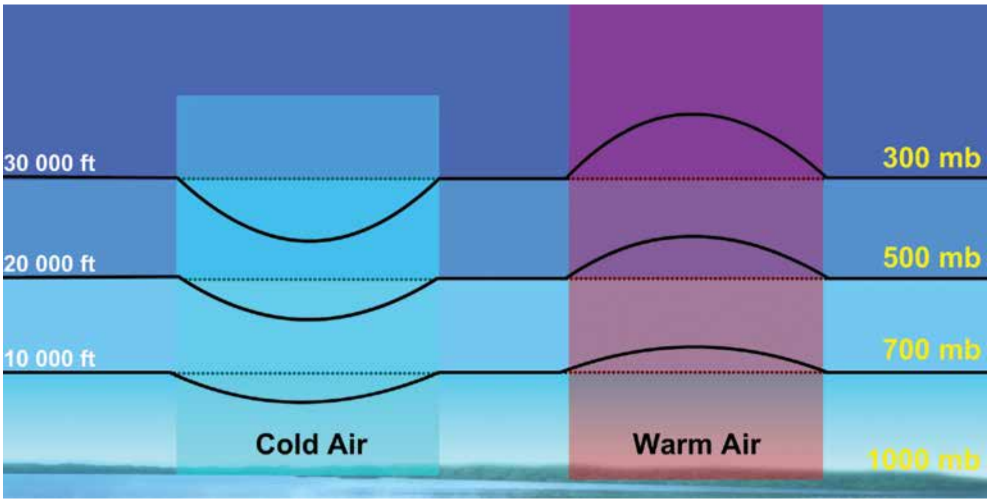

Figure 2.13 Cold air compacts pressure levels and warm air expands pressure levels.

The effect that temperature has on pressure change with height can also be shown in another way. *Figure 2.13* depicts a column of cold air on the left, and a column of warm air on the right. Notice that, since cold air causes pressure to fall more rapidly with height, the pressure levels in the cold air column are compressed towards the Earth's surface, whereas, in the warm air column, they expand away from the surface.

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The Effect of Temperature on Altimeter Readings.

The altimeter is calibrated in ISA conditions, so, if the temperature is other than the ISA value, the altimeter indication will be in error. You have already learnt that pressure changes with altitude at different rates, depending on the temperature of the air. Therefore, an altimeter is subject to temperature error.

So, the altimeter will read correctly only when ISA conditions prevail, which is almost never. However, altimeter temperature errors are not excessive.

The principle of altimeter temperature error is described briefly below.

In the ISA, if the atmospheric pressure were to be 300 millibars (or hectopascals), an altimeter would register a height of 30 000 ft. *(See Figure 2.14.)* However, if the atmosphere were to be colder than ISA, as shown on the left of *Figure 2.14*, the 300 millibar pressure level would be at a lower true altitude than 30 000 ft. But, because the altimeter has been calibrated to ISA, it would still read 30 000 ft at the 300 millibar level. The altimeter is, however, clearly in error, as the true altitude of the altimeter in the column of cold air is less than 30 000 ft. In the column of cold air, therefore, the altimeter is over-reading.

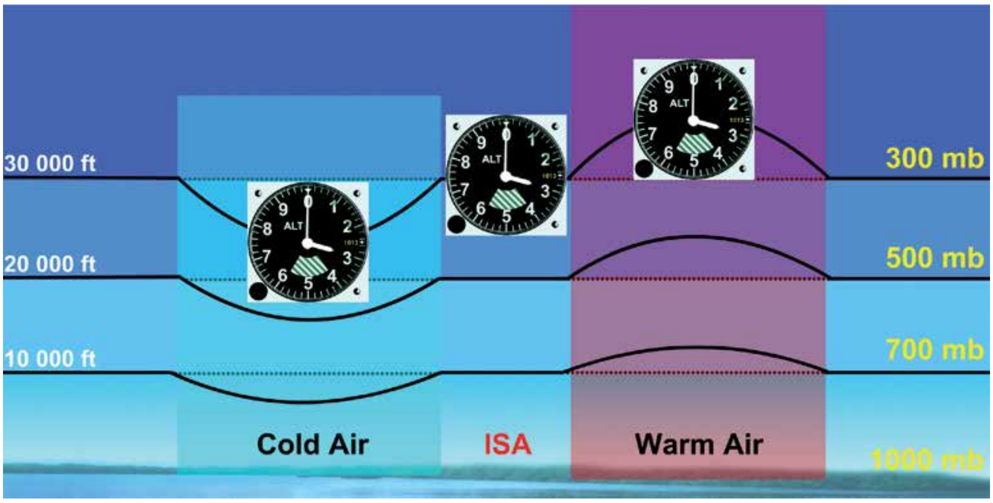

Figure 2.14 Cold air causes the altimeter to over-read. Warm air causes the altimeter to under-read.

When flying from warm air into cold air, the altimeter will over-read, indicating that the aircraft is higher than it actually is.

If the air were to be warmer than ISA, as shown on the right of *Figure 2.14*, the 300 millibar pressure level would be higher than its 30 000 ft level in ISA. Nevertheless, in warmer air, an altimeter calibrated to ISA would continue to read 30 000 ft at the 300 millibar level, even though the altimeter was clearly higher than the true altitude of 30 000 ft. Here, then, in the column of warm air, the altimeter is under-reading.

A useful phrase to recall in order to remember what you have just learnt is: “from warm to cold, don’t be bold”. Another way to remember this is to use “Hi-lo-hi, from high to low, altimeter reads high”. This phrase refers to the fact that when flying from warm air into cold air, the altimeter will over-read, giving the impression that you are at a higher altitude than you actually are. This situation obviously has inherent risks. For example, if you were at an altitude of 2 000 feet, with an outside temperature of -10ºC, well below the ISA value for that altitude, your altimeter would be over-reading by about 200 feet.

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Representative PPL-type questions to test your theoretical knowledge of Atmospheric Pressure.

1. What effect does cold air have on the vertical distribution of isobars?

   a. It compacts them
   b. It expands them
   c. It has no effect on them
   d. It raises them

2. A line drawn on a chart joining locations of equal barometric pressure at the same level is:

   a. An isotherm
   b. An isogonal
   c. A contour
   d. An isobar

3. What do tightly-spaced isobars indicate?

   a. A steep pressure gradient and strong winds
   b. A weak pressure gradient and light winds
   c. A weak pressure gradient and strong winds
   d. A steep pressure gradient and light winds

4. The pressure of the atmosphere:

   a. decreases at an increasing rate as height increases
   b. decreases at a constant rate as height increases
   c. decreases at a decreasing rate as height increases
   d. decreases at a constant rate up to the Tropopause and then remains constant

5. Compared to ISA, how does warm air affect the vertical distance represented by 1 hPa change in pressure?

   a. Increases it
   b. Decreases it
   c. Not at all
   d. It is impossible to determine

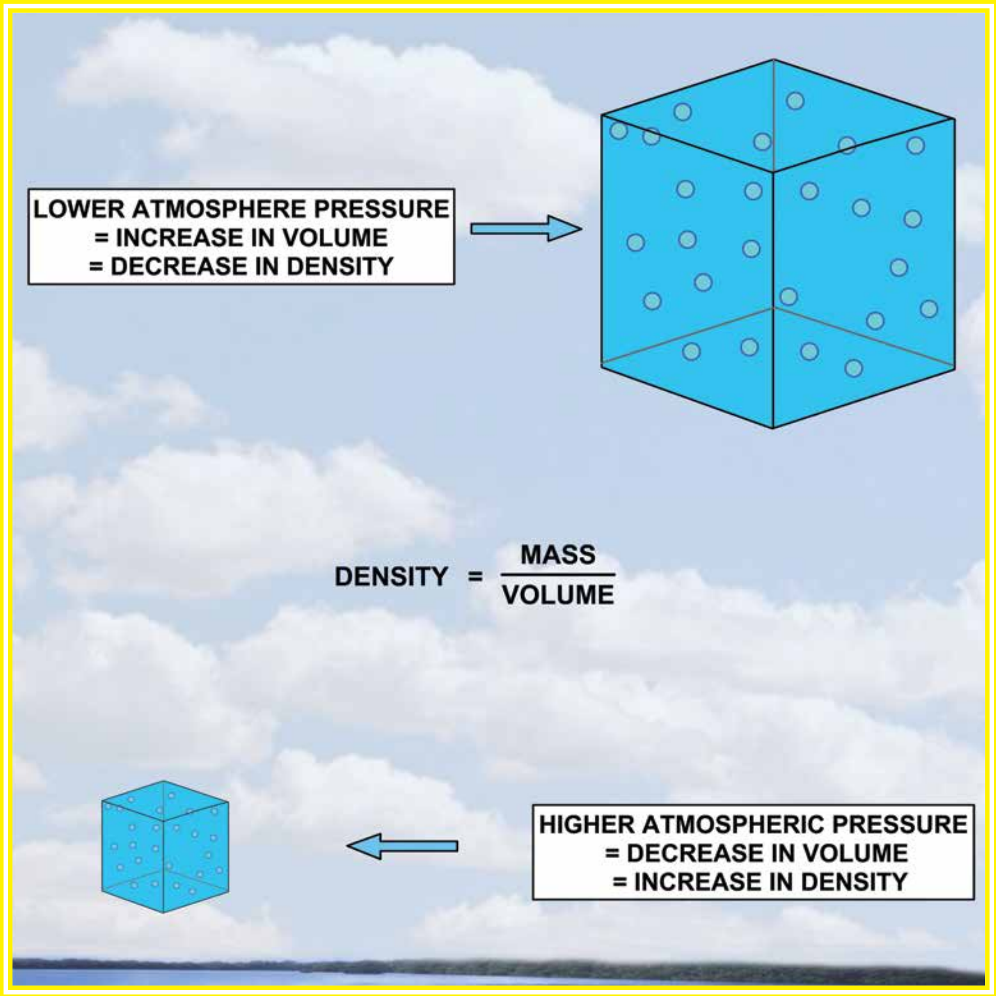
6. What is the name of the instrument which gives a continuous printed reading and record of variations in atmospheric pressure?

   a. Barometer
   b. Hygrometer
   c. Anemograph
   d. Barograph

Question	1	2	3	4	5	6
Answer						

The answers to these questions can be found at the end of the book.

CHAPTER 3
ATMOSPHERIC DENSITY



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ATMOSPHERIC DENSITY.

Density is defined as: "mass per unit volume". Air density is a measure of how much mass of air is contained within a given volume of air. Atmospheric density is commonly expressed in terms of grams per cubic metre, or in kilograms per cubic metre. In the ICAO Standard Atmosphere (ISA), at mean sea-level, the density of the atmosphere is described as 1 225 grams per cubic metre (gm/m^3).

Density is defined as mass per unit volume. The density of air at sea level in the ICAO Standard Atmosphere is 1 225 gm/m^3.

FACTORS AFFECTING ATMOSPHERIC DENSITY.

A number of factors affect atmospheric density. These factors are: pressure, temperature, altitude, and the quantity of water vapour within a given mass of air.

The Variation of Air Density with Pressure.

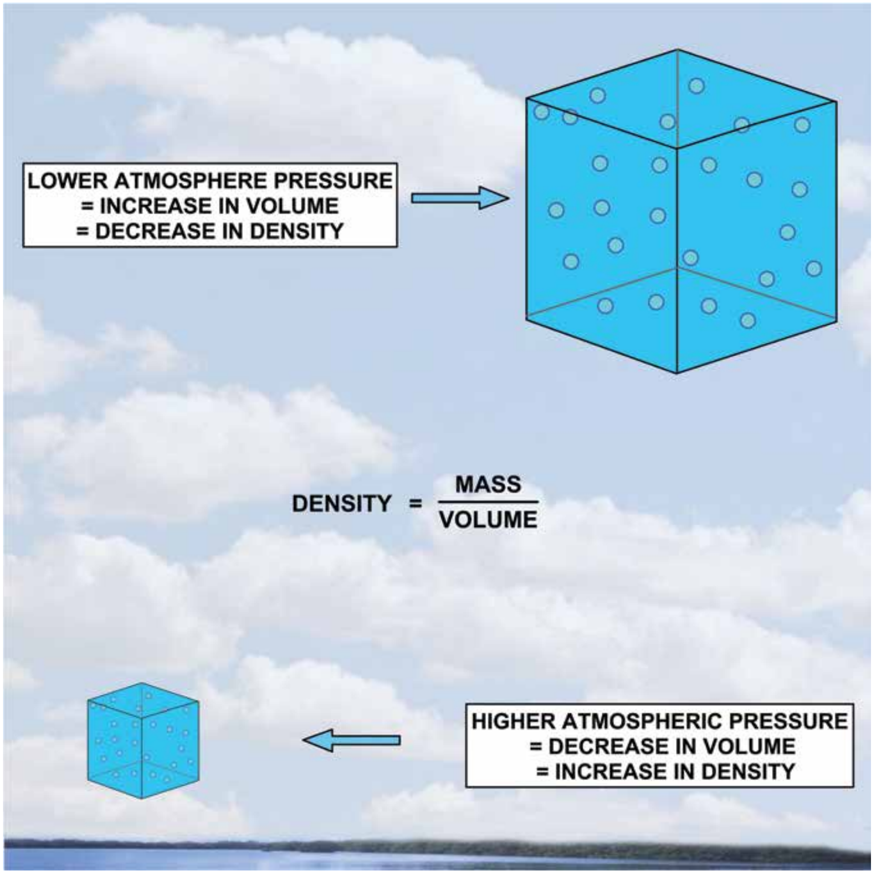

Figure 3.1 Atmospheric Density is directly proportional to atmospheric pressure.

Atmospheric density is directly proportional to atmospheric pressure. An increase in air pressure will increase the density of air. A decrease in air pressure will reduce the density of the air.

Figure 3.1 depicts two identical air masses contained within different volumes. At the lower left of the diagram, because the atmospheric pressure surrounding the volume of air is high, the volume of air is compressed, and the density of the air within the "air parcel" that we are considering is relatively high. On the upper right, the atmospheric pressure surrounding an identical mass of air is lower. The molecules of air within this second parcel of air, and which are in constant motion, therefore occupy an expanded volume. Thus, we have the same number of air molecules in a greater volume of air. The density of this second parcel of air is, consequently, relatively low.

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Physical experiments confirm that **density is directly proportional to pressure**. As atmospheric pressure increases, density increases. As atmospheric pressure decreases, density decreases.

The Variation of Air Density with Temperature.

Changes in temperature will affect atmospheric density.

An increase in temperature will reduce the density of a parcel of air. A decrease in temperature will increase the density of the air.

If a ‘parcel’ of air is heated, the energy of the molecules of air increases and they move about more rapidly, causing the parcel of air to expand, thus reducing the density of the air. Conversely, if the ‘parcel’ of air is cooled, the air molecules move around less vigorously and the air parcel shrinks in volume, causing air density to increase.

Therefore, density is inversely proportional to temperature. The lower the temperature of air, the greater is its density. The higher the air temperature, the lower is the density of the air.

The Variation of Air Density with Altitude.

We have already established that, in the Troposphere, as altitude increases atmospheric temperature falls. Therefore, given the above observations on the effect of temperature on atmospheric density, we might expect density to increase with increasing altitude. However, as altitude increases, atmospheric pressure falls, and, as we have seen, this causes air density to decrease. So what is the net effect of increasing altitude on air density? The dominant effect on the atmosphere is the change in atmospheric pressure. The fall in pressure reduces air density more than the decrease in temperature causes air density to increase.

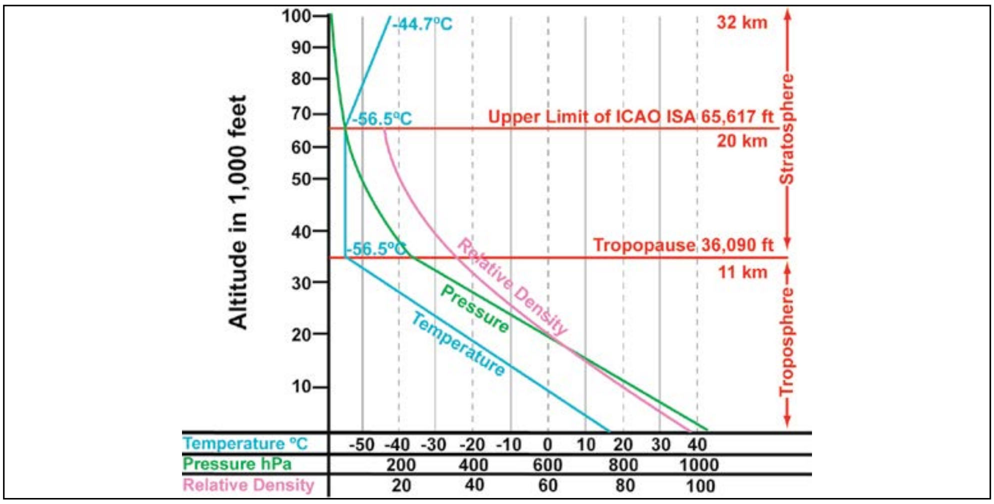

Figure 3.2 Air density decreases with altitude, but the rate of decrease also decreases with altitude.

Air density decreases with altitude.

Consequently, as altitude increases, air density decreases. However, as shown in *Figure 3.2*, in the same way as air pressure, air density decreases with altitude, at a decreasing rate.

The Effect of Water Vapour on Air Density.

As explained in the Chapter 1, the proportion of water vapour in the atmosphere is small but without it, there would be no weather.

The amount of water vapour present in a ‘parcel’ of air will affect air density.

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The density of water vapour is lower than the density of the other constituent gases in a sample of dry air. Therefore, the more water vapour there is in a "parcel" of air to displace the denser gases, the lower will be the density of that "parcel" of air. In other words, the more humid a given volume of air, the lower is its density.

An increase in humidity will reduce the density of air.

The Effects of Reduced Air Density on Aircraft Performance.

So far, it has been shown that high altitude, high temperature and high humidity will cause air density to decrease. Because changes in atmospheric density affect aircraft performance, it is, therefore, vital that pilots understand the nature and extent of this phenomenon.

Lift is directly proportional to air density; therefore, a reduction in air density will cause a reduction in lift. This is a performance-reducing characteristic that is not immediately obvious, and may be explained as follows.

For an aircraft to fly there needs to be a certain amount of lift generated by the wings. Now, the amount of lift generated depends on the mass flow of air around the wings. If the rate of mass flow of air around the wings reduces, because the air is less dense, then, to recover the loss in the lift force the aircraft will have to travel faster in order to restore the required amount of mass flow of air around the wings. This effect is especially important in the take-off phase of flight. Achieving a higher take-off speed in conditions of low air density will require a greater length of runway. Consequently, extra care in flight planning must be taken when operating in low density environments.

Air density affects piston engine performance, too. The lower the density of air, the less oxygen there will be in any given volume of air. Oxygen is essential for combustion to take place, and, therefore, a reduction in air density will cause a reduction in engine power. The combined effect on engine and wing efficiency of reduced atmospheric density obviously needs to be accounted for by the pilot in his performance calculations.

A reduction in air density will lead to a reduction in aircraft performance, and vice-versa.

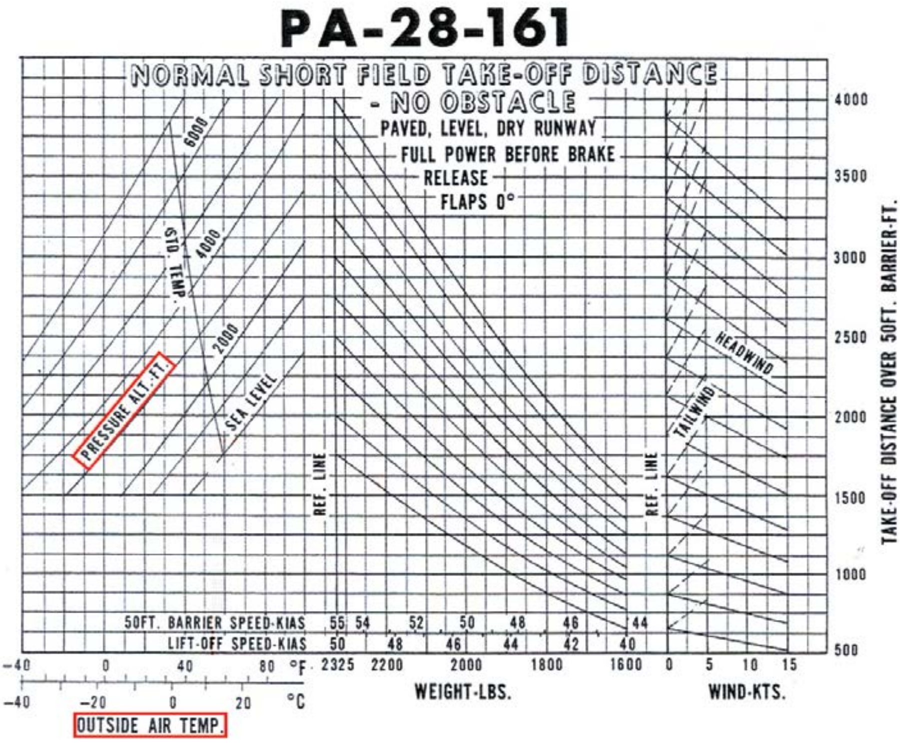

Figure 3.3 Short field take-off distance graph for a PA-28-161 Warrior.

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Most density changes can be accounted for by using performance graphs, such as the take-off distance graph, depicted in *Figure 3.3 on the previous page*, which incorporate altitude and temperature parameters. *(See highlighted values in Figure 3.3)* Note that the input parameters required by the graph are pressure altitude and temperature, which, together, give us density altitude.

Pressure altitude and density altitude are explained later in the chapter.

RELATIVE DENSITY.

The atmospheric density at mean sea-level in the ICAO Standard Atmosphere (ISA) can be used as a benchmark against which to compare the air density prevailing at any particular time and in any particular place.

The **ISA density of 1 225 grams per cubic metre at mean sea-level** is taken to be **one hundred percent**.

If, in a given place, or at sea-level, the actual density were 1 000 grams per cubic metre, this density would be approximately 82 percent of the ISA mean sea-level density, as depicted in *Figure 3.4*.

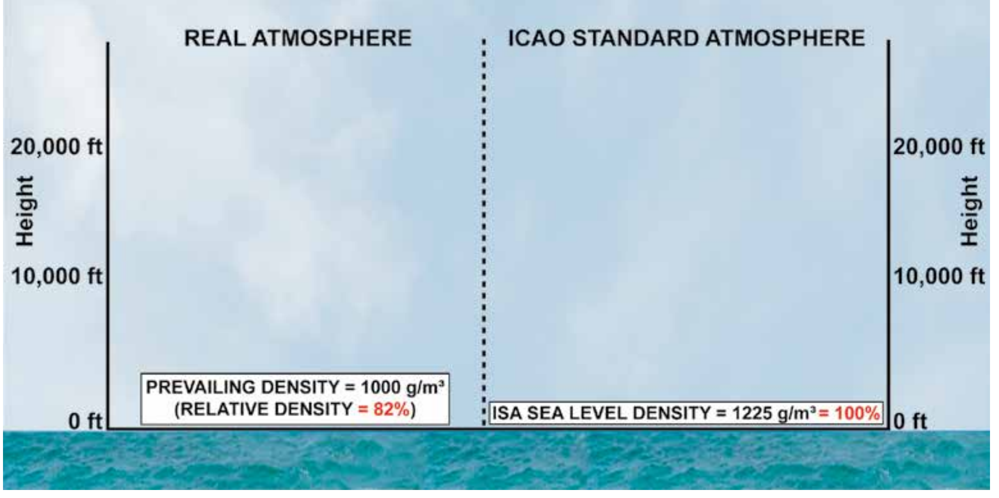

Figure 3.4 Relative density is a measure of the prevailing air density relative to the density in ISA, at mean sea-level, expressed as a percentage. At sea level in ISA, the relative density is 100%.

This method of expressing atmospheric density is called Relative Density.

Relative Density is a comparison of the prevailing air density to the ISA mean sea-level air density.

DENSITY ALTITUDE.

It is essential that pilots understand the concept of density altitude, as it plays a vital role in the calculation of aircraft performance, especially in hot, high or humid atmospheric conditions.

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Density Altitude is, simply defined, the altitude in the ICAO Standard Atmosphere (ISA), at which the actual prevailing density would occur.

Density Altitude is the altitude in the ICAO Standard Atmosphere at which the actual prevailing density would occur.

If, for example, an aircraft were to be about to take off from an aerodrome at sea-level, and the atmospheric conditions of the day happened to be exactly the same as ISA conditions, the air density at sea-level in the real atmosphere would correspond exactly to that found at 0 feet in ISA, and the aircraft's density altitude would be 0 feet. *(See Figure 3.5.)*

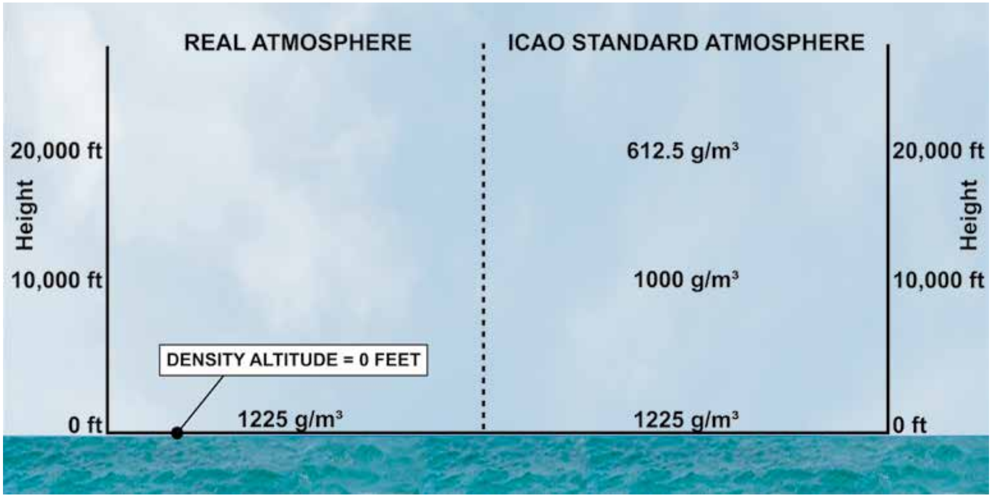

Figure 3.5 "Density altitude" is defined as the altitude in ISA at which the prevailing air density would be found.

However if, on a different day, atmospheric density at sea-level in the real atmosphere were to be 1 000 grams per cubic metre, this lower atmospheric density would correspond to a density found at an altitude in ISA, higher than sea-level (0 feet). *Figure 3.6* shows that the atmospheric density at sea-level, in this second example, equates to a density found at 10 000 ft in ISA. Consequently, the density altitude at mean sea-level in the real atmosphere, at this location, on this particular day, is 10 000 ft.

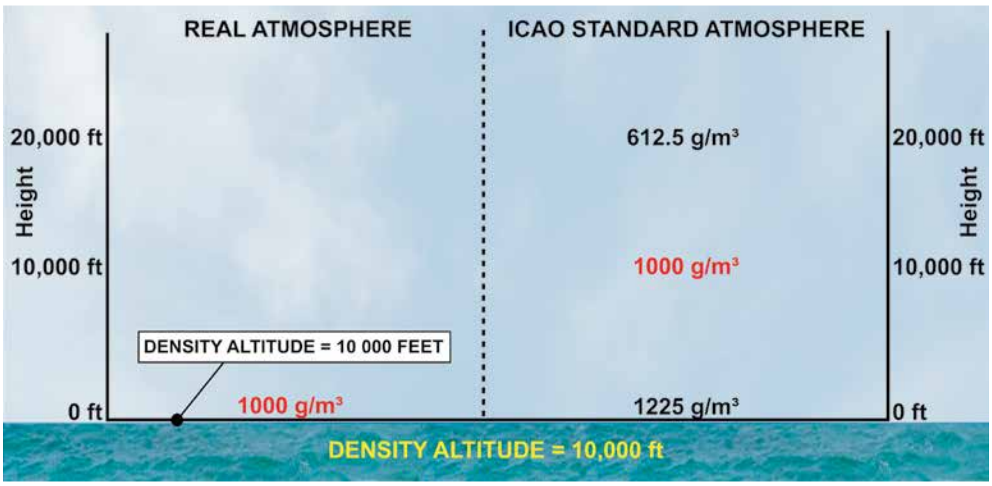

Figure 3.6 A surface density of 1 000 g/m³ would give a density altitude of 10 000 ft at the surface.

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As we have mentioned, density altitude is an important parameter for determining aircraft performance, because an aircraft's published performance figures most commonly assume that ISA conditions prevail. It is particularly important when calculating take-off and landing distance required, that the density altitude of the aerodrome concerned is calculated by the pilot. Density altitude is usually taken into account when pressure altitude and temperature are entered into standard performance graphs.

Calculating Density Altitude.

There are two simple ways of calculating density altitude. One method is to use a navigation computer (see Volume 3; 'Navigation'), and the other, described below, is by using a simple mathematical formula.

Expressed in words, the mathematical formula tells us that every one degree Celsius deviation from ISA conditions corresponds to a difference in altitude of 118.8 feet. The altitude we use for our calculations is the aircraft's pressure altitude; that is, its altitude with respect to the Standard Pressure Setting of 1013.2 millibars (hectopascals).

The formula, itself, is expressed as follows:

DENSITY ALTITUDE = PRESSURE ALTITUDE ± (ISA DEVIATION × 118.8) feet

If the actual temperature is higher than ISA, density altitude will be greater than the measured pressure altitude. If the actual temperature is lower than ISA, the density altitude will be lower than the measured pressure altitude.

For example, on a given day, let the pressure altitude be 2 000 feet and the temperature at that altitude, 25°C.

In the ISA, the temperature at 2 000 feet would be 11°C. (Remember, ISA sea-level temperature is 15°C, and the ISA temperature lapse rate is approximately 2°C per 1 000 feet.)

So, in our example, at 2 000 feet, the temperature of 25°C is 14°C higher than the ISA temperature, at that altitude. Therefore, the ISA deviation is ISA+14.

So, applying the formula for density altitude, we obtain:

DENSITY ALTITUDE = PRESSURE ALTITUDE ± (ISA DEVIATION × 118.8) feet

DENSITY ALTITUDE = 2 000 + (14 × 118.8) = 3 663 feet

Therefore, in our example, the density altitude, on the day in question, at a measured pressure altitude of 2 000 feet, is 3 663 feet.

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Representative PPL - type questions to test your theoretical knowledge of Atmospheric Density.

1. Generally, within the Troposphere, as altitude increases:

   a. temperature decreases and density increases
   b. temperature, pressure and density decrease
   c. temperature and pressure increase and density decreases
   d. temperature decreases, pressure and density increase

2. What is the effect of reduced density on aircraft performance?

   a. There will be an increase in performance
   b. There will be a decrease in performance
   c. There will be no change in performance
   d. There will be less lift but more engine power

3. Density is defined as:

   a. mass per unit volume
   b. mass per unit area
   c. weight of air per unit area
   d. volume divided by mass

4. Under which of the following conditions would the air density at a given location be least?

   a. Low altitude, high temperature and high humidity
   b. High altitude, high temperature and low humidity
   c. High altitude, high temperature and high humidity
   d. Low altitude, low temperature and low humidity

5. What is the density at sea-level in the ICAO Standard Atmosphere?

   a. 1225 g/m^3
   b. 12.25 g/m^3
   c. 1.225 g/m^3
   d. 122.5 g/m^3

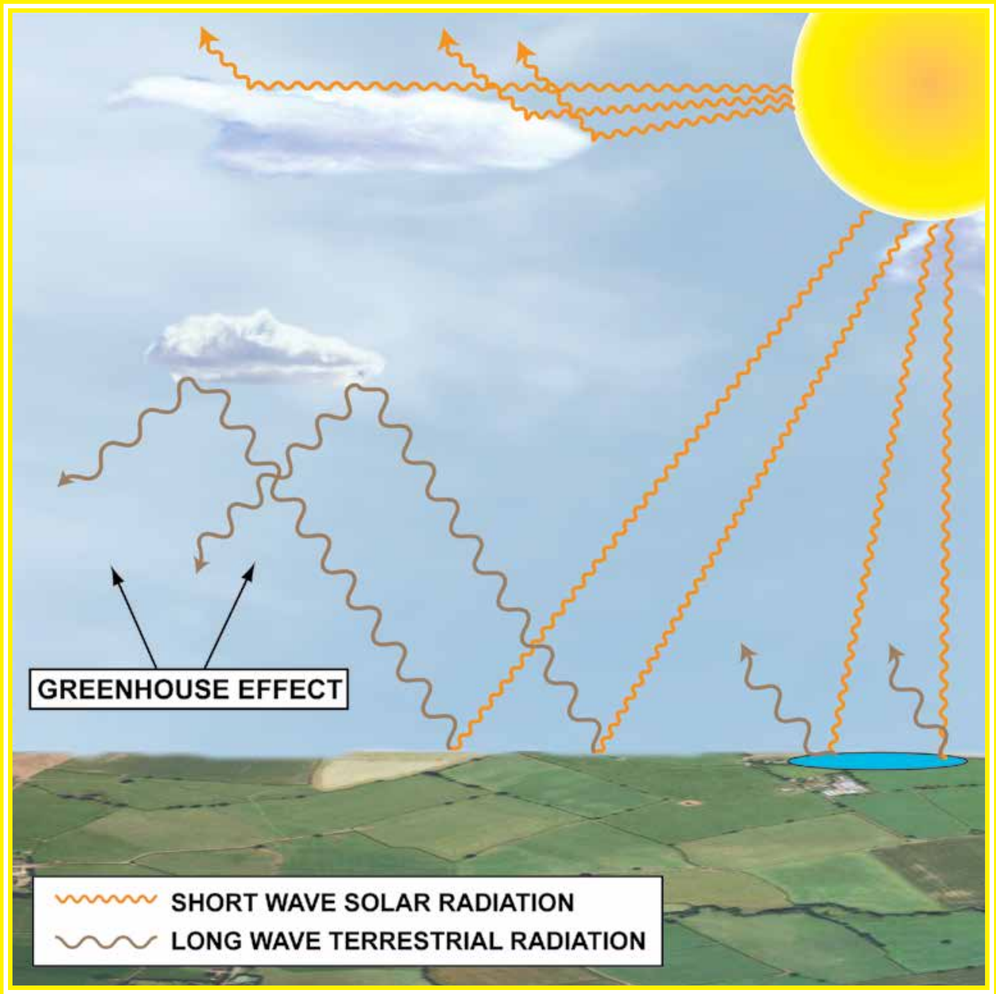
6. Air density at the Earth's surface will be low when:

   a. pressure is high and temperature is high
   b. pressure is high and temperature is low
   c. pressure is low and temperature is low
   d. pressure is low and temperature is high

Question	1	2	3	4	5	6
Answer						

The answers to these questions can be found at the end of the book.

CHAPTER 4
TEMPERATURE



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INTRODUCTION.

This chapter will investigate temperature and demonstrate its importance to Aviation Meteorology.

The diurnal, seasonal, vertical and regional variations in temperature have a great influence on the world's weather.

In the atmosphere, the temperature of the air varies throughout the course of any given day, from day to day, from season to season, from one altitude to another, and from location to location, increasing as one moves from the Poles to the Equator. This diurnal, seasonal, vertical, and regional variation in temperature has a great influence on our weather.

Temperature is defined as "a measure of the heat energy derived from the movement and collision of molecules (kinetic energy) in a gas or system". The higher the kinetic energy possessed by the gas molecules within any given system, such as the atmosphere, the higher will be the temperature of that system.

TEMPERATURE SCALES.

Temperature can be measured on a variety of scales. The two most common scales are: degrees Celsius (sometimes called Centigrade) and degrees Fahrenheit. These scales are depicted in *Figure 4.1.*

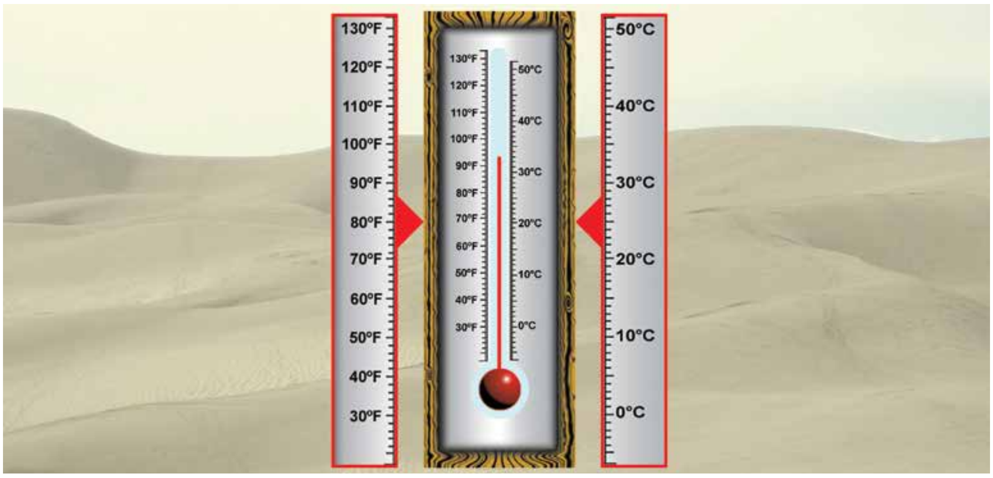

Figure 4.1 Temperature Scales: Fahrenheit (ºF) and Celsius (ºC).

There is another well-known scale of temperature known as the Kelvin Scale. The Kelvin scale, which measures absolute temperature, is rarely used in aviation meteorology, but you may see it in scientific formulae. At absolute zero, or 0 Kelvin, all molecular activity has ceased. 0 Kelvin is equal to -273º Celsius.

Celsius is the scale the we will use throughout this book.

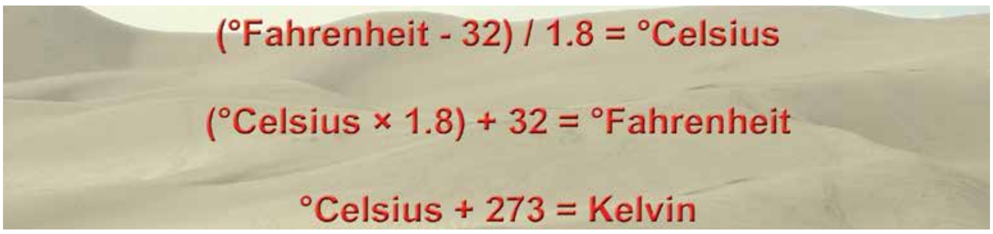

Figure 4.2 Temperature Scale Conversions.

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There is often a requirement to convert from one temperature scale to another. To convert degrees Fahrenheit into degrees Celsius, subtract 32º from the Fahrenheit value and then divide the answer by 1.8. To convert degrees Celsius to degrees Fahrenheit, multiply the Celsius value by 1.8 and add 32º to find the answer. To convert Celsius into Kelvin, add 273º. These conversions are illustrated in *Figure 4.2*.

Instead of dividing by 1.8, you may find it easier to divide by 9 and multiply by 5. Instead of multiplying by 1.8, you could divide by 5 and multiply by 9.

There is a conversion scale for Fahrenheit and Celsius on most flight navigation computers. (See *Figure 4.3*.)

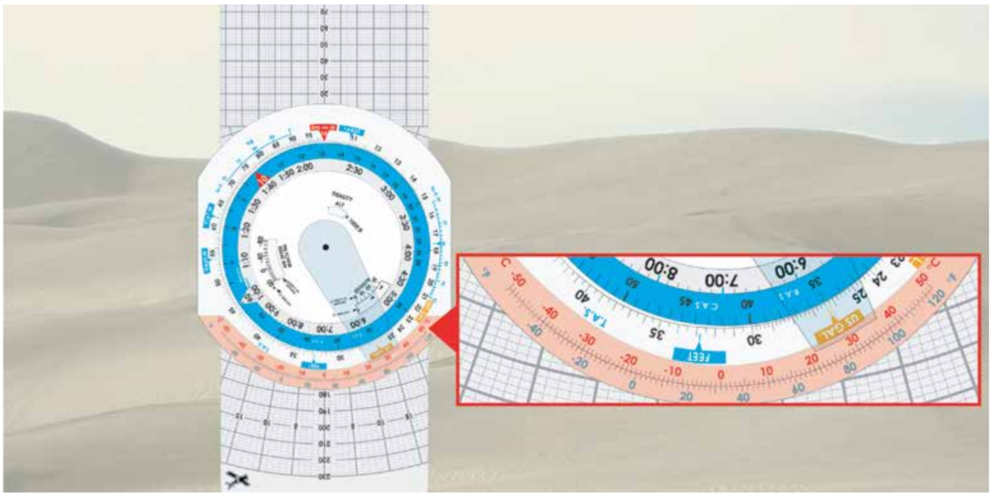

Figure 4.3 Temperature Conversion scale on the Navigation Computer.

MEASURING TEMPERATURE.

The instrument used to measure temperature is called a thermometer *(see Figure 4.1)*. In meteorology, thermometers which are used to measure the temperature of free air are usually housed in a Stevenson Screen as illustrated in *Figure 4.4*.

Figure 4.4 Measuring free air temperature: a Stevenson Screen.

The Stevenson Screen is located 4 feet above ground level, allowing the free passage of air through the housing, but preventing direct exposure to the Sun's radiation.

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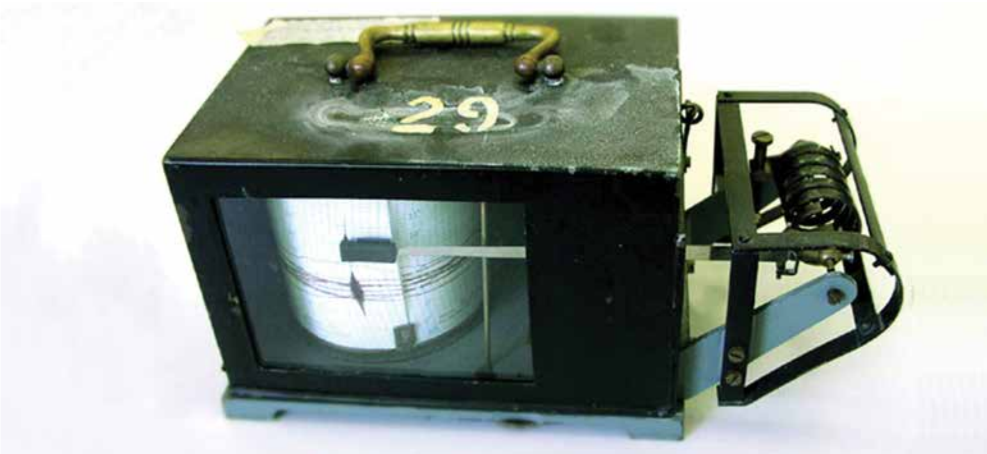

Figure 4.5 Measuring temperature over time: a Thermograph.

The type of thermometer illustrated in *Figure 4.5* is a thermograph. The thermograph is similar to the barograph, but, instead of recording variation in pressure over time, it records temperature variation over time, on a chart wrapped round a rotating drum.

SOLAR RADIATION.

Energy from the Sun, often referred to as solar radiation, is of short wavelength. The Earth's atmosphere is almost totally transparent to this incoming short-wave solar radiation. Consequently, incoming solar energy passes through the atmosphere without heating the atmosphere to any significant extent. Only when solar radiation encounters the Earth's surface and is re-radiated into the atmosphere, is there any significant raising of the temperature of the atmosphere.

Clouds reflect some incoming solar energy out to space again. The remaining radiation continues through the atmosphere to the Earth's surface. *(See Figure 4.6.)* On a cloud-free day, approximately 85% of solar radiation reaches the Earth's surface. At the Earth's surface, surfaces of different characteristics absorb different amounts of solar radiation. Generally, the darker the surface the more radiation will be absorbed, and the warmer that surface will become. Reflective surfaces, such as areas of ice or snow, will reflect short wave solar radiation back into the atmosphere. It is the surfaces which absorb solar radiation which have the greatest heating effect on the atmosphere.

Short wave radiation from the Sun has no direct heating effect on the atmosphere.

TERRESTRIAL RADIATION.

Where the incoming short-wave solar radiation, also known as insolation, is absorbed by the Earth's surface, the Earth's surface heats up. Where this happens, the Earth now acts as a heat source, which continually radiates the absorbed heat energy back into the atmosphere, but now as long wave radiation.

Land, water and concrete all absorb short-wave solar radiation. Land and concrete heat up quickly and re-radiation of solar energy to the Earth's atmosphere, from those surfaces, is the main source of atmospheric heating during the day. Water absorbs solar radiation much more slowly, and so re-radiation to the atmosphere from large water surfaces does not commence for many hours, taking place mostly at night.

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The atmosphere is not heated directly by short-wave solar radiation, but from beneath, by long wave terrestrial radiation.

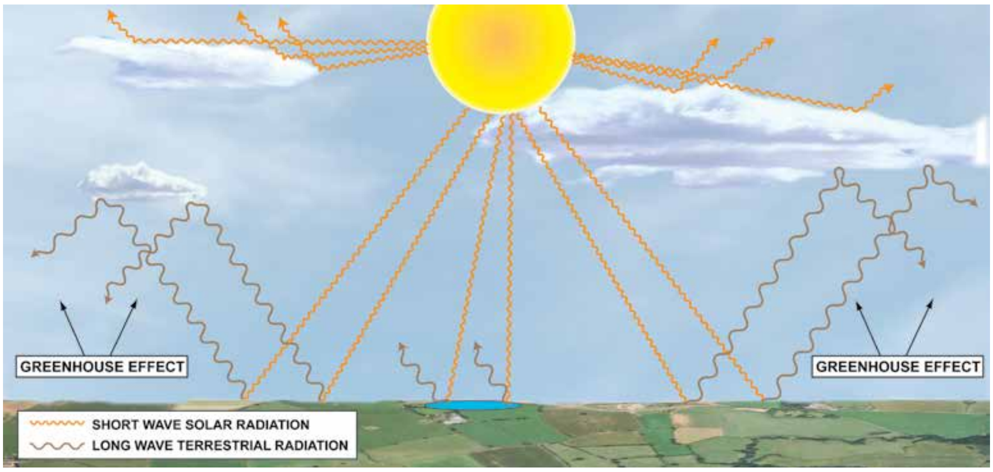

Figure 4.6 Insolation.

Heat energy in the form of long wave radiation is much easier for the atmosphere to absorb than the short-wave solar radiation. The atmosphere, then, is heated up, not by the short-wave solar radiation which comes directly from the Sun, but, from beneath, by the long wave terrestrial radiation emitted by the Earth's surface. *(See Figure 4.6.)*

HEATING THE ATMOSPHERE.

So how does terrestrial radiation heat up the atmosphere? Well, the most important factor in atmospheric heating is the role played by two so-called greenhouse gases: water vapour and Carbon Dioxide.

As we have seen, short-wave solar radiation passes through the Earth's atmosphere without heating up the air to any appreciable extent. But, after being absorbed by the Earth's surface, the long-wave terrestrial radiation emitted back to the atmosphere is trapped in the atmosphere by greenhouse gases, causing the atmosphere to heat up.

The Sun's strong short wave radiation heats the Earth's surface; long wave terrestrial radiation then heats the atmosphere, particularly the CO² and water vapour content. This is the "Greenhouse Effect".

Figure 4.7 Heating the Atmosphere.

The highest concentrations of water vapour and carbon dioxide are in the regions of the atmosphere closest to the Earth's surface. It is in these lower regions that most atmospheric heating takes place.

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This fact helps explain why temperature decreases with altitude.

The upper atmosphere is cold because it experiences very little heating from the Earth's surface. There is very little water vapour and carbon dioxide present in the upper atmosphere, and, the greater part of the terrestrial radiation has already been absorbed by the greenhouse gases in the lower atmosphere. This atmospheric heating mechanism is known as "the greenhouse effect" because the process is similar to that which heats up the air within a typical garden greenhouse.

The atmosphere is heated from the Earth's surface. Most atmospheric heating takes place in the lower atmosphere where ***CO_2*** *and* ***water vapour*** *are very effective absorbers of heat. Temperature therefore, decreases with* ***altitude****.*

However, the atmosphere is heated by a number of other methods, too, as we shall now see.

Conduction.

Conduction is the process by which heat is transferred from one body to another through direct physical contact between the two bodies. In the case of atmospheric heating, the two bodies in contact are the Earth's surface and the lower atmosphere. The red line on the graph in *Figure 4.8* shows that, during the day, the lowest layers of the atmosphere, in direct contact with the Earth, are the warmest areas, because the atmosphere is heated from the Earth's surface upwards. As altitude increases, the red line shows that day-time temperature decreases linearly.

The very lowest layer of the atmosphere is warmed by conduction.

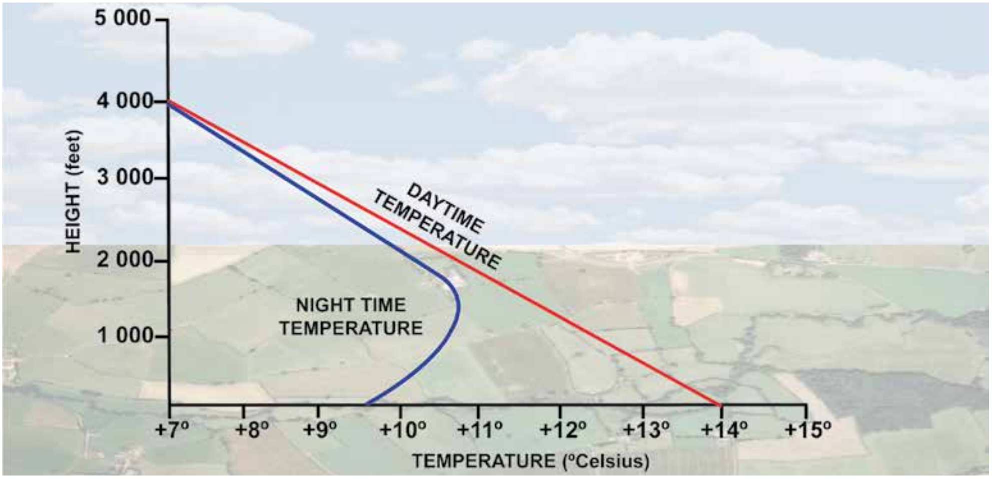

Figure 4.8 During the day, the atmosphere is heated by conduction, from the surface upwards. At night, the surface cools and the lowest part of the atmosphere is also cooled, leading to a temperature inversion.

However, during the night, especially when there is no low-level cloud, as the land cools, the temperature of the air in contact with the cooling land falls more rapidly than areas higher up in the atmosphere. This night-time temperature profile arises because air is a poor conductor of heat. Consequently, while at altitudes beyond the immediate influence of the Earth's surface, daytime temperatures are retained, the air in direct contact with the Earth's surface is colder than the air layers immediately above it. As a result of this phenomenon, a temperature inversion arises, as shown by the lower part of the blue line in *Figure 4.8.*

At night, the Earth's surface cools more rapidly than the air. Consequently, the air in direct contact with the surface is often colder than the air above it, leading to a ***temperature inversion****.*

This latter effect is most marked on clear nights in winter and late autumn, or early spring. It is on clear nights, at these times of the year, that surface frosts are experienced.

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Convection.

Convection is defined as: the process by which masses of warmer air are raised into the atmosphere, with compensatory downwards movements of cooler air. Convection, therefore, is heat transfer caused by the circulation of rising warm air, of low density, and sinking cooler air, of higher density.

Different types of surface heat up to different extents, giving rise to convection and the formation of convective cloud.

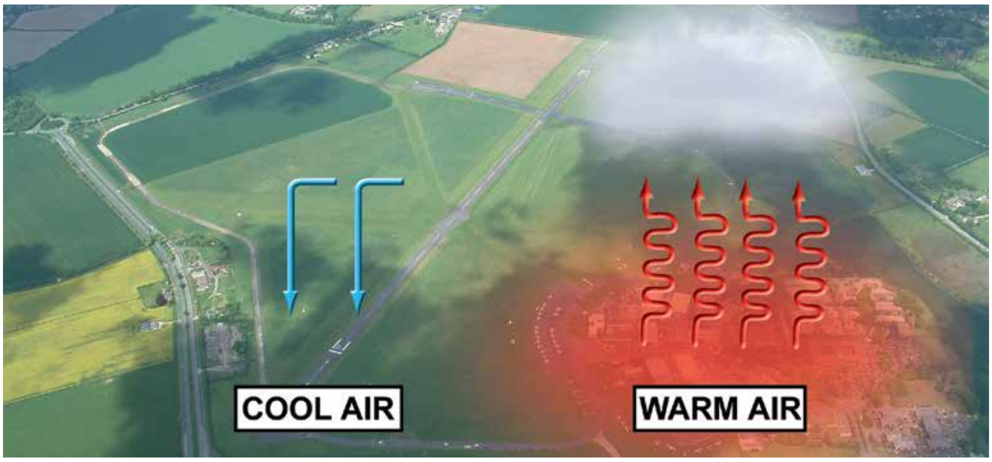

Figure 4.9 Convection: uneven heating of the Earth's surface leads to parcels of warm, low-density air rising, while cooler, denser air sinks.

Different surfaces on the Earth absorb heat to different extents. For example, under the influence of the Sun's radiation, a large area of concrete will become warmer than a green field lying next to it. The warmer, less dense air above the concrete will rise, by the process of convection, while air above the cooler green field will sink.

On hot summer days, this localised convection can be seen as a shimmering heat haze and is often made dramatically visible by the presence of large, vertically-growing cloud masses called cumulus clouds.

Atmospheric convection is the mechanism which permits glider pilots to soar in the rising columns of air which they call thermals.

Glider pilots exploit these rising columns of air, which they call thermals, to gain height in their sailplanes and, therefore, remain airborne for many hours, and cover hundreds of miles cross-country.

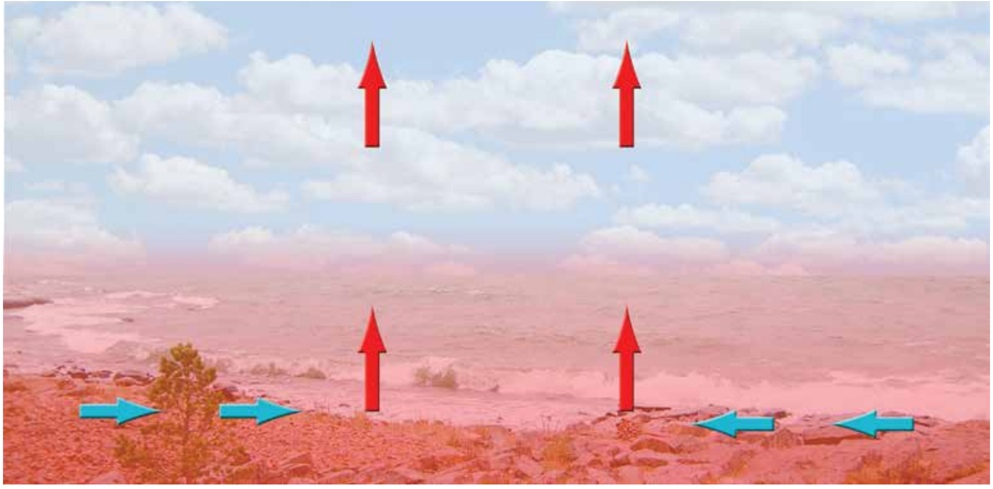

Figure 4.10 Advection - the horizontal transfer of heat.

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In certain conditions, convective cumulus clouds may even grow in vertical extent up to Tropopause level, transferring heat high up into the atmosphere. *Figure 4.9* represents the process of convection. Warm air is rising over the concrete parking area of an airfield, and cooler air is sinking over the grassy areas.

Advection.

Advection is similar in principle to convection, but, with advection, the transfer of heat takes place in the horizontal plane. As warm air rises, cooler air moves horizontally to replace the rising air. This movement of cooler air is called cold advection. Cold advection is depicted in *Figure 4.10*.

Latent Heat.

Heat may be transferred by the absorption or release of what is known as latent heat. Latent heat is heat liberated or absorbed when a substance changes physical state**.**

When water vapour changes state from a gas to liquid water, by the process of condensation, energy is released in the form of latent heat into the surrounding air. Cloud is formed when water vapour condenses in rising, cooling air.

Conversely, when evaporation takes place as water droplets change to water vapour, latent heat is absorbed from the air. The process of transfer by latent heat is described in detail in Chapter 7, Humidity.

TEMPERATURE VARIATION.

Temperature Variation With Altitude.

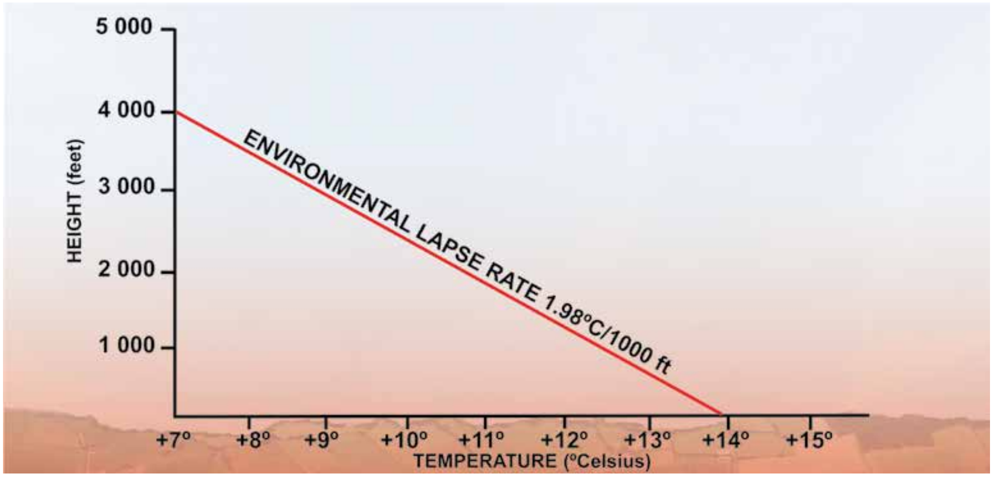

Figure 4.11 Within the Troposphere, temperature gradually decreases with altitude. In ISA, the average temperature lapse rate is 1.98ºC/1 000 feet.

The general decrease of temperature with altitude throughout the atmosphere is known as the Environmental Lapse Rate (ELR). In the ICAO Standard Atmosphere (ISA), the ELR is 1.98°C/1 000 feet. However, under certain conditions, the ELR can vary significantly from this average, especially in the lower Troposphere.

If the temperature remains constant through a given depth of atmosphere, it is described as being isothermal, as depicted in *Figure 4.12*. The most striking example of an isotherm is the almost constant temperature of the lower part of the Stratosphere. But isotherms can also be found near the Earth's surface, as depicted in *Figure 4.12.*

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Temperature will generally decrease with height, but it is possible for temperature to remain constant with altitude. In such a case, the temperature is said to be isothermal. Temperature may even increase with height. This phenomenon is called a temperature inversion.

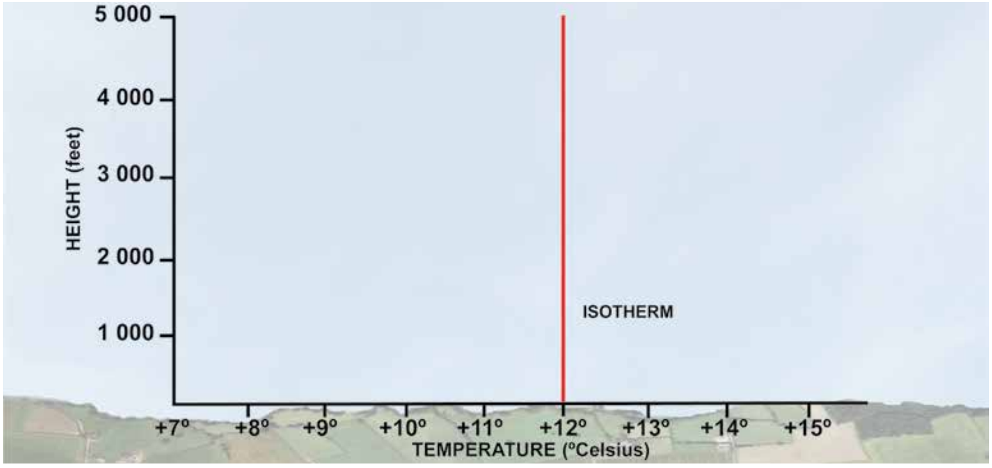

Figure 4.12 An Isotherm - temperature remains constant with height.

Under certain circumstances, such as on clear, cloudless nights in winter, temperature may increase with altitude; this phenomenon, known as a temperature inversion, was mentioned earlier in the chapter under the heading Conduction.

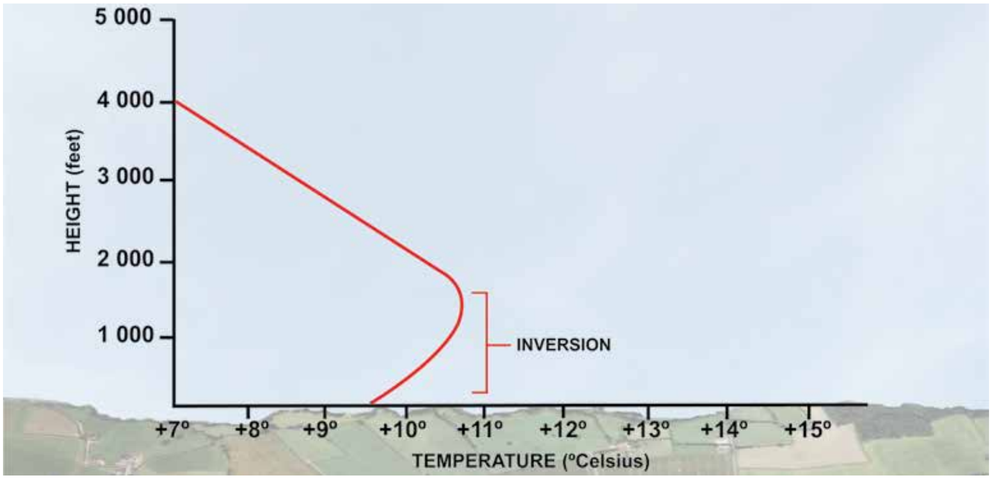

Figure 4.13 Inversion - temperature increasing with height.

Diurnal Variation.

In general, temperature varies with time over a 24 hour period. Because of "thermal inertia" the hottest time is 2 to 3 hours after the sun has reached its highest point, at local noon, and the coldest about 30 minutes after dawn.

The temperature of the air will vary greatly in a given location through a 24-hour period. This is called diurnal variation (from the Latin diurnus meaning daily.) The Sun is at its highest at noon, with the maximum incoming solar radiation occurring at that time. However, due to 'thermal inertia', the surface of the Earth continues to receive more incoming solar radiation than it emits as terrestrial radiation. Therefore, the actual maximum air temperature usually occurs some two to three hours after maximum solar elevation, usually at about 1500 local time. Similarly, as a result of 'thermal inertia', the time at which the minimum temperature is reached is around half an hour after dawn. *Figure 4.14* shows diurnal variation over a twenty four hour period.

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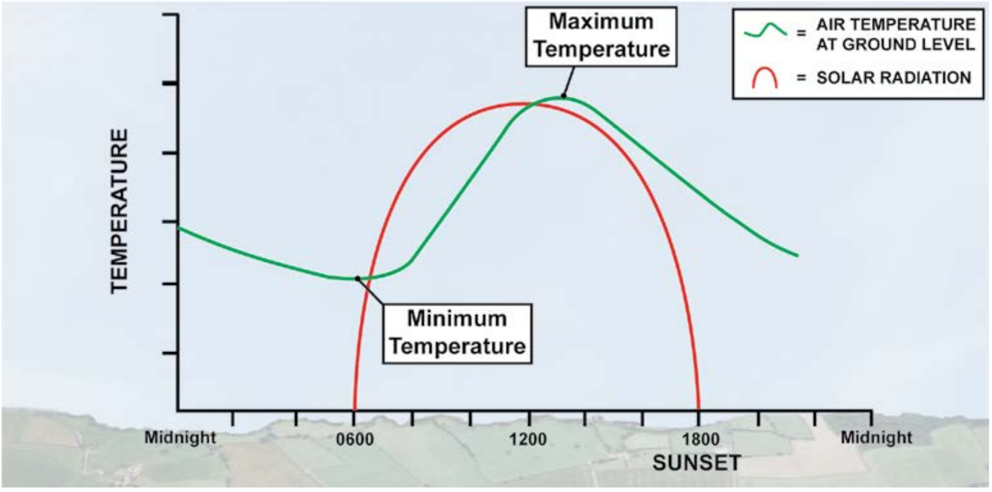

Figure 4.14 Diurnal Variation - the change of temperature over a 24-hour period. The temperature is highest at 15:00 local time, and lowest just after dawn.

Clouds and Diurnal Variation.

Clouds have a great influence on the maximum and minimum air temperatures. Clouds reflect some incoming solar radiation during the day, thereby reducing the incoming solar radiation, which, in turn, will reduce the maximum daily temperature. But, at night, cloud acts in a very different manner. Heat energy stored inside the cloud layer, by water vapour, is radiated back to the atmosphere, especially to that part of the atmosphere lying beneath the cloud. In this way, cloud acts like a blanket around the Earth. The release of latent heat from cloud, as it forms by the process of convection, also contributes to the warming effect.

A cloud layer will modify the diurnal variation. Cloud will reduce the maximum temperature, and increase the minimum temperature.

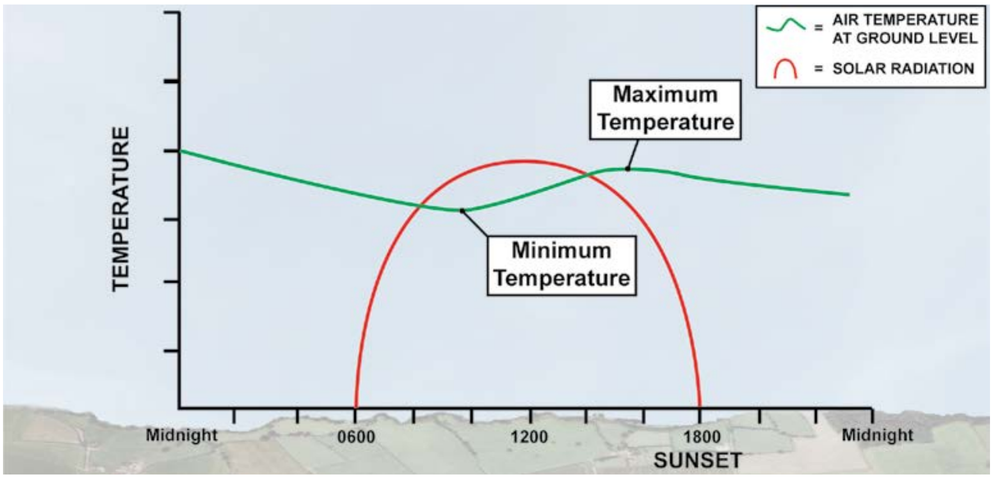

Figure 4.15 Cloud cover reduces diurnal variation.

When it is cloudy, therefore, minimum night time temperatures are higher than if skies were clear.

Cloud cover, then, will reduce the extent of diurnal variation of the temperature of the atmosphere. Note, however, that the basic form of the diurnal variation curve is almost the same, whether or not cloud is present. *Figure 4.15,* shows how the diurnal variation is modified by cloud cover. With cloud cover, maximum daytime temperature is lower, and the minimum temperature, occurring just after dawn, is higher.

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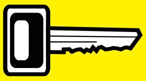

Wind will modify the diurnal variation by mixing; this reduces the maximum daily temperature and increases the minimum daily temperature.

Wind and Diurnal Variation.

The wind also affects diurnal variation of temperature. By day, the effect of wind is to reduce the maximum temperature. *Figure 4.16* depicts turbulent mixing of the lower parts of the atmosphere, caused by wind, bringing down cooler air from above, and mixing this cooler air with warmer air near the Earth's surface. During the day, then, mixing causes the surface temperature to be lower than it would have been if there had been no wind.

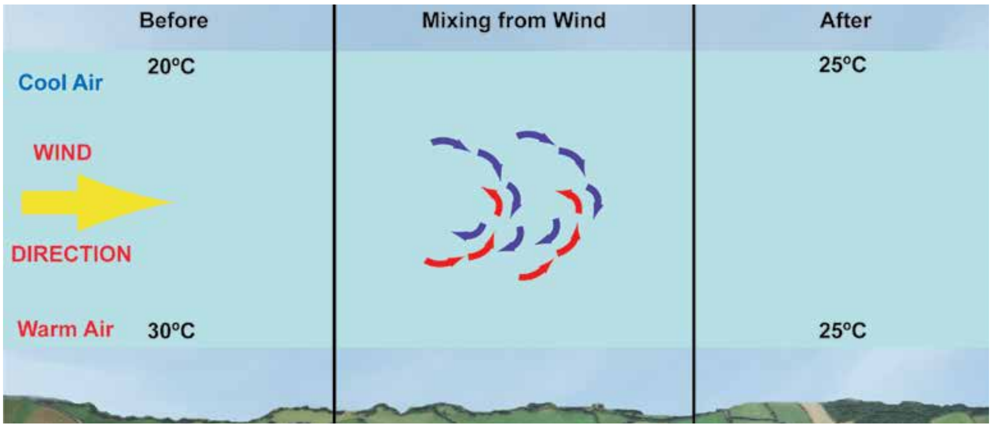

Figure 4.16 Mixing: by day, the wind causes the cooler air at altitude to mix with the warmer air at the surface, reducing air temperature at the surface.

At night, the mixing process has the opposite effect. The presence of wind keeps surface air temperatures higher than they otherwise would be. *(See Figure 4.17.)*

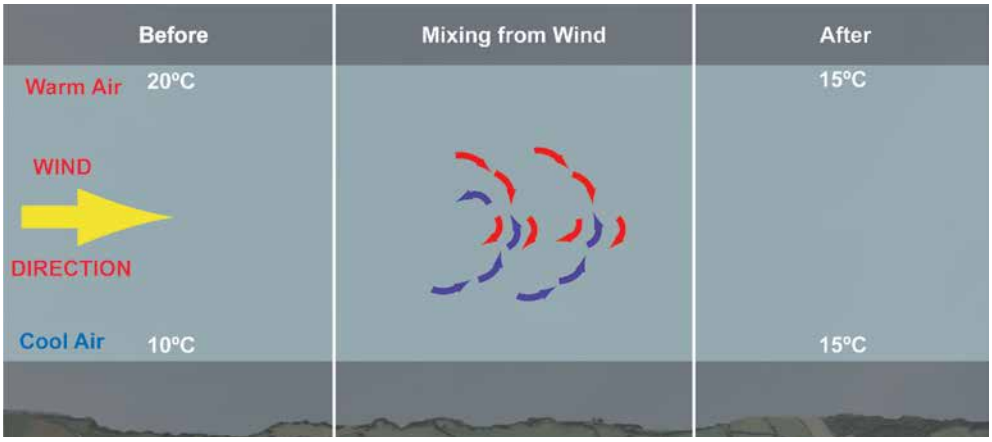

Figure 4.17 At night, mixing causes the warmer air at altitude to mix with the surface layer of air, raising the temperature of the surface air.

At night, if there is no wind and no cloud, the Earth's surface will cool down rapidly, because there is no longer any incoming solar radiation. The air in direct contact with the Earth's surface, therefore, will also cool down, while air at higher altitudes will not be as greatly affected by the cooling from the surface. This phenomenon gives rise to a temperature inversion. If wind is present, however, turbulent mixing will bring warmer air down from a higher level, averaging-out the temperature throughout an appreciable depth of the lower atmosphere.

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Variations with Latitude.

There are also large temperature variations across the surface of the Earth. The latitude of a given location has a marked effect on the amount of energy received from the Sun. *Figure 4.18, below,* shows that, when considering a unit cross section of radiated energy from the Sun, the same amount of energy is spread across a greater area at higher latitudes than at the Equator. Therefore, a location on Earth, at a high latitude, near the Poles, will receive less energy from the Sun than a location at a lower latitude, nearer to the Equator.

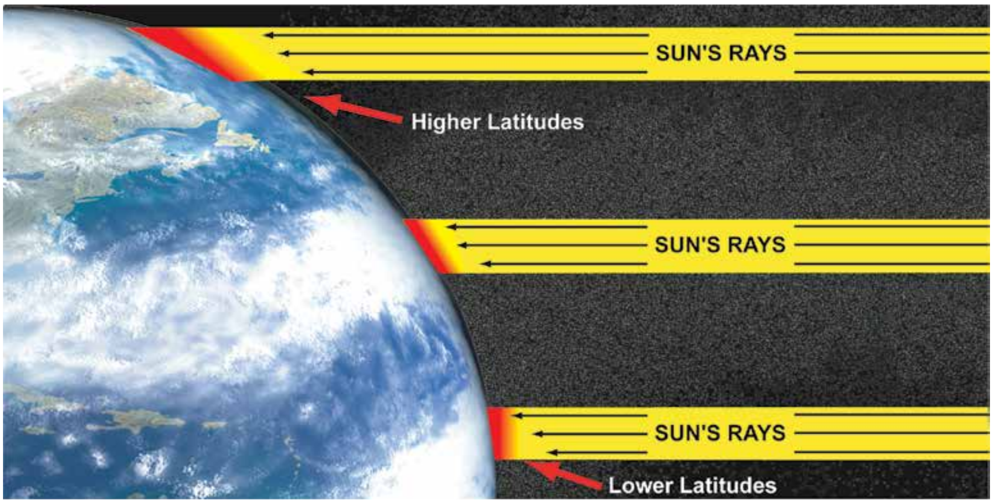

Figure 4.18 Variations of temperature due to latitude.

The angle at which the Sun's rays hit the Earth affects the amount of insolation in a given area. Thus, high latitudes receive less insolation than the tropics.

The Equator is warmer because, at the Equator, a beam of radiated energy from the Sun meets the Earth's surface at approximately 90º to the surface, which means that solar radiation is spread over a smaller area, than an identical amount of radiation nearer the Poles would be. Of course, the insolation at the Poles varies seasonally, too. The Pole tilting towards the Sun will receive more solar radiation over an equivalent area than the Pole tilting away from the Sun. *(See Figure 4.19, below.)*

Seasonal Variations of Temperature.

The Earth's spin axis is tilted at 23.5º to a line passing vertically through its orbital plane. This tilt causes seasonal variations in temperature across the Earth's surface.

The degree of Insolation at any given location on Earth varies with latitude and seasons.

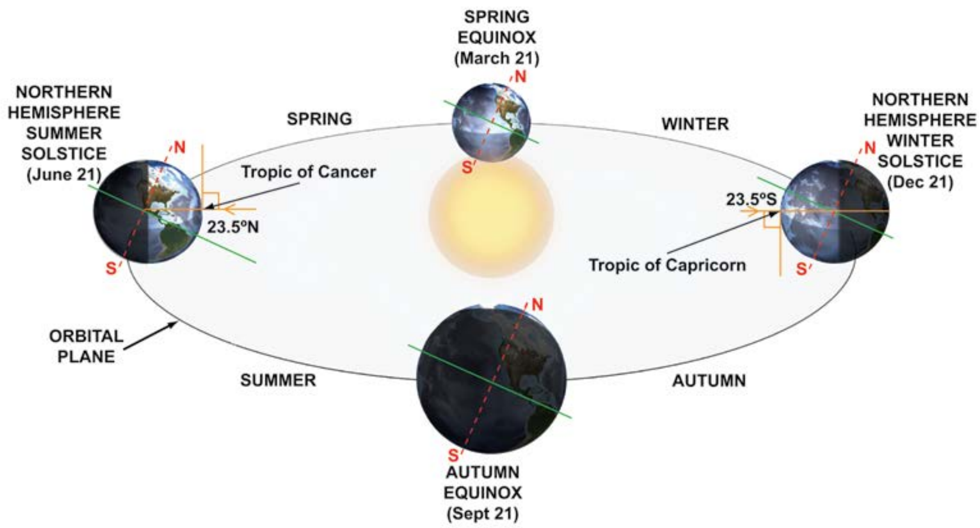

Figure 4.19 The Earth's tilt and its effect on the seasons in the Northern Hemisphere.

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From *Figure 4.19*, we can see that, on 21st June, the summer solstice in the Northern Hemisphere, the tilt of the Earth causes the Northern Hemisphere to receive a greater amount of radiation from the Sun, than the Southern Hemisphere. This fact defines the Northern Hemisphere summer and the Southern Hemisphere winter. In fact, from simple geometry, we may calculate that the latitude of 23.5° North marks the point of maximum solar radiation in the Northern Hemisphere summer, i.e. on 21st of June. The latitude of 23.5° North is commonly referred to as the Tropic of Cancer.

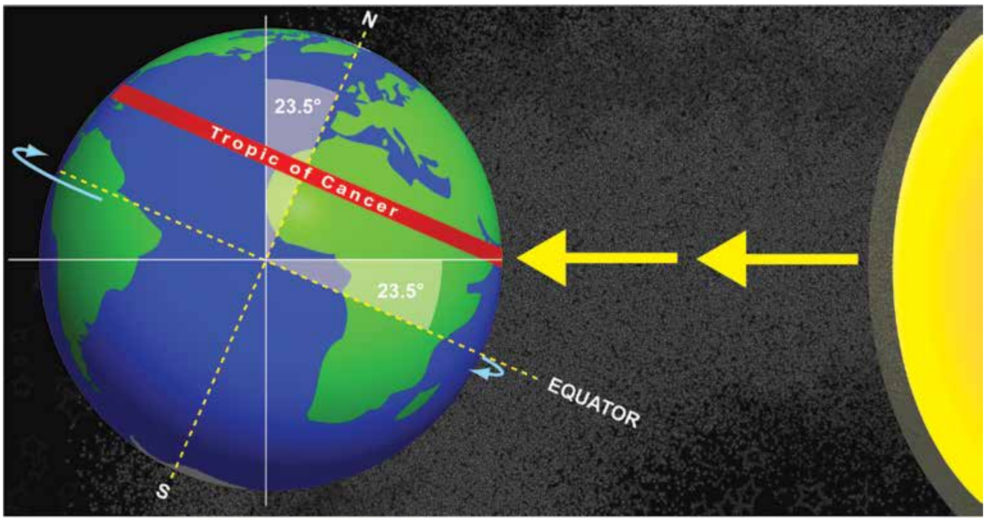

Figure 4.20 At the summer solstice, in the Northern Hemisphere, maximum solar radiation is received at 23.5° North, the Tropic of Cancer.

Looking back at *Figure 4.19*, you can see that on 21st December, the winter solstice in the Northern Hemisphere, the tilt of the Earth causes more of the Southern Hemisphere to be exposed to the Sun. In December, then, the Southern Hemisphere is warmer than the Northern Hemisphere. This defines the Southern Hemisphere summer and the Northern Hemisphere winter. The latitude of 23.5° South marks the point of maximum solar radiation on 21st December in the Southern Hemisphere. The latitude of 23.5° South is commonly referred to as the Tropic of Capricorn.

The geographic region of the Earth between the Tropic of Cancer, in the Northern Hemisphere, and the Tropic of Capricorn, in the Southern Hemisphere, is called the Tropics. The Tropics include all the areas of the Earth where the Sun reaches a point directly overhead (90°), at least once during the year. Therefore, the Tropics represent the warmest areas on the Earth.

Seasonal temperature change in any locality on Earth is, therefore, caused by regular variations in insolation over different parts of the Earth as the seasons progress.

Temperature Variations from Land to Sea.

Compared to the land, the sea takes a longer time to heat up and cool down. Therefore, the diurnal temperature variation of the sea is less than that of the land. This is because the sea has a larger specific heat capacity than the land. Consequently, the sea requires more heat energy to raise its temperature than does the land, for an identical temperature increase. This effect is noticeable, both

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daily and seasonally. *Figure 4.21* shows that, while the temperature of the world's oceans generally varies by only five degrees in a 24-hour period, the temperature of the land masses varies by up to three times that figure.

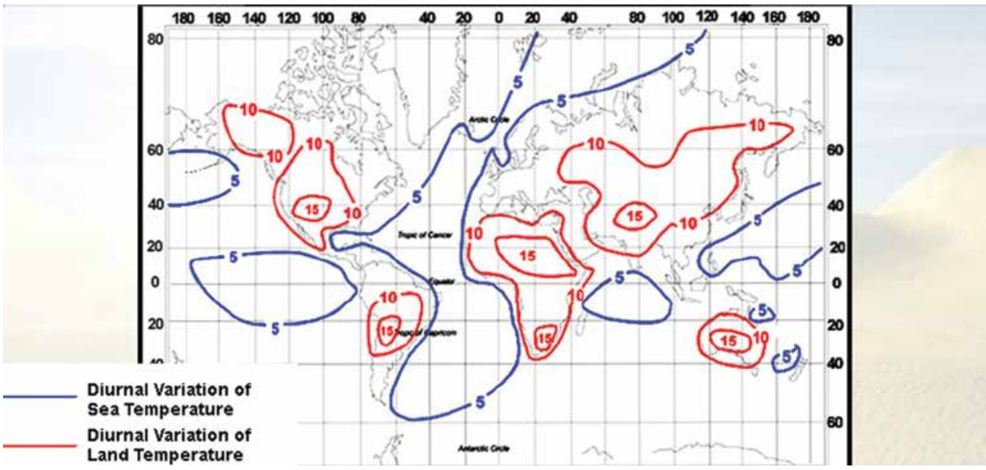

Figure 4.21 Diurnal temperature variation of the land and sea.

The diurnal variation of the sea temperature is less than that of land temperature. This is the underlying cause of sea breezes, by day, and land breezes, by night.

During the day, and in the summer months, the land will be at a higher temperature than the sea, but, during the night and in the winter months, this situation is reversed, with the sea generally being warmer than the land.

The differences in temperature between the land and the sea are the cause of sea breezes and land breezes We will examine sea and land breezes in Chapter 12.

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Representative PPL - type questions to test your theoretical knowledge of Temperature.

1. If a temperature inversion is present in the lower atmosphere:

   a. there is no horizontal gradient of temperature
   b. there is no change in temperature with height
   c. there is an increase in temperature as height increases
   d. there is a decrease in temperature as height increases

2. The surface of the Earth is heated by:

   a. convection
   b. conduction
   c. long wave solar radiation
   d. short wave solar radiation

3. Which of the following words defines temperature remaining constant with an increase in altitude?

   a. isotherm
   b. isogonal
   c. isobar
   d. inversion

4. The method by which heat energy is transferred from one body to another, with which it is in contact, is called:

   a. radiation
   b. convection
   c. conduction
   d. latent heat

5. The diurnal variation of temperature is:

   a. greater over the sea than the land
   b. less over desert areas than over temperate grassland
   c. increased by convection currents
   d. greater when the wind is strongest

6. Replace the missing words:

   The sun radiates ______ amounts of heat energy with ______ wavelengths. The Earth radiates ______ amounts of heat energy with ______ wavelengths.

   a. great, short, smaller, long
   b. small, short, greater, long
   c. great, long, greater, long
   d. great, long, smaller, short

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7. Cloud cover will reduce surface diurnal variation of temperature because:

   a. incoming solar radiation is reflected back to space and outgoing terrestrial radiation is reflected back to earth
   b. incoming solar radiation is re-radiated back to space and atmospheric heating by convection will stop at the level of the cloud layer
   c. the cloud stops the sun's rays getting through to the earth and also reduces outgoing conduction
   d. incoming solar radiation is reflected back to space and terrestrial radiation is absorbed by the cloud and re-radiated back to the surface.

8. Diurnal variation of the surface temperature will:

   a. be unaffected by a change in wind speed
   b. decrease as the wind speed increases
   c. increase as the wind speed increases
   d. be at a minimum in calm conditions

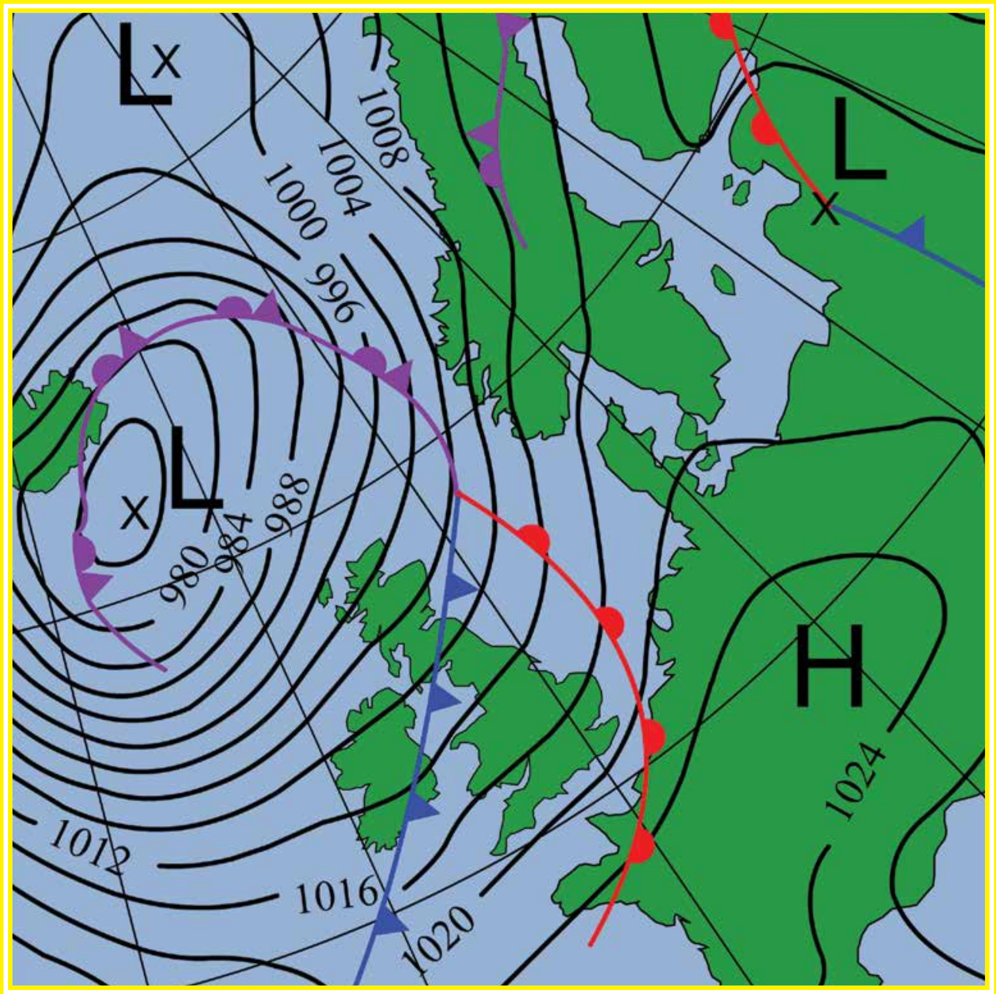
9. The primary source of atmospheric heating is:

   a. long-wave solar radiation
   b. long-wave terrestrial radiation
   c. short-wave solar radiation
   d. latent-heat of evaporation

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Answer									

The answers to these questions can be found at the end of the book.

CHAPTER 5
PRESSURE SYSTEMS



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INTRODUCTION.

The different pressure systems found across the surface of the Earth play a primary role in determining the Earth's weather. Understanding pressure systems is central to the understanding of weather itself.

It is important to note, from the outset, that in low pressure areas, air is rising, while in high pressure areas, air is descending. This general vertical movement of air constitutes the primary distinction between high and low pressure systems. Pressure systems are not defined by the numerical value of the prevailing atmospheric pressure within the systems themselves, but by the relative pressures.

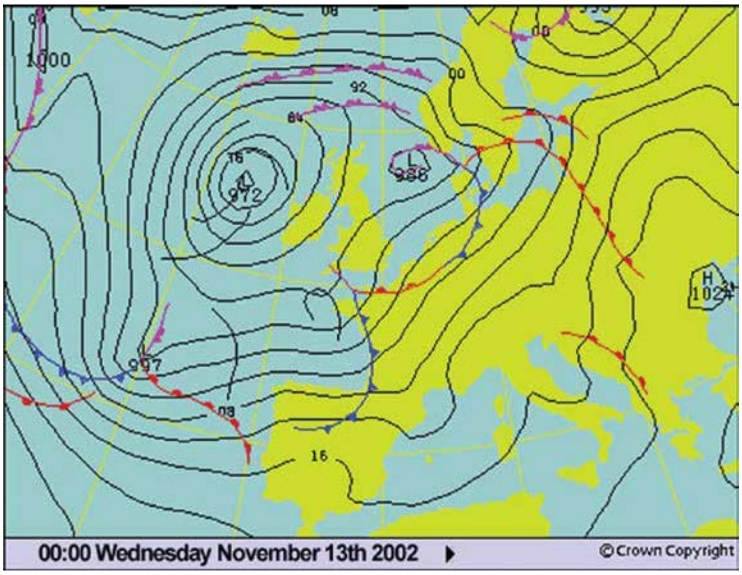

Figure 5.1 Lows, Highs and Cols.

The two principal types of pressure system, are low pressure systems (also called depressions or cyclones) and high pressure systems (also called anticyclones). There are also a number of subsidiary pressure systems called cols, ridges and troughs.

High pressure areas are also referred to as "anticyclones". Low pressure areas are often called "depressions".

LOW PRESSURE SYSTEMS.

There are two forms of low pressure system: small scale low pressure areas and large scale low pressure areas.

The difference between a low pressure area and a high pressure area is defined by the fact that in a 'low' the air is rising, and in a 'high' the air is descending.

SMALL SCALE LOWS.

Small scale lows, or depressions, can be found almost anywhere on the Earth's surface. They are created when there is unequal heating of the Earth's surface.

Variations in pressure, both horizontally and vertically, are a basic cause of weather.

As you have learnt, an increase in temperature leads to a decrease in air density. Air lying above a warm surface will be heated by that surface through conduction. (See Chapter 4.) So, the heating process and the associated reduction in air density will cause air to rise. The rising air travels up through the atmosphere and eventually, when it reaches high altitudes and has cooled again to the temperature of the surrounding air, diverges, or spreads out. The total weight of the column of air above the warm surface of the Earth reduces as the air diverges, causing the atmospheric pressure to fall at the surface.

Surface atmospheric pressure falls in low pressure systems.

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As air rises, the air surrounding the low pressure area will be drawn inwards in an attempt to fill the low, and return the air pressure to equilibrium. However, the inward-moving air will experience friction as it moves over the Earth's surface, slowing it down. Consequently, more air leaves the divergence area in the upper atmosphere than can be replaced at the surface. Therefore, low pressure above the warm surface is maintained, and air pressure may continue to fall over time as this process evolves. The development of a small scale low is depicted in *Figure 5.2*.

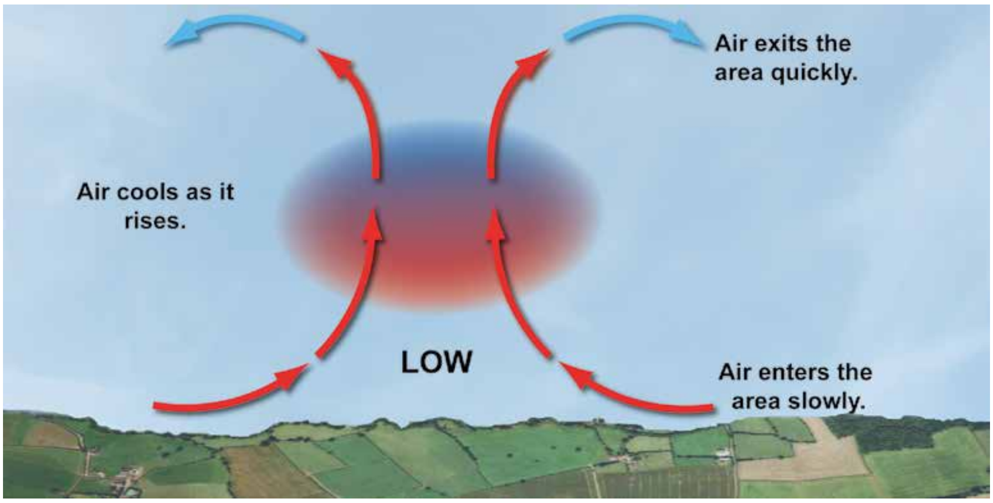

Figure 5.2 Rising air in a small scale low.

Small scale lows are created by unequal heating of the Earth's surface which gives rise to convection. Condensation in the rising air leads to the development of cumulus cloud.

As the air in the centre of the depression rises, the volume of air will expand, because pressure decreases with increasing altitude. This expansion will cause the rising air to cool as it ascends by a process called adiabatic cooling. Adiabatic cooling will be covered in detail in Chapter 8. Condensation will take place when the air temperature has fallen to its dew point. The dew point is the temperature to which the air must be cooled, at constant barometric pressure, for the water vapour contained in the air to condense. As water vapour changes state to become liquid water droplets, cloud is formed. The clouds which are created within a small scale low develop vertically, and are called cumuliform clouds, or, more simply, cumulus clouds. *(See Figure 5.3.)*

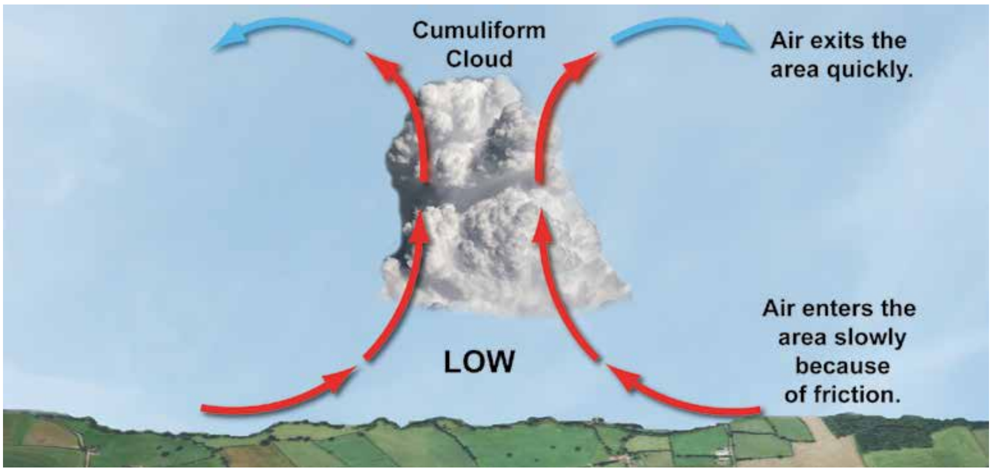

Figure 5.3 Cumuliform clouds formed by adiabatic cooling, as air rises in a low pressure area.

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HAZARDS TO AVIATION FROM SMALL SCALE LOWS.

Small scale low pressure areas can set in motion large amounts of energy, and may present some serious hazards to the general aviation pilot. Hazards associated with small-scale low pressure areas include:

- Turbulence.
- Precipitation.
- Icing.
- Poor visibility.

Turbulence and Precipitation.

The velocity of the rising air can be very significant inside a vigorously developing cumuliform cloud. In some cases, hail stones up to 2 lbs (1 kg) in weight may be suspended inside the cloud by strong upcurrents. When the weight of the water droplets or hail stones suspended within the cloud exceeds the force of the rising air, they will fall to the Earth as precipitation. The onset of precipitation associated with small scale lows is generally both rapid and intense, resulting in air being forced downwards toward the Earth's surface, creating very active down draughts. The strong updraughts and downdraughts within small scale lows generate moderate to severe turbulence. *(See Figure 5.4.)*

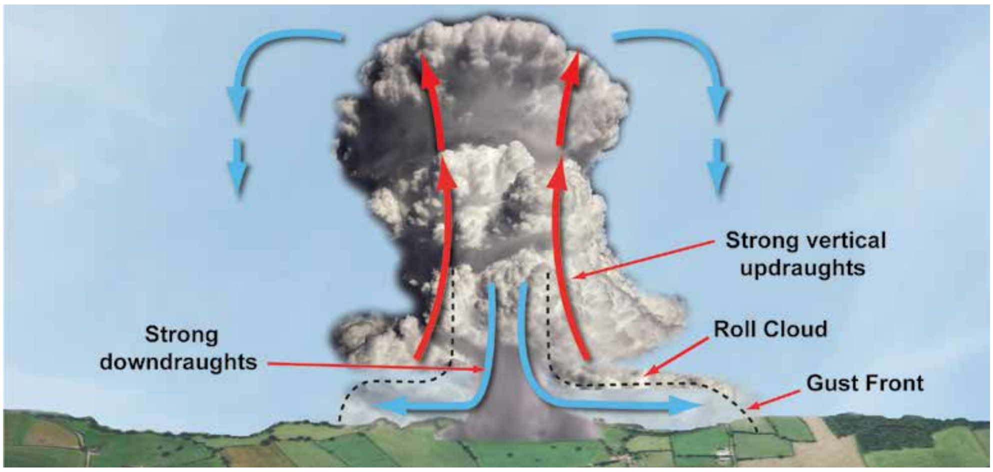

Figure 5.4 Turbulence and precipitation hazards in small scale lows. Strong updraughts are generated inside the clouds, while strong downdraughts are associated with precipitation.

Icing.

Another phenomenon associated with small scale lows and of significance to aircraft is icing. Icing occurs when sub-zero liquid or supercooled water, held within the cloud, freezes onto an aircraft's surfaces. The formation of ice dramatically affects the aircraft's performance and ability to remain airborne. *(See Figure 5.5.)*

Aircraft Icing will be covered in detail in a later chapter; for the moment, it is important that you should note that the icing risk can be moderate to severe in weather phenomena associated with intense small-scale low pressure areas.

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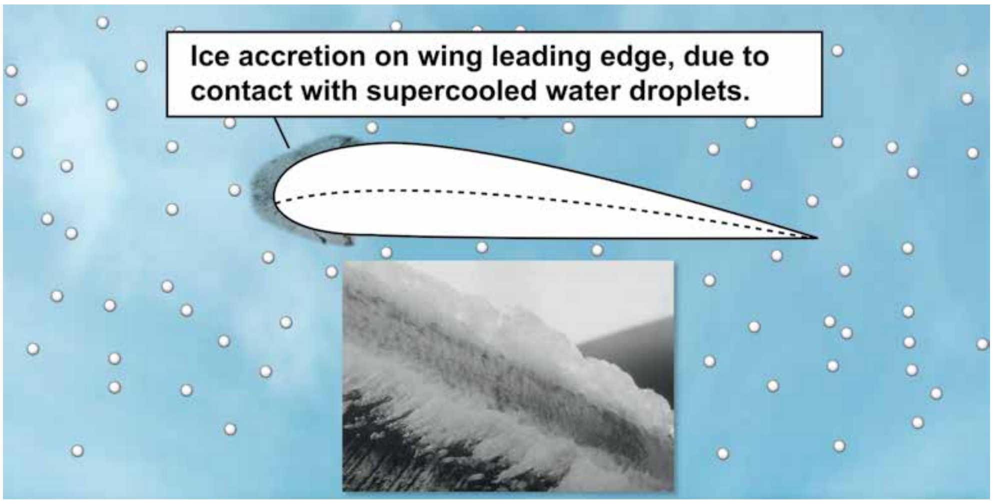

Figure 5.5 Icing may be moderate to severe in cumuliform clouds.

The hazards of small scale lows are turbulence and icing. Visibility, outside cloud and showers, is good, but visibility in precipitation may be very poor, reducing to almost zero in heavy precipitation.

Visibility.

One other concern for pilots, connected with small scale low pressure areas, is the horizontal visibility near the Earth's surface. When air is converging and rising, any impurities near the Earth's surface will be drawn up into the upper atmosphere leaving much clearer air at the surface. Nevertheless, although surface visibility may be good, in precipitation, visibility can be very poor, reducing to almost zero in heavy precipitation.

THE EQUATORIAL LOW PRESSURE BELT.

Small scale lows commonly form over land masses in the summer months, especially in Asia, Central Europe and the USA. However, the most frequent occurrence of small scale low pressure areas is around the Equator. *Figure 5.6,* depicts bands or belts of low pressure systems centred on the Equator, created by warm rising air. The central belt is the Equatorial Low Pressure Belt where very extensive cumuliform cloud developments occur.

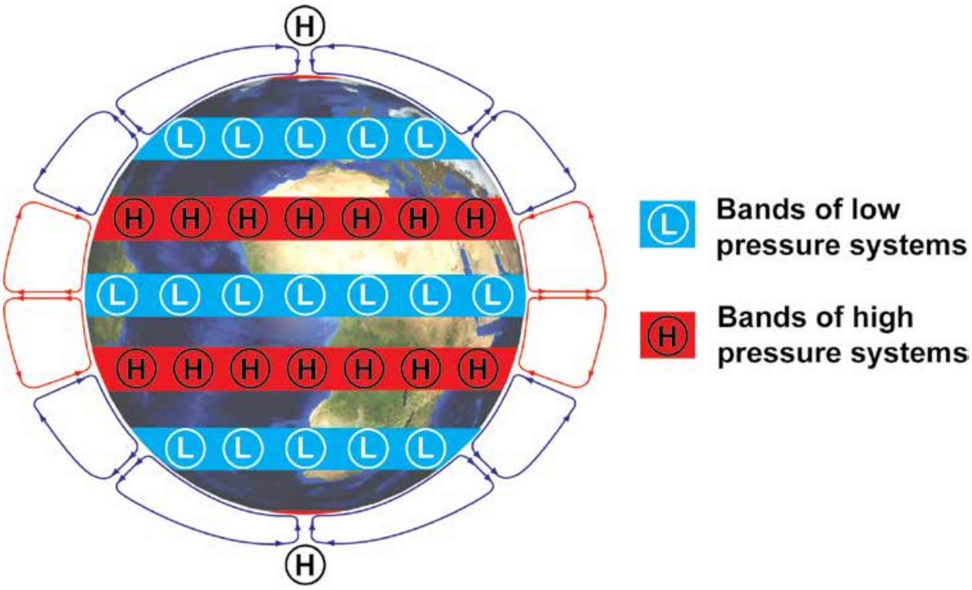

Figure 5.6 A global pressure distribution model.

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Under certain circumstances, the small scale depressions around the Equator can evolve into some of the most violent weather phenomena on the surface of the Earth, called tropical revolving storms, or, as they are more commonly known, hurricanes, cyclones or typhoons. Storm systems of this type can expand to over 700 nautical miles in diameter. As these storm systems expand to this much larger scale, the action of the Earth's rotation becomes significant, and, unlike in the small scale low, the airflow is deflected as it is drawn towards the centre of the depression. This deflection of the airflow can result in rotational wind speeds of up to 200 miles per hour. Such storms are generally found only over the tropical oceans and require specific environmental conditions for them to develop.

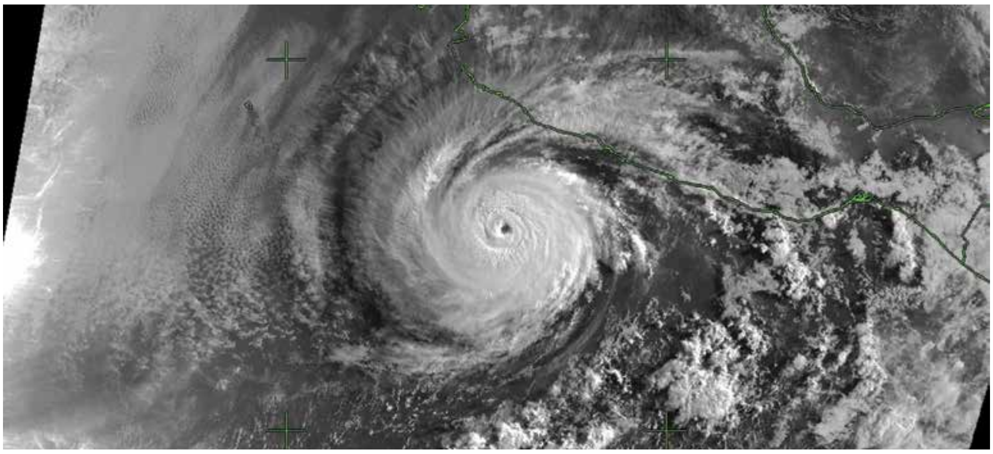

Figure 5.7 Under certain conditions, small scale low pressure areas can develop into large scale Tropical Revolving Storms, featuring very strong rotational winds.

Figure 5.7 shows a satellite photograph of a Tropical Revolving Storm off the coast of Central America.

LARGE SCALE LOW PRESSURE AREAS (DEPRESSIONS).

Polar frontal depressions are large scale low pressure areas, which are created in a very different manner from the small scale heat lows. Polar front depressions are found along the polar front which lies principally in the higher latitudes at about 40º to 60°, North *(see Figure 5.9)* and South, depending upon the season. You can see these two bands of low pressure in *Figure 5.6,* near the top and bottom of the globe. The depressions typically move from West to East across the Earth's surface, and the process of their formation is complex. *Figure 5.8,* shows a typical polar front depression over the British Isles.

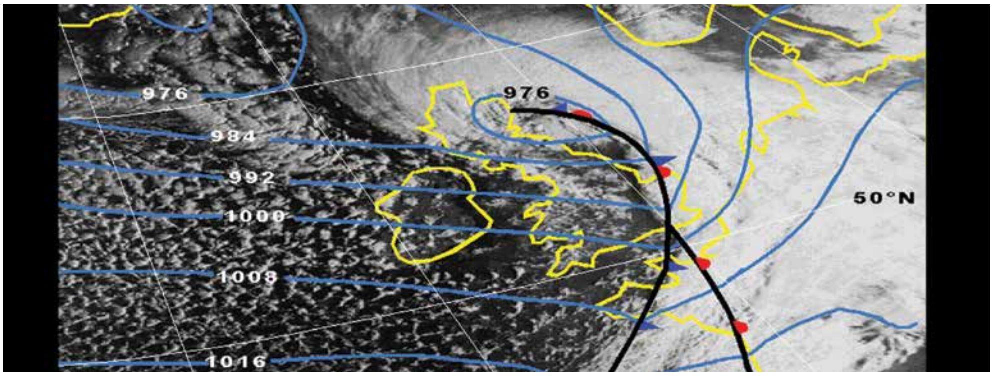

Figure 5.8 Large scale low pressure areas are called Polar Front Depressions.

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FORMATION OF POLAR FRONT DEPRESSIONS.

In the temperate latitudes (between the tropics and the polar circles), warm tropical air meets cold polar air. The boundary between warm and cold air masses is called the polar front. As with any boundary between two air masses of different densities, the boundary will not be a straight line. At some points along the front there will be "kinks" or small irregularities. In these kinks, the warm tropical air intrudes into the cooler polar air, as depicted in *Figure 5.9*.

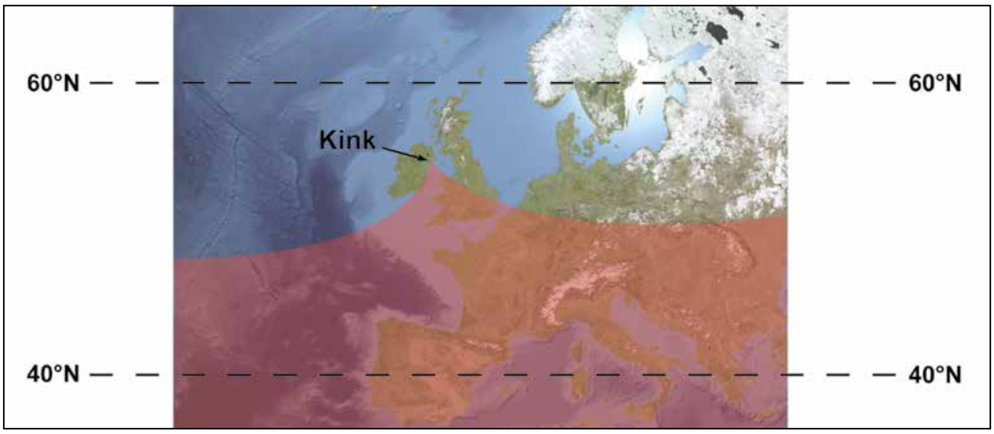

Figure 5.9 Along the Polar front, kinks develop. This is where warmer, less dense, air intrudes into colder air, reducing the weight of the air and creating a centre of low pressure at the Earth's surface.

The lighter, warmer air in the kink replaces the colder, heavier air, so the weight of the overlying air is reduced, leading to a fall in the surface pressure.

As the surface pressure falls, air will be drawn in towards the area of low pressure. However, because the air movement is on a large scale, this displacement of air is deflected by the rotation of the Earth.

In the Northern Hemisphere, the deflection of the moving air mass, as shown in *Figure 5.10,* is to the right, causing winds to blow anti-clockwise around the depression. In the Southern Hemisphere the deflection is to the left, and so, South of the Equator, the wind blows clockwise around a depression. This deflection of the moving air mass is caused by a force known as the Coriolis Force. Coriolis Force will be covered in more detail in Chapter 12, Low Level Winds.

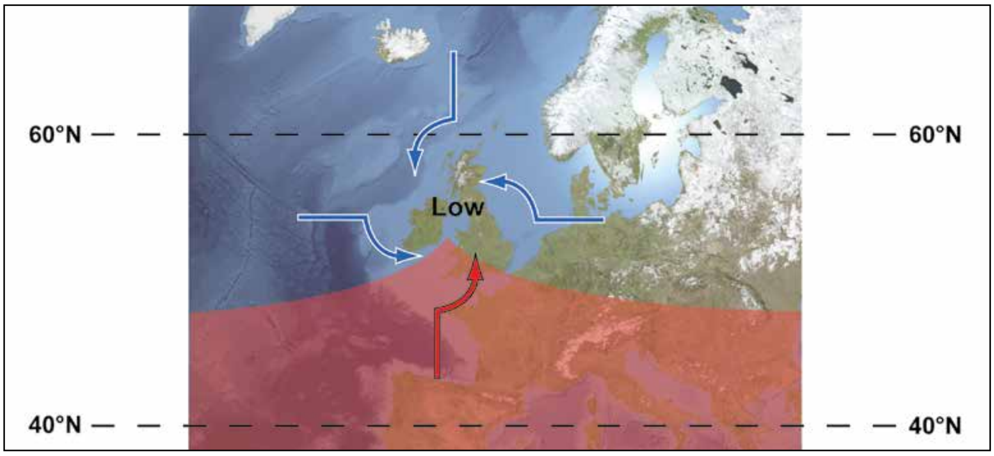

Figure 5.10 In the Northern Hemisphere, air is drawn towards the Low, and is deflected to the right by Coriolis Force, causing the wind to blow anti-clockwise around the depression.

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There are two types of interaction between the warm and cold air masses which are fundamental to the understanding of frontal weather systems.

The Warm Front.

Along the section of the **front** depicted by the red semi-circular symbols in *Figure 5.11*, warm air is being forced against the cooler air.

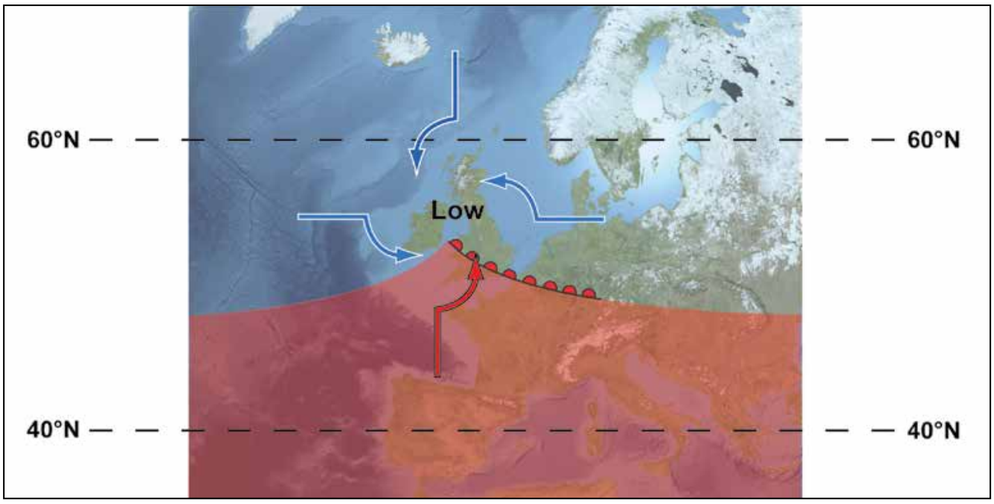

Figure 5.11 The red semi-circular symbols indicate a warm front, where warm air along the ***polar front*** *rides up over cold air.*

The warmer air, being less dense, will ride up and over the colder air. The weather feature created in this way, and depicted in *Figure 5.12,* in cross section, is called a warm front.

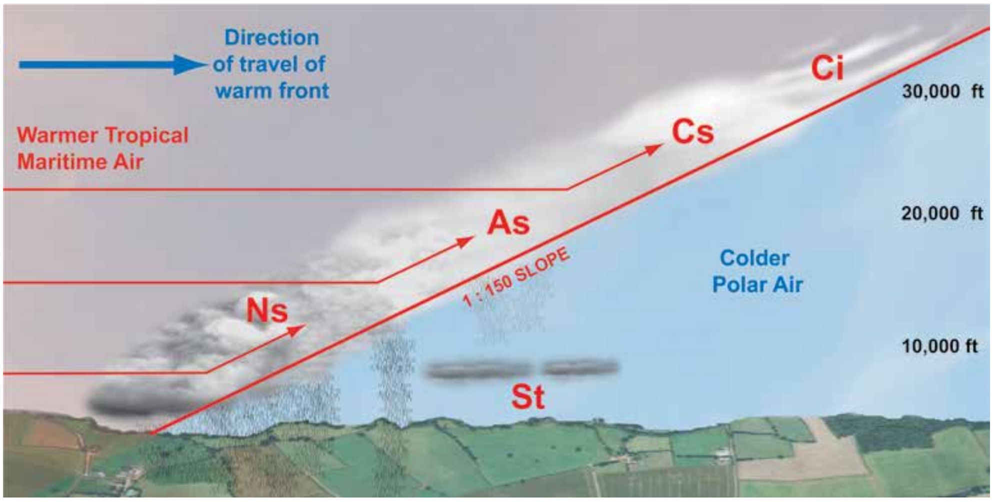

Figure 5.12 The warm front - warm air being forced over cooler air.

CLOUD TYPES ASSOCIATED WITH THE WARM FRONT

Ci = Cirrus
Cs = Cirrostratus
As = Altostratus
Ns = Nimbostratus
St = Stratus

Because the warm air is being forced upwards into lowering atmospheric pressure, the air expands and cools. Water vapour in the air, therefore, condenses, creating cloud along the frontal boundary. The cloud takes on a horizontal, layered appearance since the slope of the warm front is about one in one hundred and fifty, much shallower than the slope indicated in the diagram at *Figure 5.12*. This layer-type cloud is called stratiform cloud.

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The Cold Front.

The other main feature of the polar front is depicted in *Figure 5.13*. Along the line marked by the blue triangles, the blue colder air is being forced against the red warmer air. The colder, heavier air will undercut the warmer, lighter air in the form of a wedge creating a cold front *(see Figure 5.14)*. The blue triangles, in *Figure 5.13* are the standard symbols denoting a cold front.

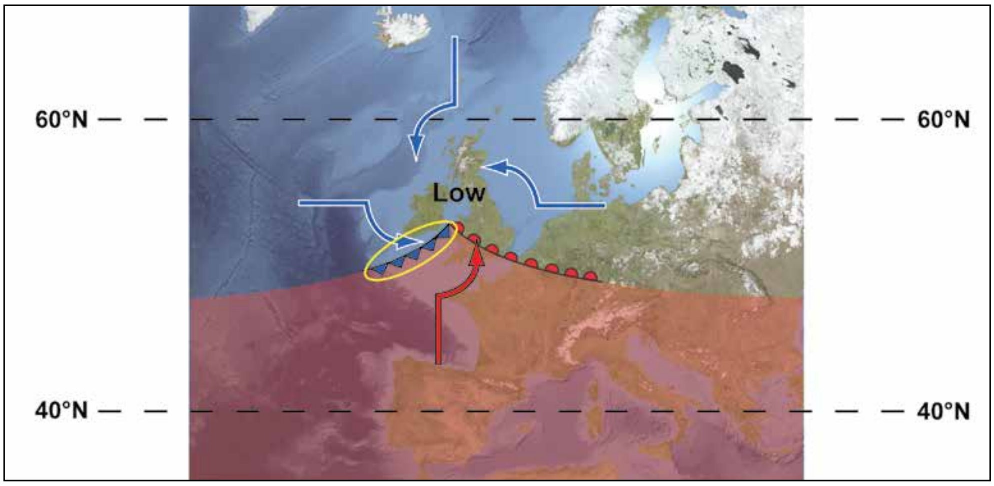
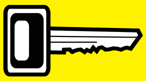


Figure 5.13 The cold front. The blue triangle symbols denote a cold front, where cold air pushes itself under the warm air.

As the cold air advances, it forces the warm air upwards causing the warm air to cool. The water vapour in the warm air mass, consequently, condenses, and clouds are created. The slope of the cold front boundary is steeper than that of the warm front, with a gradient of approximately one in fifty. If we consider the whole extent of the cold front, cloud will still take on a general stratiform appearance. However, there is a fundamental difference along the cold front compared to the warm front. Notice that the cold front slopes forwards first, then slopes backwards creating a wedge shape. The wedge shape is formed because the portion of the front in contact with the ground will slow down due to friction as the front advances, and, as a result, will lag behind the air immediately above it. This phenomenon creates instability in the warm air which is in direct contact with the wedge.



CLOUD TYPES ASSOCIATED WITH THE COLD FRONT

Cs = Cirrostratus
As = Altostratus
Ns = Nimbostratus
Cu = Cumulus
Cb = Cumulonimbus

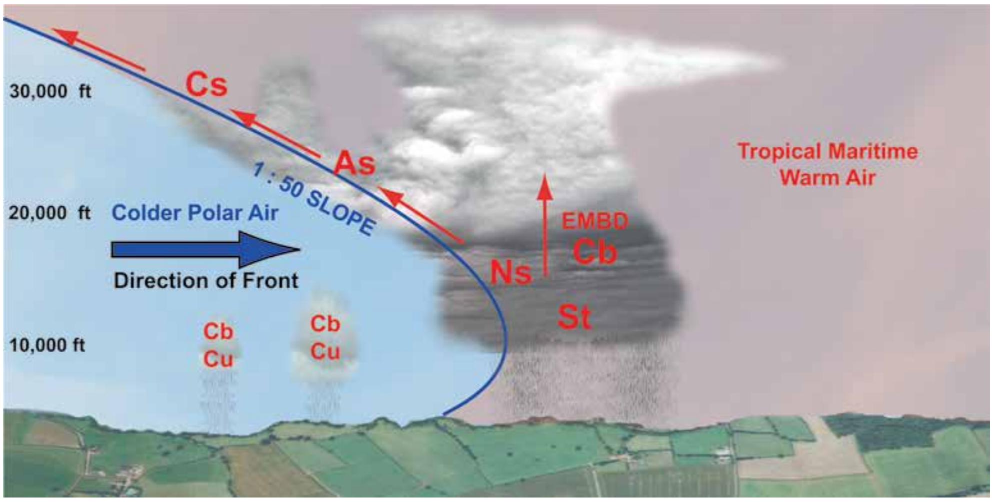


Figure 5.14 The Cold Front - cooler air undercuts warmer air, forcing it to rise. Just ahead of the cold front, vigorous vertical ascent of the warm air creates cumuliform cloud.

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The unstable air just ahead of the cold front is, therefore, forced to rise vigorously. This vigorous vertical ascent creates vertically developed cumuliform cloud. The cumuliform clouds formed in advance of the cold front are potentially hazardous, often becoming storm clouds, called cumulonimbus which may often be embedded or concealed within the stratiform cloud. *(See Figure 5.14.)*

Note that the cold and warm fronts, depicted on weather charts by the semi-circular and triangular symbols, mark the surface position of each of the fronts.

Isobars.

Isobars on weather charts are lines of equal surface pressure. A typical pattern of isobars around a polar front depression is shown in *Figure 5.15.*

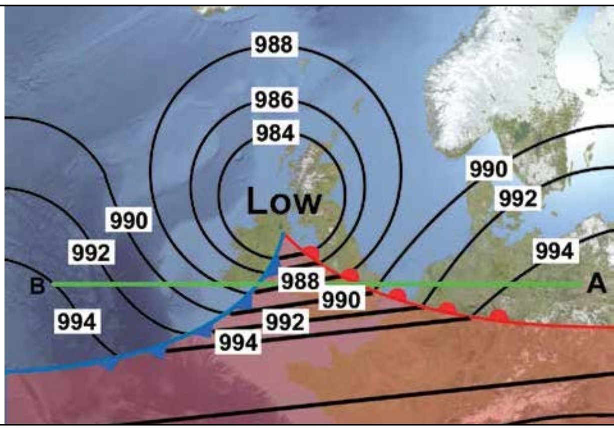

Figure 5.15 Isobars on weather charts show the fall and rise in pressure as a depression moves from West to East.

Polar front depressions are formed by kinks which develop in the boundary between tropical and polar air. Warm air is forced upwards by the cold air and cloud is formed.

You should note that Polar Front Depressions move from West to East, so that, in a typical frontal system, the warm front precedes the cold front. Therefore, as the warm front approaches from the West, pressure falls. Between the fronts, the pressure falls slightly, but after the cold front has passed, pressure will start to rise again. *(See Figure 5.15.)*

Figure 5.16, is a typical UK Met Office chart showing Polar Front Depressions with their associated cold and warm fronts and isobars. In *Figure 5.16,* there is, however, a feature that we have not yet mentioned. This is the occluded front.

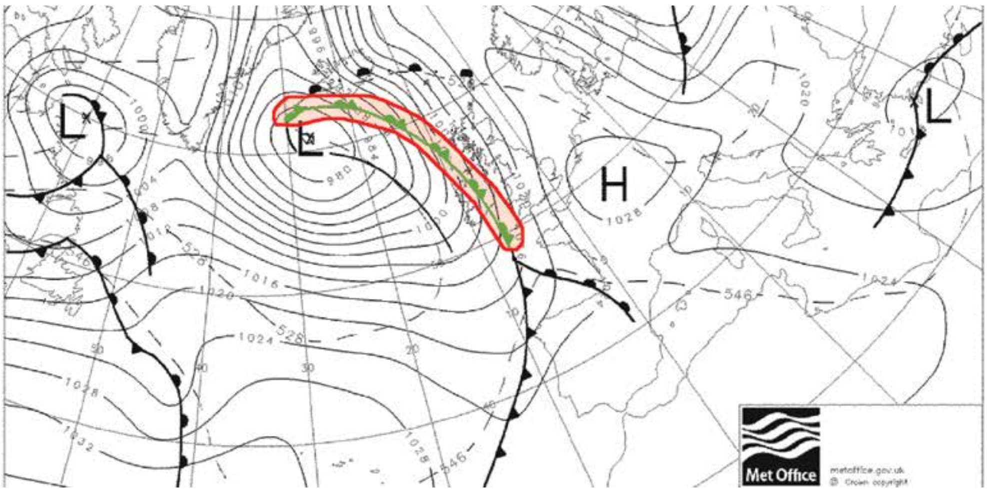

Figure 5.16 Occluded front - the merging of a cold and warm front.

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The Occluded Front.

If you examine the highlighted area in *Figure 5.16* you will notice that the warm and cold front symbols are found together along one line. When the symbols are arranged in this manner, they indicate the presence of an occluded front. Occluded fronts are created when the cold and warm fronts merge. Occluded fronts will be explained in more detail later on, in Chapter 15, "Air Masses and Fronts".

ISOBARIC TROUGHS.

Depressions of any kind will change over time, and can be a variety of shapes and sizes. By analysing the pattern of the isobars it is possible to identify the shape of the depression. If the isobars form a finger-like protrusion away from the centre of the depression, *(see Figure 5.17)* an isobaric trough of low pressure is present.

A surface trough is a finger-like protrusion of low pressure away from the centre of a low. Trough weather can be as active as that in the main depression, with active cumuliform cloud.

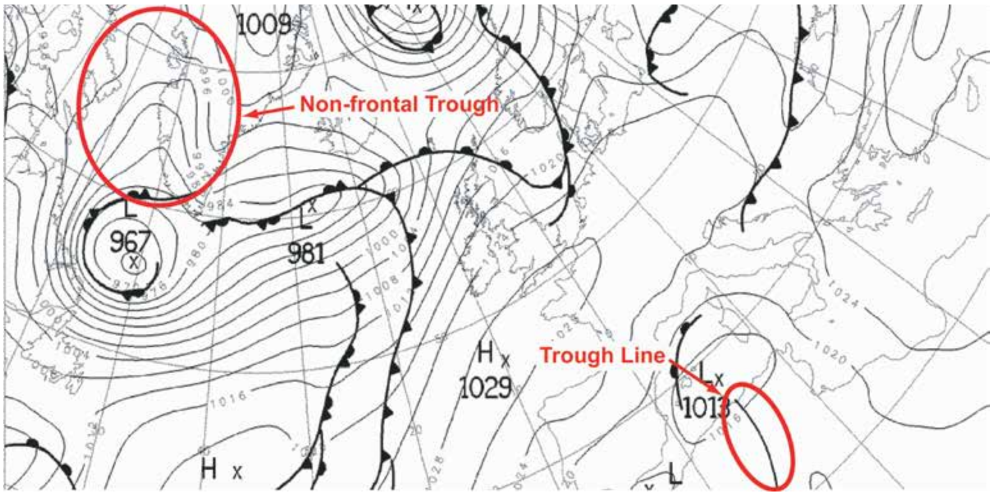

Figure 5.17 Isobaric troughs are extensions or protrusions of low pressure that can be as active as the main depression. Trough lines are areas of strong uplift giving rise to cumuliform clouds.

Weather in an isobaric trough can be as active as that of a main depression.

There is another type of surface trough, also shown in *Figure 5.17*, which is caused by processes higher up in the atmosphere. These are known as trough lines, and are represented on surface pressure charts with a solid black line. Significant formations of cumuliform storm cloud can occur along these trough lines.

Troughs can be associated with fronts, or may be non-frontal. Both types can be seen in *Figure 5.17*. A non-frontal trough is usually U-shaped, such as the trough highlighted in *Figure 5.17*. Non-frontal troughs are characterised by convergence of air at the Earth's surface, causing air to rise over a large area, producing extensive cloud with associated rain and showers.

HIGH PRESSURE SYSTEMS.

A high pressure area, also referred to as an anticyclone, is created when the weight of a column of air is increased, causing subsidence of the air mass. The increase in weight of an air mass can occur in a number of ways. The most common process is one of convergence of air in the upper atmosphere. In *Figure 5.6,* earlier in the chapter, you will have noticed that there is a band of high pressure over each of the Tropics, as well as a high pressure area over each Pole. Above these locations, you will see that air is converging in the upper atmosphere.

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Because convergence in the upper atmosphere increases the mass of air overlying the Earth's surface at that location, the surface pressure will rise. As the surface pressure rises, air along the Earth's surface will naturally want to move away from the high pressure region. However, the outward flow of air is slowed down by surface friction, whereas, in the upper atmosphere, the convergence is more rapid. This phenomenon continually adds to the mass of air overlying the area, and sustains the high pressure. The airflow associated with a high pressure area is shown in *Figure 5.18*.

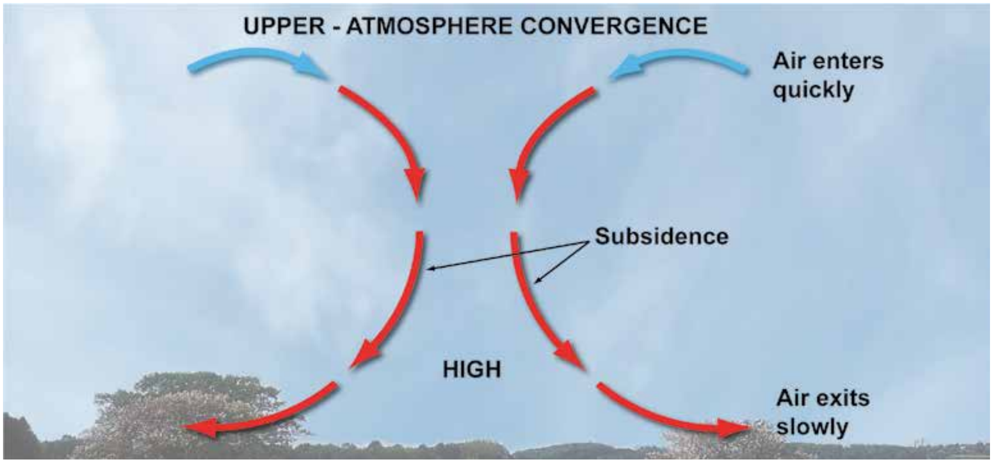

Figure 5.18 High Pressure Areas (Anticyclones) are created by convergence of air in the upper atmosphere, increasing the weight of the air overlying an area and causing subsidence.

High pressure areas, anticyclones, are formed by convergence in the upper atmosphere.

We may summarise the pattern of airflow within a high pressure system by saying that air converges in the upper atmosphere, and then descends and diverges along the Earth's surface. The descent of air in a high pressure area is sometimes called subsidence.

Subsidence in high pressure areas (anticyclones) is the principal characteristic of weather within an anticyclone. As the air mass descends it is compressed by the increase in pressure in the lower atmosphere. This compression, of course, causes the temperature of the air to rise by a process called adiabatic warming. Warming of the descending air in an anticyclone inhibits condensation and the formation of cloud. (*See Figure 5.19.)*

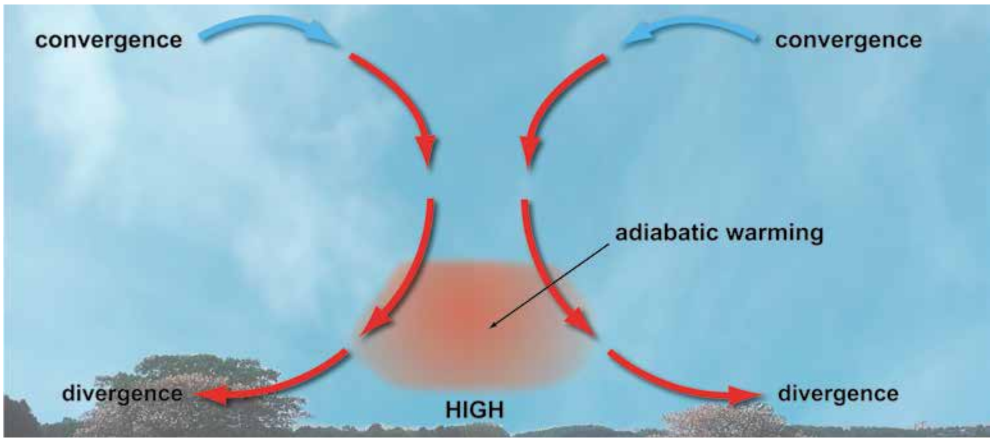

Figure 5.19 Descending air in a high pressure area is warmed adiabatically. Adiabatic warming inhibits the formation of cloud, leading to clear skies.

In an anticyclone, descending air warms adiabatically, leading to cloudless skies, but often poor visibility because of trapped dust and smoke particles.

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In general, within high pressure areas, there is little significant cloud or weather. But the descent of air does cause one weather problem. Contaminants within the atmosphere such as smoke and dust are trapped in the lower layers leading to a reduction in visibility. Haze is a common weather feature found in high pressure areas, especially in summer. However, in winter, because the air near the Earth's surface cools significantly without cloud cover, fog is a prevalent feature in anticyclones, together with surface temperature inversions.

The cloudless skies of an anticyclone produce hazy warm weather in summer, but low temperatures and fog in winter, along with temperature inversion.

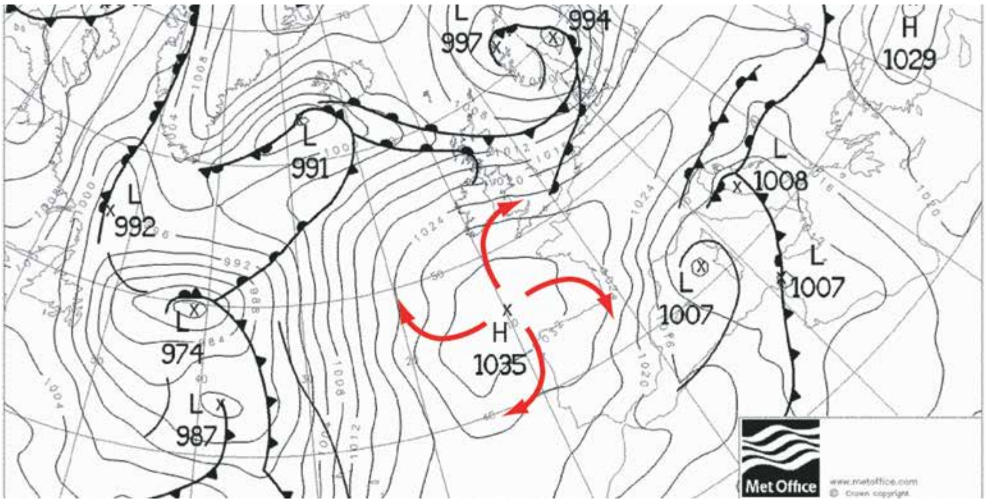

Figure 5.20 In areas of high pressure (anticyclones), clear skies, light winds and hazy visibility will be the predominant features.

In *Figure 5.20* shows a typical chart; note the lack of frontal cloud in the high pressure area to the south.

Wind associated with Anticyclones.

Air descends at the centre of an anticyclone and then diverges outwards along the Earth's surface. Because the high pressure areas are of such a large scale, the diverging air (or wind) is deflected by the rotation of the Earth. This deflection of the wind, due to the Coriolis Force, is to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. So the air moves around high pressure areas clockwise in the Northern Hemisphere. However, unlike a low pressure area, the isobar spacing around an anticyclone is typically a lot wider and, therefore, the winds associated with high pressure areas are usually light.

Sub Tropical High Pressure Belt and Polar Highs.

Looking back to *Figure 5.6,* you will identify bands of high pressure created by upper air convergence. The two bands either side of the Equator, in the Tropics, are called the Sub-Tropical High Pressure Belt. Most of the major deserts are located within this belt. Similar convergence occurs in the upper atmosphere over the Poles, creating other areas of high pressure. These are the Polar Highs.

THE RIDGE OF HIGH PRESSURE (ISOBARIC RIDGE).

If you examine the pattern of the isobars around the high pressure area in *Figure 5.21,* you will see that the isobars form a finger-like protrusion away from the centre of the anticyclone, forming a ridge of high pressure. A ridge of high pressure is usually interposed between two depressions and is, therefore, a weather feature of short duration. The weather characteristics of a ridge of high pressure are similar to

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those of the main high pressure system, except that atmospheric subsidence is not so pronounced, allowing greater convection to take place which produces cumulus cloud and improved visibility. A ridge of high pressure often marks an excellent flying day.

The weather in a Ridge of High Pressure will be similar to that in the centre of the anticyclone, except that subsidence is not quite as strong and some convection may take place, producing isolated cumuliform clouds, with good visibility.

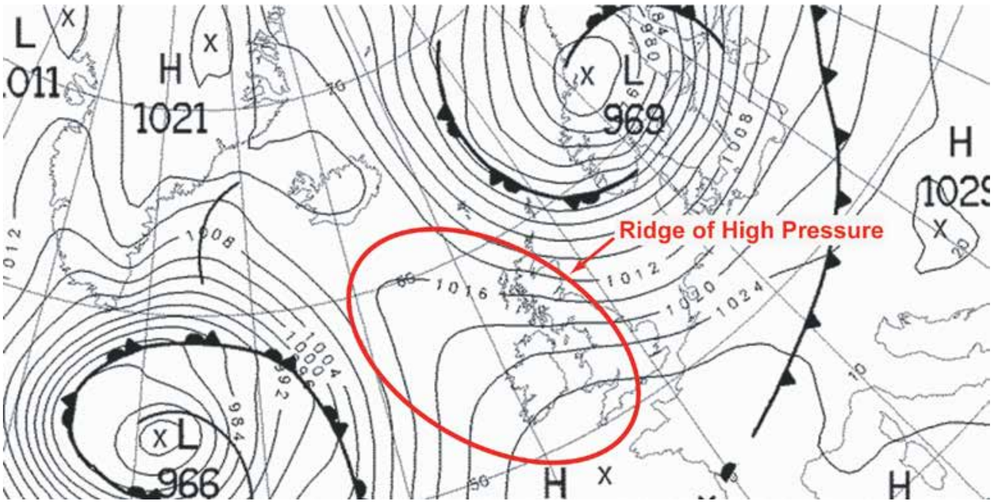

Figure 5.21 An Isobaric Ridge or Ridge of High Pressure.

COLS.

A col is an area of widely spaced isobars and light winds, between two highs and two lows.

A col is an area on the Earth's surface not directly under the influence of either a high or a low-pressure system. A col is the region in the middle of two lows and two highs, as depicted in *Figure 5.22*. The meteorological col is analogous to a topographical col located between two mountains and two valleys. Within the col, the isobars are very widely spaced. Because of this wide spacing of the isobars, the winds within a col are very light, and variable in direction.

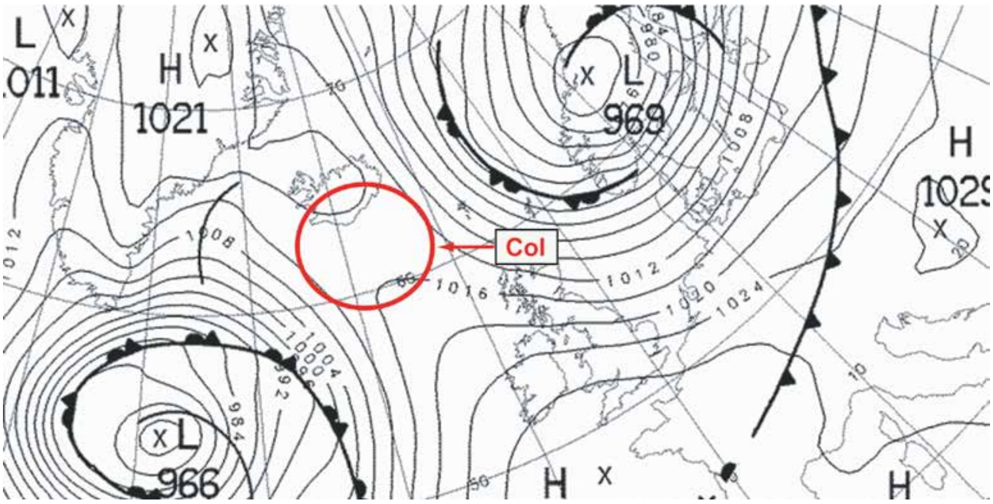

Figure 5.22. A col - the area between two highs and two lows. Winds within a col are light and variable.

The weather within a col is dependent on the season. Generally, over land areas in summer, typical col weather would be thundery, whilst, in winter, the weather is likely to be mainly foggy.

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HORIZONTAL PRESSURE CHANGES AND BUYS BALLOT'S LAW.

As you can see from the pressure charts in *Figures 5.20, 5.21, 5.22,* atmospheric pressure can vary greatly across the Earth's surface. In the 19th Century, the Dutch meteorologist Buys Ballot postulated a law relating wind direction to pressure systems.

Buys Ballot's law states that: In the Northern Hemisphere, if an observer stands with his back to the wind, the low pressure area is on his left.

As you will learn in Chapter 12, Coriolis force, a force linked to the rotation of the Earth, causes wind, in the Northern Hemisphere, to blow anticlockwise around a depression and clockwise around an anticyclone. *Figure 5.23* illustrates the direction of wind around a depression. It is easy to see from this diagram that Buys Ballot's Law holds good. You can also see from *Figure 5.23* that, if an aircraft is subject to starboard drift, it is flying towards Low Pressure.

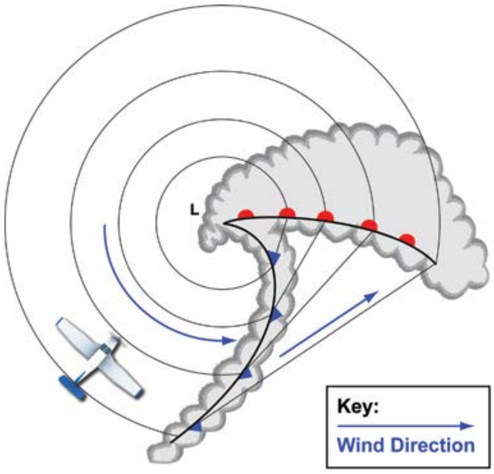

Figure 5.23 In the Northern Hemisphere, wind blows anti-clockwise around a depression.

More detailed explanation of the importance of horizontal variations of pressure is given in Chapter 6, Altimetry.

SUMMARY.

Each type of pressure system has its own associated weather characteristics. If a pilot knows what type of pressure system is dominating the area in which he is flying, he should be able to predict what the weather will be like.

Generally speaking, low pressure weather is dominated by cloud and precipitation, whereas high pressure areas have clear skies, with poor visibility in fog or haze. The best flying weather for general aviation pilots is often associated with a ridge of high pressure.

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Representative PPL - type questions to test your theoretical knowledge of Pressure Systems.

1. Which of the statements below best describes a Col?

   a. An area between two highs where the isobars are very close together
   b. An extension of high pressure
   c. An extension of low pressure
   d. An area of widely spaced isobars between two highs and two lows

2. A ridge of high pressure is generally associated with:

   a. convergence at the surface, causing increased cloud and precipitation
   b. atmospheric subsidence, but not so pronounced as in an anticyclone, fine-weather cumulus, and moderate to good visibility
   c. tightly packed isobars, causing strong winds blowing anticlockwise around the high pressure system
   d. subsidence of air, then divergence at the surface causing clear skies and poor visibility

3. An area of widely spaced isobars and light and variable winds, between two depressions and two anticyclones, is called:

   a. a trough
   b. a ridge
   c. a col
   d. a saddle

4. With an anti-cyclone predominating over the United Kingdom the expected weather would be:

   a. thunderstorms in summer, fog in winter
   b. stratus in summer with drizzle, cumulus and snow in winter
   c. clear skies or possibly fair weather cumulus in summer, fog in winter
   d. clear skies in summer with haze, and cold frontal weather in winter

5: During the winter months, which of the following weather conditions would most likely be produced by an anti-cyclone?

   a. Subsidence due to surface cooling creating extensive cloud
   b. During the day, the surface warming would create an unstable atmosphere with extensive cloud cover
   c. During the night as the land cools, there would be an increase in the vertical cloud development
   d. General subsidence producing clear skies, inversion with poor surface visibility, and heavy surface frosts

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6. A trough of low pressure at the surface is generally associated with:

   a. surface convergence causing increased cloud and precipitation
   b. surface divergence causing increased cloud and precipitation
   c. subsidence causing increased cloud and precipitation
   d. subsidence causing decreased cloud and precipitation

7. If a pilot flying at a given altitude in the Northern Hemisphere experiences a constant drift to the right, he will probably be flying:

   a. towards the centre of an anticyclone
   b. towards the centre of a depression
   c. away from a low pressure area
   d. within a col

8. What is the cause of high pressure at the Earth's surface within an anticyclone?

   a. lower atmosphere convergence
   b. large scale ascending air
   c. upper atmosphere convergence and subsidence
   d. rotating winds

9. What is the cause of low pressure around a Polar Front depression?

   a. the intrusion of warm air into a colder air mass along a Polar Front
   b. subsidence
   c. upper atmosphere convergence
   d. divergence at the Earth's surface

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Answer									

The answers to these questions can be found at the end of the book.

CHAPTER 6
ALTIMETRY

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THE ALTIMETER.

Because of the variation of air pressure with altitude, a pilot is able directly to read his aircraft's vertical separation from the Earth's surface, using an instrument called the altimeter.

Figure 6.1 Altimetry is based on the fundamental relationship between pressure and altitude. The altimeter is an aneroid barometer calibrated to read height.

The altimeter is a form of barometer but is calibrated in feet (or metres) to read altitude or height.

The altimeter is a form of aneroid barometer. As you learnt in Chapter 2, any change in air pressure will cause the partially evacuated metal capsule of the aneroid barometer, to expand or contract. In the altimeter, this capsule is linked to a pointer which moves over a scale, calibrated in feet or metres, so that the pilot can read his altitude or height.

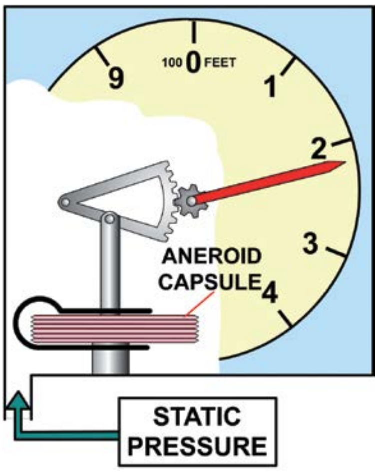

Figure 6.2 A Simple Altimeter.

As an aircraft climbs, the atmospheric pressure surrounding the aircraft decreases causing the capsule within the altimeter to expand, and the altimeter pointer to move clockwise over the scale to indicate an increase in height. Conversely, when the aircraft descends, atmospheric pressure increases, compressing the capsule, causing the altimeter pointer to move anticlockwise, over the scale to indicate a decrease in height.

Basically, then, the aircraft's altimeter is an instrument which measures atmospheric pressure and, in doing so, is calibrated so as to indicate the vertical separation of the aircraft from a defined pressure datum level.

It is important to note that the pressure altimeter is unable to measure vertical separation above any datum level other than a pressure datum.

We must consider, therefore, where the altimeter reading is measured from, in other words, where is the altimeter assuming the datum level to be?

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ALTIMETER SUB-SCALE SETTINGS.

The datum with respect to which the altimeter's scale is calibrated is neither a physical, nor geographical level; it is a pressure value. It follows, then, that the altimeter must be given a pressure value to begin measuring from, before it can indicate a vertical separation of any use to the pilot. This pressure value is selected by means of an adjustable sub-scale. The altimeter sub-scale takes the form of a small window in the face of the altimeter; which shows the selected datum pressure value, either in millibars, hectopascals or inches of mercury. (*See Figure 6.3.)*

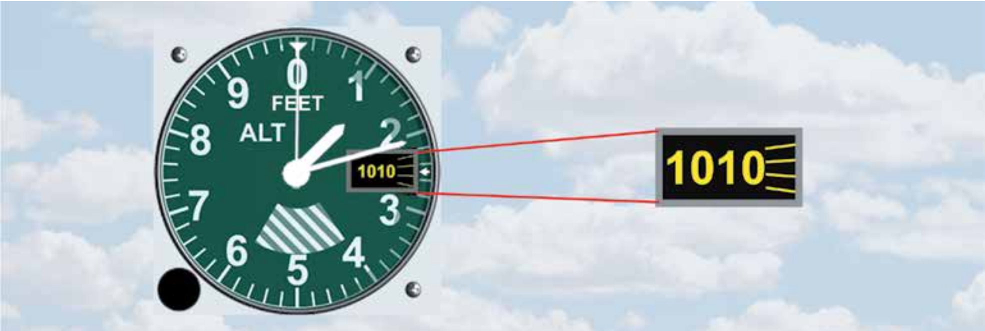

Figure 6.3 The Altimeter Sub Scale Settings - the altimeter will read the vertical separation from the pressure datum level set on the subscale. In this case, the subscale is set to 1010 millibars (hectopascals), and the altimeter scale is in feet.

The altimeter indicates vertical separation from a defined pressure datum level which the pilot selects in the altimeter sub-scale.

The pressure value set in the altimeter's sub-scale window, is the pressure level that the altimeter will start measuring from; in other words, the pressure level that the altimeter will assume to be zero feet. So, if a pilot wishes the altimeter to read height above an airfield, the atmospheric pressure at the airfield must be determined and selected on the altimeter's subscale.

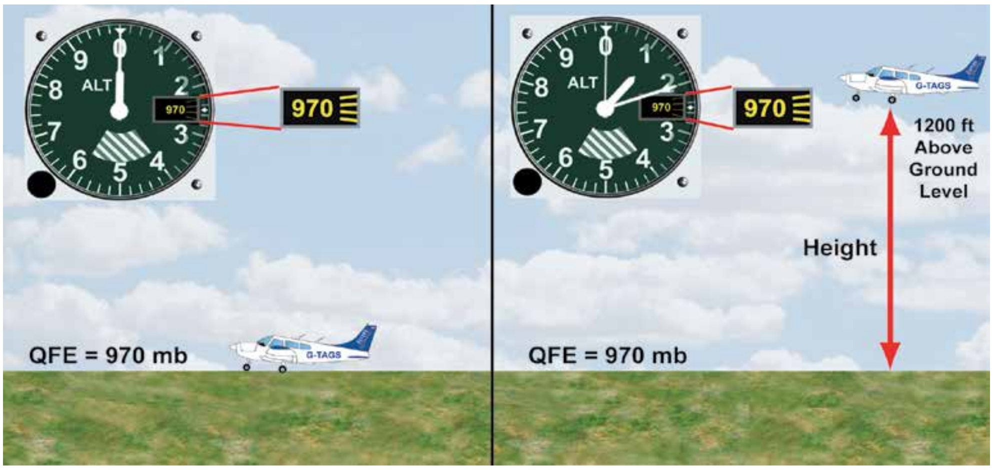

Figure 6.4 QFE is the pressure at the aerodrome ground level.

With the aircraft on the ground, the pressure value at airfield level may be set on the altimeter subscale, by rotating the altimeter sub-scale setting knob until the altimeter reads zero feet.

With QFE set on the sub-scale, an aircraft's altimeter will read zero when on the ground at the runway threshold or airfield datum.

The altimeter now has its zero datum point set at a pressure which equates to the pressure at the airfield; this pressure value is commonly referred to as the QFE. In practice, the QFE is passed to a pilot by an Air Traffic Service Unit. The QFE will be the air pressure either at the runway threshold or at some other airfield reference point. If the aircraft were then to take-off and climb, the altimeter would show the

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aircraft's height above the airfield. QFE is the normal altimeter sub-scale setting for circuit flying, or operations in the immediate vicinity of the airfield.

When airborne, with QFE on the altimeter sub-scale, an altimeter will indicate the aircraft's height above airfield level.

But when flying away from the airfield, QFE is of limited use. With QFE set, the altimeter would still read the height above the departure airfield, wherever the aircraft happened to be; so unless the terrain of the region were perfectly flat, the altimeter would no longer indicate the aircraft's height above the ground. QFE, then, gives the pilot no useful information on separation from terrain when flying cross-country. Consequently, an alternative datum for altimeter settings is required.

When on a cross country flight, it is practical to set the altimeter to read vertical distance above sea-level. Elevation figures given for terrain, and obstacles, on aeronautical charts, are given in feet above sea-level. So, if the altimeter is set to indicate vertical distance above sea-level, the task of maintaining safe separation from the terrain becomes much simpler for the pilot; he simply subtracts the elevation of the terrain over which he is flying from his altitude above sea-level to obtain his vertical separation from the ground beneath him.

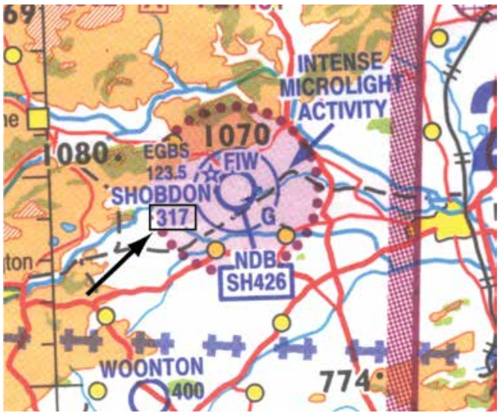

Figure 6.5 Elevation figure for Shobdon Aerodrome: 317 feet.

With an aircraft on the ground and QNH set on the altimeter subscale, the altimeter will read the elevation of the airfield.

Obviously, if the altimeter is to indicate vertical distance above mean sea-level, the atmospheric pressure at mean sea-level must be determined. One way of achieving this is to set the airfield's elevation on the altimeter before take-off. The elevation of the departure airfield can be taken from an aeronautical chart *(see Figure 6.5)*, or from another information source such as Pooley's Flight Guide. When the pilot rotates the altimeter's sub-scale setting knob until the altimeter's needle points to the airfield elevation figure on the dial, the altimeter subscale window will then show the atmospheric pressure at mean sea-level.

This pressure setting on the subscale is called the QNH. With QNH set on the altimeter subscale, the indication on the altimeter is referred to as "altitude". Altitude is defined as vertical distance of a movable object, e.g. aircraft, above mean sea-level.

The altimeter of an aircraft, in flight, with QNH set on the sub-scale, will indicate the aircraft's altitude. Altitude is defined as vertical distance of a movable object, e.g. aircraft, above mean sea-level.

Figure 6.6 With QNH set on the sub scale, the altimeter will indicate ALTITUDE above sea-level, when the aircraft is in the air, and airfield elevation when the aircraft is on the ground.

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Figure 6.6 shows an aircraft, in flight, with the altimeter indicating 1 450 feet above mean sea-level (AMSL), with a QNH of 985 millibars set on its sub-scale. The altimeter of the same aircraft, when on the ground, reads 300 feet AMSL, the airfields elevation.

In practice, QNH is determined by Air Traffic Control using a special barometer such as the one shown in *Figure 2.5* of Chapter 2.

HORIZONTAL PRESSURE VARIATION.

As explained in Chapter 5, atmospheric pressure varies horizontally as well as vertically. This phenomenon can lead to problems for the pilot, because the atmospheric pressure at any given level in the atmosphere will rarely remain constant. So if a pilot flies at a constant indicated altitude, his true altitude will usually vary over time and distance.

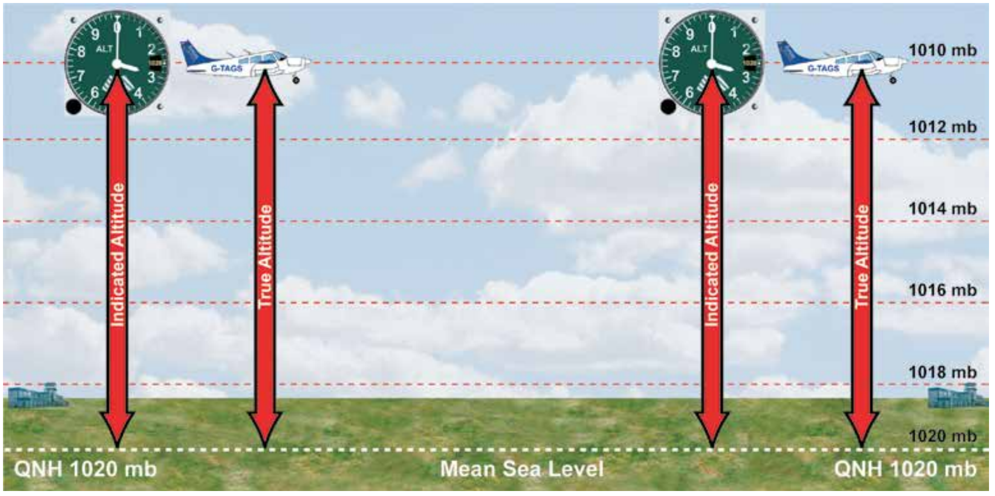

Figure 6.7 If the pressure is the same at the departure airfield and at the destination, constant indicated altitude will give the pilot a constant true altitude.

If an aircraft flies from high pressure to low pressure while maintaining the same sub-scale setting, the altimeter will over-read. At a constant indicated altitude, the aircraft will be descending.

However, if, as in *Figure 6.7,* the atmospheric pressure at both departure and destination airfields were to be the same, the lines of equal pressure, or isobars, at all levels between the two airfields would be horizontal. In these circumstances, as the aircraft flew along the route between the airfields, the indicated altitude, and the true altitude above sea-level would be the same.

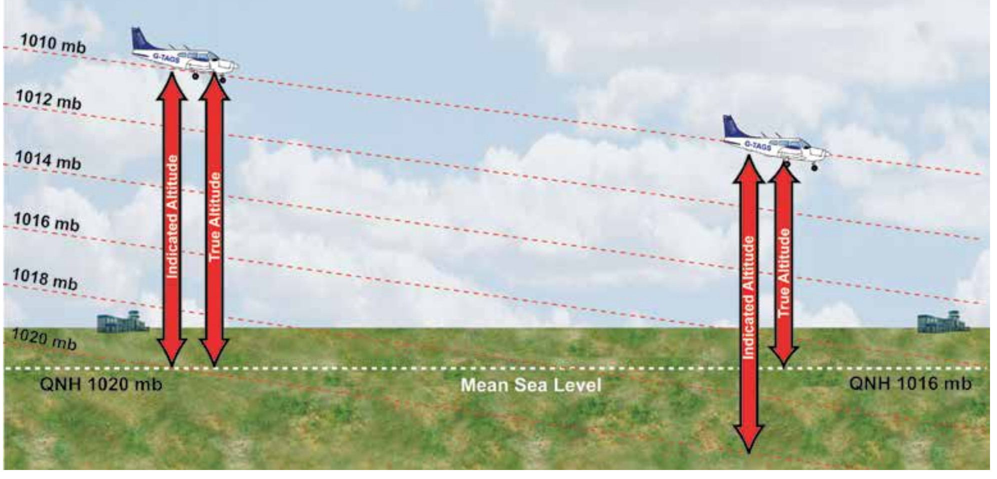

Figure 6.8 When flying from high pressure to low pressure, true altitude will be less than indicated altitude.

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In *Figure 6.8*, atmospheric pressure at the destination airfield is lower than at the departure airfield. Notice that, now, the isobars slope downwards. Consequently, by flying at a constant indicated altitude, say at 3 000 feet, the aircraft would be following the pressure datum which causes the altimeter to read 3 000 feet. In reality, therefore, the aircraft would be descending.

So, when flying from a high pressure area to an area of lower pressure, true altitude is reducing whilst the indicated altitude remains the same. You will doubtless realise immediately that this is a potentially hazardous situation. There is, however, a saying to help you remember this fact. "From High to Low, Look out Below." Another way to remember this is to use "Hi-lo-hi, from high to low, altimeter reads high."

In *Figure 6.9,* the situation is reversed, the QNH at the destination airfield being higher than at the departure airfield. The isobars, therefore, now slope upwards. So, if an aircraft were to fly from the departure airfield to the destination airfield, while maintaining a constant indicated altitude, the aircraft would climb, following the upwards-sloping pressure surfaces. This time true altitude is increasing, while the indicated altitude remains constant. This situation is not as dangerous as the former, since the aircraft's true altitude is increasing, but, nevertheless, the altitude indication is not accurate, so the altimeter subscale setting would not be suitable for landing. In this case we can use "Low-hi-low, from low to high, the altimeter reads low."

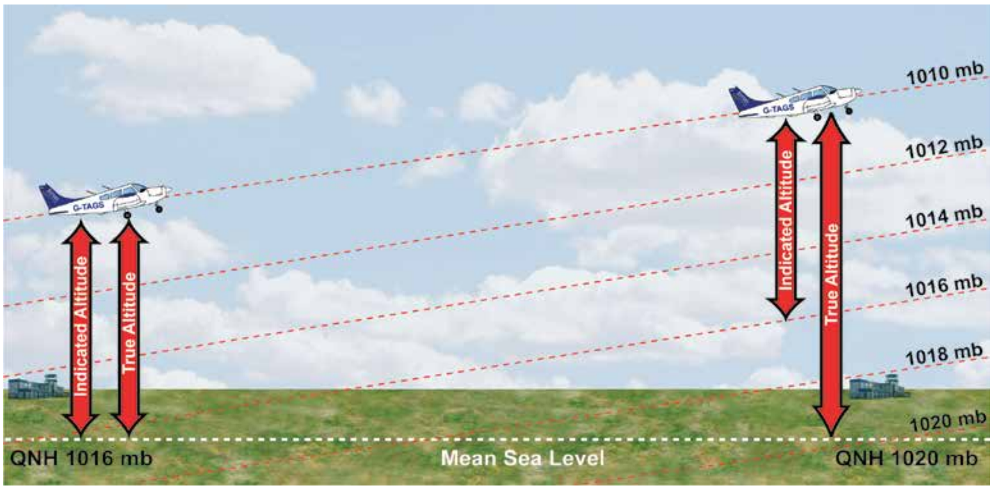

Figure 6.9 Flying from low pressure to high pressure, true altitude will be greater than indicated altitude.

The above examples illustrate why pilots need to adjust the pressure setting on the altimeter subscale in order to take into account horizontal variation in pressure. Resetting the altimeter subscale, when required, is, therefore, a vital part of aircraft operations. When taking off or landing at an airfield with an Air Traffic Control Unit, the controller will normally give the pilot the airfield QNH, which must be read back to confirm that it has been received correctly. The pilot must then set QNH on the altimeter's subscale. This essential practice ensures that the altimeter is not only reading correctly, but is reading the same as the altimeters in other aircraft, operating in the vicinity of the aerodrome.

The Regional Pressure Setting is the lowest forecast pressure in a defined altimeter setting region.

The procedure of setting airfield QNH gives an appropriate altimeter subscale setting for departure or arrival at an airfield, or operating in its vicinity. A different pressure setting will be required as the aircraft progresses en-route.

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Regional Pressure Settings.

With an airfield QNH set on the altimeter, its indications may be inaccurate when the aircraft is flying cross-country at considerable distances from the departure aerodrome. In the United Kingdom, this problem is solved by the provision of Regional Pressure Settings. Regional Pressure Settings (RPS) may be obtained from any Air Traffic Service Unit providing a Flight Information Service.

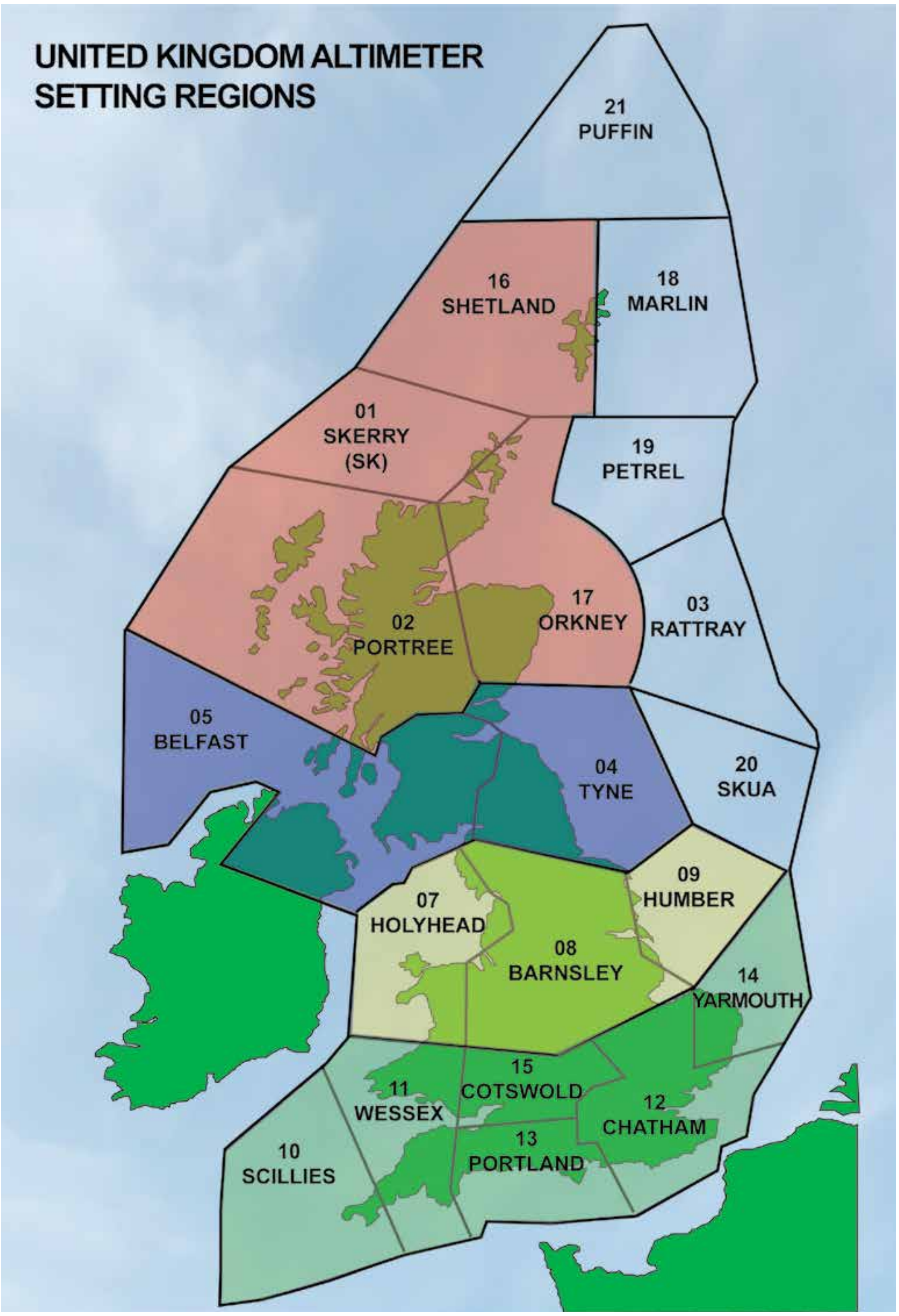

Figure 6.10 Altimeter Setting Regions. Each of these regions will have its own Regional Pressure Setting

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Figure 6.10 shows the regions of the United Kingdom for which Regional Pressure Settings (RPS) values are issued. These regions are known as Altimeter Setting Regions (ASRs). When flying in these regions, below the transition altitude, the altimeter should be set to the appropriate RPS which will be passed to pilots by the Air Traffic Service Unit with which they are in contact. Selecting the correct RPS will ensure a reasonably accurate, but more importantly, safe, altimeter reading.

On approach to an aerodrome, ensure that you have the aerodrome QNH or QFE set on your altimeter.

On the approach to an airfield, the Air Traffic Service Unit will pass pilots the airfield's QNH. Generally, the aerodrome QNH will differ only little from the RPS. The RPS value is based on the lowest forecast pressure within the whole of the Altimeter Setting Region, and is valid for one hour. An individual airfield may have a slightly higher value of pressure, but will certainly be more accurate than the RPS, since it is an observed value.

When on a cross-country flight below the Transition Altitude, ensure that you have the appropriate Regional Pressure Setting on the altimeter subscale.

The Standard Pressure Setting of 1013.2 millibars.

In the United Kingdom, flight below a set transition altitude (predominantly 3 000 feet above mean sea-level) is, in general, conducted with the altimeter sub-scale set to an aerodrome QNH or RPS, as these sub-scale settings allow a pilot to determine the vertical separation of his aircraft from the terrain beneath. *(See Figure 6.11.)*

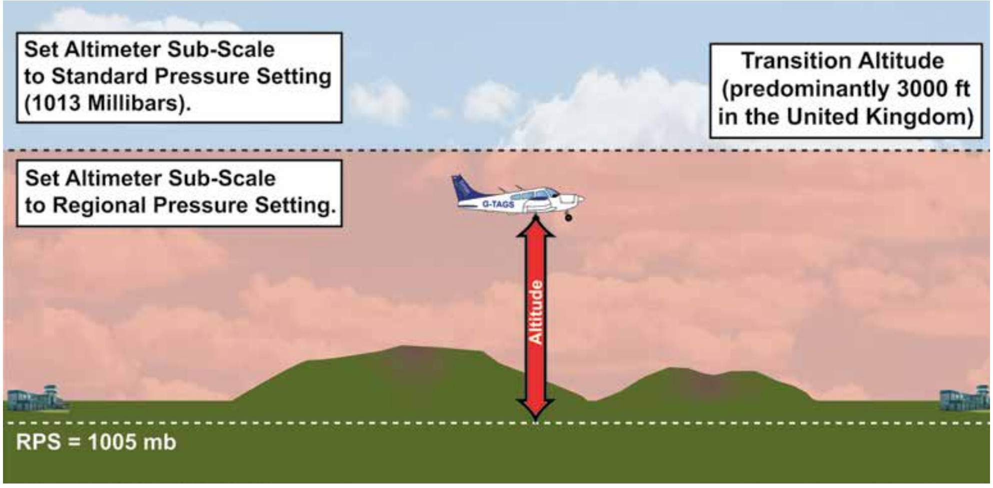

Figure 6.11 When en-route and cruising below the transition altitude, the pilot should, in general, set the Regional Pressure Setting, and keep it regularly updated.

However, when the aircraft climbs through the transition altitude, in the United Kingdom, it is usual, but not always necessary, to change to the Standard Pressure Setting (SPS). For flight at these higher altitudes, where variations in pressure are less likely to endanger the aircraft, flight at a constant altimeter pressure setting is more convenient for the pilot, and for Air Traffic Control Units.

The Standard Pressure Setting for use above the Transition Altitude is 1013.2 mb.

In the United Kingdom, the transition altitude is, over most of the country, 3 000 feet. When flying above this altitude, pilots should set the Standard Pressure Setting (SPS) of 1013 millibars on the altimeter subscale. Above the Transition Altitude, vertical distance above the SPS of 1013.2 millibars is referred to as a Flight Level or a Pressure Altitude *(Figure 6.12, next page)*. Air Traffic Control Units (ATCU) will usually refer to Flight Levels above the Transition Altitude. With all aircraft which are flying above the Transition Altitude having the SPS set on their altimeters, ATCUs are able to maintain vertical separation between aircraft more easily.

Above the Transition Altitude, with 1013 mb set on the altimeter, altimeter indications are referred to as Flight Levels.

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The Standard Pressure Setting is 1013.2 mb.

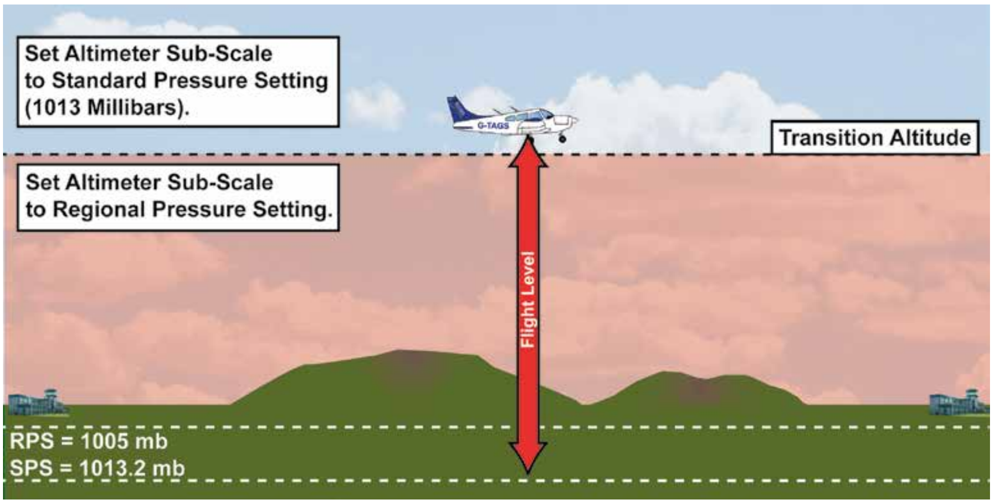

Figure 6.12 When cruising above the Transition Altitude, the pilot should set the Standard Pressure Setting, especially when flying IFR.

However, you should note that the Transition Altitude is not always 3 000 feet on QNH or RPS. Within the London Terminal Manoeuvring Area, for example, it is 6 000 feet. Also, in some countries, the elevation of airfields can be greater than 3 000 feet. In such cases, the Transition Altitude will be much higher. In the United States, for instance, the Transition Altitude is 18 000 feet. Always be sure to check the Transition Altitude at unfamiliar aerodromes.

When descending to an aerodrome, the pilot must re-set the altimeter to airfield QNH. The level during the descent at which this adjustment take place is known as the Transition Level. The Transition Level (which is the lowest Flight Level available for use by pilots) is not a fixed level. The Transition Level depends on the prevailing atmospheric pressure. *(See Figure 6.13.)*

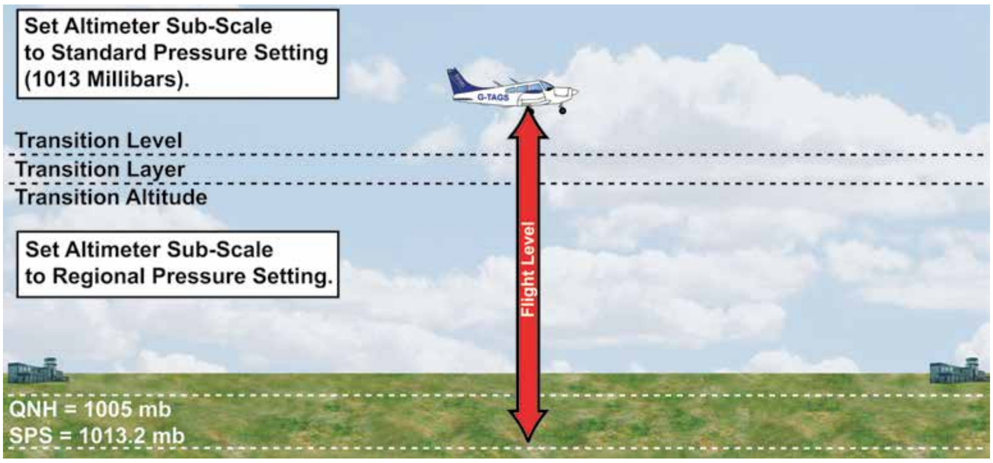

Figure 6.13 The Transition Level is the lowest usable Flight Level above the Transition Altitude; its actual level will depend on prevailing atmospheric pressure. Transition Level is determined by ATC.

The Transition Level is always above the Transition Altitude.

The Transition Level is always higher than the Transition Altitude. The layer between these two levels is known as the Transition Layer. Air Traffic Control determine the Transition Level. The relationship between Transition Altitude and Transition Level and the relevant altimeter sub-scale settings, is covered in detail in Volume 3 of this series, Navigation.

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QNE.

Finally, we must mention a special use of the SPS which is referred to as QNE. QNE is seldom used, and, then, only at high-altitude airfields, although it is theoretically possible for it to be needed at low-altitude airfields with extremely low atmospheric pressures.

On rare occasions, QFE or QNH cannot be selected on the altimeter subscale when atmospheric pressure values are outside the range of the subscale. At these times the pilot will be instructed by the ATCU to set 1013.2 millibars on his altimeter subscale. The pilot will then be passed the elevation of the airfield above the 1013.2 millibar pressure datum. QNE is defined as the pressure altitude indicated on landing at an aerodrome, when the altimeter sub scale is set to 1013.2 millibars.

TEMPERATURE ERROR.

In Chapter 2, Pressure, you learnt how the temperature of the air affects the rate at which pressure decreases with altitude. There is, however, no altimeter setting which will compensate for temperature error. The altimeter is calibrated against the ISA temperature and pressure lapse rate profile and is unable to compensate for the effect on its indications of any deviations from ISA.

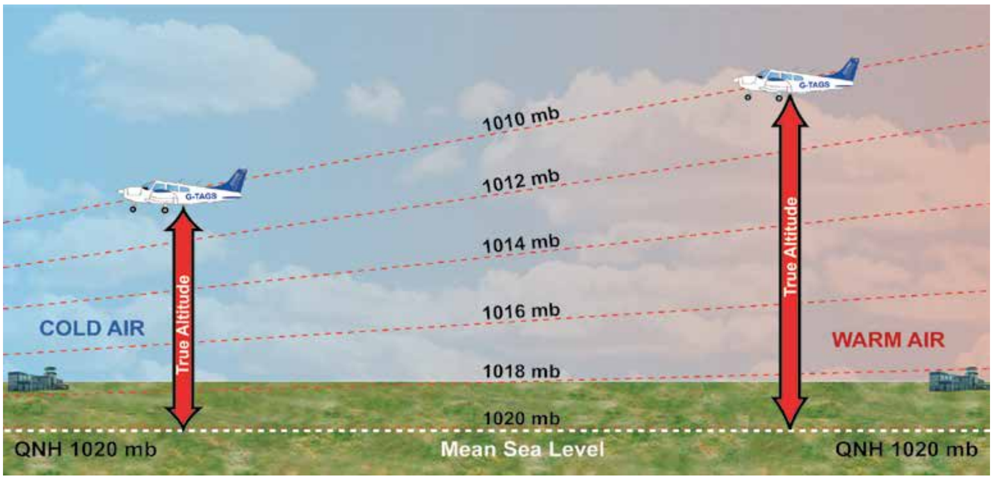

Figure 6.14 When flying from warm air to cold air, the altimeter will over-read.

If an aircraft is flown from an area of high temperature to an area of low temperature, the altimeter will over-read. This is potentially a hazardous situation.

Figure 6.14 shows a typical horizontal pressure variation caused by temperature differences within the atmosphere. If air cools, the isobars become closer together, causing an increase in the pressure lapse rate; in other words, the pressure change with height is greater. However, a rise in air temperature has the opposite effect, causing the pressure lapse rate with height to decrease. If an aircraft were to fly from the area on the right of *Figure 6.14* **(**warm air) to the area on the left (cold air), at a constant indicated altitude, the aircraft would be following a pressure level or isobar, and, as you can see from the diagram, would descend.

This is a potentially hazardous situation. To help the pilot remember the danger involved in flying from an area of high temperature to an area of low temperature he should recall the saying: "When flying from hot to cold, don't be bold" or, even more dramatically, "cold kills". So, never forget that, in cold air, the altimeter will over-read.

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If an aircraft is flown from an area of low temperature to an area of high temperature, the altimeter will under-read.

Conversely, if an aircraft is flown from cold air into warm air, true altitude will increase while indicated altitude remains constant, and, therefore, the aircraft will climb. In warm air, the altimeter will under-read. *(See Figure 6.15.)*

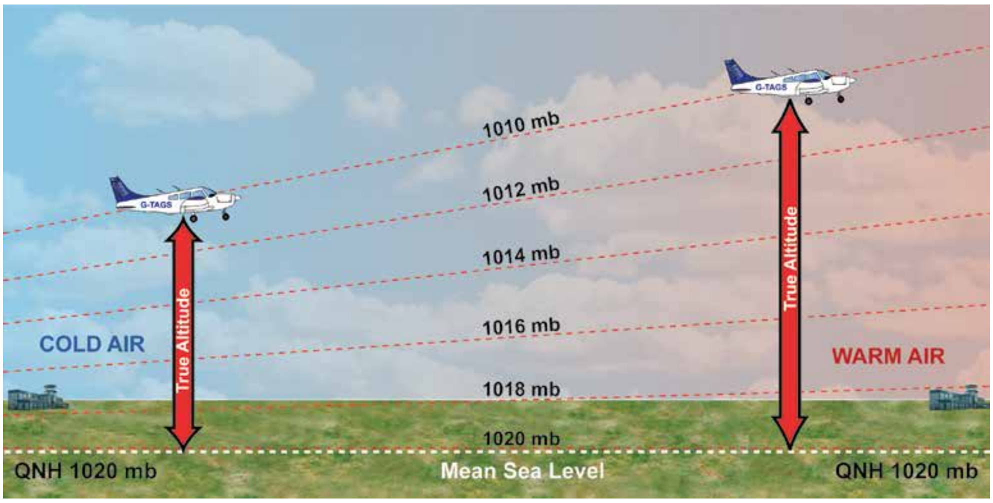

Figure 6.15 When flying from cold air to warm air, the altimeter will under-read.

ALTIMETER PROBLEMS.

Having completed the theory of the altimeter it may be useful to work through some typical altimetry problems and solutions. For simple calculations below 5 000 feet above mean sea-level, you should assume a height change of 30 feet per millibar. This means that for every one millibar change in pressure, the altimeter will show a height change of 30 feet.

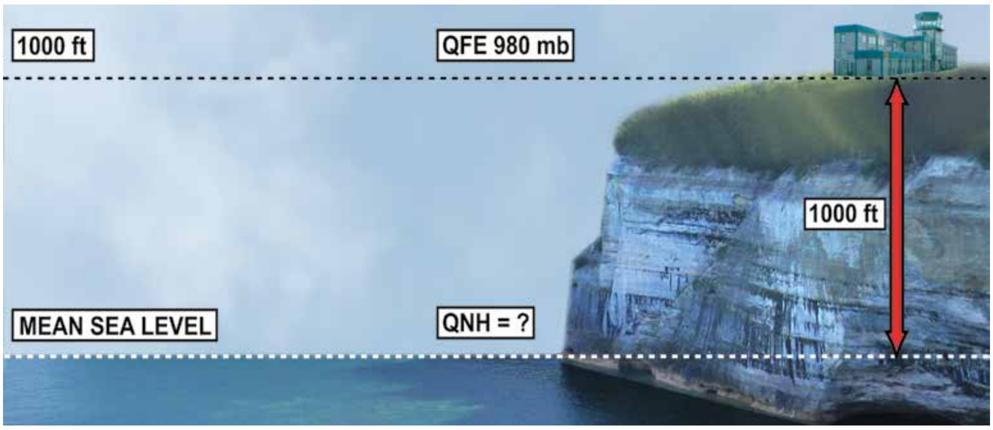

Figure 6.16 An airfield whose elevation is 1000 feet, has an observed QFE of 980 millibars. What is the airfield QNH?

Problem 1.

Let us assume that an airfield is 1 000 feet above mean sea-level. If the observed QFE at the airfield is 980 millibars, what is the QNH?

At sea-level, pressure is obviously higher than that at the airfield, but by how much?

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We are assuming that pressure changes by approximately 30 feet per millibar. Therefore, 1 000 feet divided by 30 feet tells us that the pressure change in 1 000 feet is approximately 33 millibars. So we simply add this pressure value to the airfield QFE to find the QNH. In this example, the QNH will be 980 plus 33, which equals 1013 millibars.

For altimeter "pressure to height" conversions, assume that 1 mb equates to 30 feet.

Problem 2.

An airfield is 2 100 feet above mean sea-level and, on a particular day, has a QNH of 1005 millibars. What is the airfield's QFE?

Since the QFE is the airfield pressure, and the airfield is above mean sea-level, the QFE will have a lower value than the QNH. But, by how much?

Well, over an altitude of 2 100 feet there is a pressure change of approximately 70 millibars (2 100 divided by 30). Therefore, the airfield QFE will be 1005 millibars minus 70 millibars, giving a QFE of 935 millibars.

Problem 3.

An aircraft flies from Aerodrome A, at which the QNH is 1020 millibars (hectopascals), and whose elevation is 1000 feet above mean sea-level, to Aerodrome B, at which the QNH is 1010 millibars, and whose elevation is 500 feet above mean sea-level.

The pilot has a QNH of 1020 millibars set on his altimeter. If he does not change the altimeter sub-scale setting, what will be the altimeter indication on landing at Aerodrome B?

Firstly, draw a diagram using the information provided in the question. Such a diagram might look like the image shown below. When drawing the QNH pressure levels, remember that pressure decreases with altitude; therefore, the 1010 millibar pressure level will be found above the 1020 millibar pressure level.

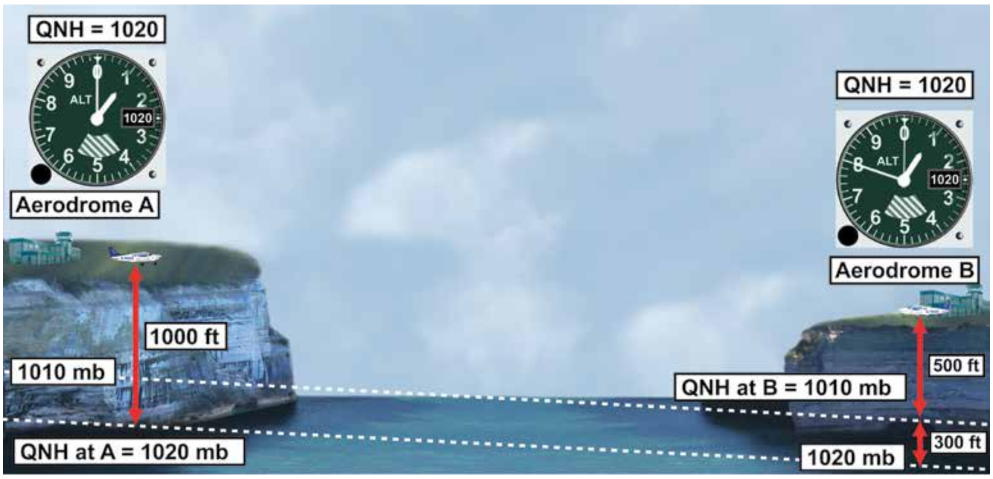

Figure 6.17 Flying from Aerodrome A to Aerodrome B, maintaining an altimeter setting of QNH 1020 millibars (hectopascals).

As the pilot has Aerodrome A's QNH set on his altimeter's sub scale, his altimeter will indicate 1 000 ft, the elevation of Aerodrome A, when the pilot is still on the ground at Aerodrome A.

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From the image, then, you should be able to deduce that the question is essentially asking for the vertical distance of Aerodrome B above the pressure level 1020 millibars.

To find this out, you must first of all calculate the vertical distance between the two pressure levels of 1020 millibars and 1010 millibars. The pressure difference between these two pressure levels is 10 millibars. Now, you have learnt that for every 1 millibar change of pressure, the height difference is approximately 30 feet, and 10 × 30 feet gives us 300 feet.

So, the 1020 millibar pressure level is 300 feet lower than the 1010 millibar pressure level. Consequently, when the aircraft lands at Aerodrome B, whose elevation is 500 feet, it will be (500 + 300) feet above the 1020 millibar pressure datum level to which the altimeter is set.

On landing at Aerodrome B, then, the aircraft's altimeter will read 800 feet.

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Representative PPL - type questions to test your theoretical knowledge of Altimetry.

1. The aerodrome QFE is:

   a. the reading on the altimeter at an aerodrome when the aerodrome barometric pressure is set on the sub-scale
   b. the reading on the altimeter at touchdown at an aerodrome, when 1013.2 millibars is set on the sub-scale
   c. the reading on the altimeter at an aerodrome, when the sea-level barometric pressure is set on the sub-scale
   d. the observed barometric pressure at the aerodrome

2. You are flying at a constant indicated altitude with a QNH of 1015 mb set on the altimeter sub-scale and you notice that the outside air temperature has been falling constantly. What can you expect to happen to your true altitude?

   a. It will decrease
   b. It will increase
   c. It will remain the same
   d. It will increase then decrease

3. When flying towards a depression, at a constant indicated altitude, the true altitude will be:

   a. lower than indicated
   b. higher than indicated
   c. the same as indicated
   d. lower than indicated at first then the same as indicated later

4. The altimeter will always read:

   a. the altitude above mean sea-level, with 1013 set
   b. the height above the airfield datum with the airfield QNH set
   c. the vertical distance above the pressure level set on the altimeter sub-scale
   d. the correct flight level with the regional QFE set

5. When an altimeter sub-scale is set to the aerodrome QFE, the altimeter reads:

   a. the elevation of the aerodrome at the aerodrome reference point
   b. zero at the aerodrome reference point
   c. the height of the aircraft above sea-level
   d. the appropriate altitude of the aircraft

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6. An aircraft flies from aerodrome "A", where the QNH is 1020 mb, to aerodrome "B" where the QNH is 999 mb. Aerodrome "A" is 800 feet above mean sea-level and Aerodrome "B" is 500 feet above mean sea-level. If the altimeter sub-scale is not changed from 1020 mb, what will be the altimeter indication on landing at Aerodrome "B"?

   a. 1 430 feet
   b. 130 feet
   c. 1 130 feet
   d. -130 feet

7. The name given to the lowest forecast mean sea-level pressure in an Altimeter Setting Region, in the United Kingdom, is:

   a. QFE
   b. Regional Pressure Setting
   c. QFF
   d. QNE

8. An aircraft flies at a constant indicated altitude from airfield A (QNH 1009 mb) to airfield B (QNH 1019 mb). If the sub-scale remains on 1009 mb, when the aircraft arrives over airfield B:

   a. the indicated altitude will be the same as the actual altitude
   b. the indicated altitude will be less than actual altitude
   c. the indicated altitude will be more than actual altitude
   d. the indicated altitude may be greater or less depending on the airfield elevation

9. You experience a constant drift to the right when flying over Europe at a constant indicated altitude. If the altimeter sub-scale is not updated, this will result in:

   a. flying at a progressively lower true altitude
   b. flying at a progressively higher true altitude
   c. flying at a progressively lower indicated altitude
   d. flying at a progressively higher indicated altitude

10. When an aircraft is on the ground at an airfield, its altimeter will read airfield elevation with which pressure setting on the sub-scale?

   a. QFF
   b. QFE
   c. QNE
   d. QNH

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11. An aircraft is descending to land from above the transition altitude. If the aerodrome QNH passed to the pilot is 1009 millibars (hectopascals), how will the altimeter reading change when the pilot changes the altimeter sub-scale setting from the SPS (1013 mb) to QNH, at the transition level?

    a. It will remain the same
    b. It will decrease
    c. It will increase
    d. The pilot must not change the sub-scale setting as he descends through the transition level

12. After take-off from an aerodrome on a cross country flight, in the United Kingdom, at an altitude of 2500 feet, and well away from controlled airspace, a pilot would, in general, on leaving the vicinity of the aerodrome, change the altimeter sub-scale setting from:

    a. Local QNH to QFE
    b. RPS to QFE
    c. Airfield QNH to the Regional Pressure Setting
    d. SPS to QNH

13. Which of the following pressure settings should a pilot select on the altimeter sub-scale when operating above the transition altitude in the en-route phase of flight?

    a. The Standard Pressure Setting
    b. The Regional Pressure Setting
    c. The QFE of the nearest aerodrome
    d. The QNH of the nearest aerodrome

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Answer												

Question	**13**
Answer	

The answers to these questions can be found at the end of the book.

CHAPTER 7
HUMIDITY

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INTRODUCTION.

The term humidity refers to the amount of water vapour held in the air. High humidity means that there is a lot of water vapour in the air. Low humidity means that the amount of water vapour in the air is low. Under normal atmospheric conditions, water is continually evaporating and condensing, so the amount of water vapour in the air is constantly changing. This, of course, is the same as saying that the humidity of the air is constantly changing, too. The level of humidity in the air has a significant effect on weather.

We will begin our examination of humidity by looking at the three states of water.

THE THREE STATES OF WATER.

Water can exist in three states: the solid state, called ice, the liquid state, simply called water, and the gaseous state, called water vapour. Water vapour is an invisible gas.

CHANGES OF STATE.

Latent Heat.

The mechanism by which water changes from one state to another is fundamental to all weather phenomena.

Whenever water changes state, energy, in the form of heat, is either released to, or absorbed from the environment. Because this transfer of heat takes place without any rise or fall in the temperature of the water, the heat released or absorbed is known as latent heat. (From the Latin latere meaning to lie hidden).

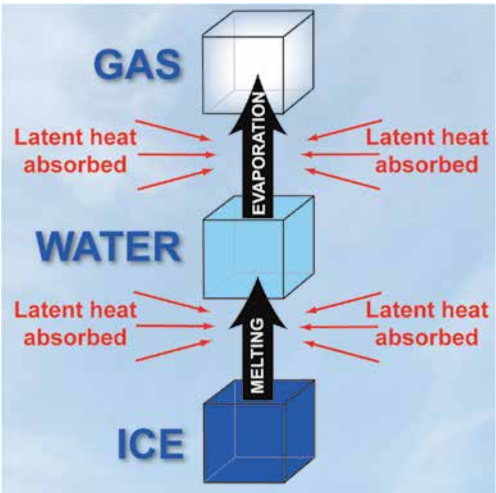

Fig 7.1 Latent heat is absorbed during melting and evaporation.

Melting.

When a substance changes state from solid to liquid, it is said to melt. As the solid melts, energy, in the form of latent heat, is absorbed from the surrounding environment, and stored within the liquid.

When water changes from the solid to liquid state, ice becomes liquid water.

When ice changes to water, latent heat is absorbed from the environment.

Evaporation.

The change of state from liquid to gas is known as evaporation. During evaporation, latent heat energy is absorbed from whichever surface the liquid is in contact with, and stored within the gas. When water changes from its liquid to its gaseous state, liquid water becomes water vapour. You will have experienced the process of heat exchange during evaporation in everyday life. When the human body gets too hot, it starts to sweat, producing moisture on the skin. Heat energy is then absorbed from the body as the sweat evaporates. This process explains why we often feel chilly after a swim, when we leave the water and return to the open air.

When a liquid changes to a gas the process is called evaporation. During evaporation latent heat is absorbed from the environment.

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The changes of state from ice to liquid to water vapour, and the associated heat transfer, are shown diagrammatically in *Figure 7.1*.

Although heat is absorbed from the environment during a change of state, there will be no change in the temperature of the water while the change of state is in progress. For instance, only after all the ice has melted will the temperature of the water begin to rise, if more heat is absorbed.

As we have mentioned, it is because there is no change in temperature during the change of state from ice to water, and water to water vapour, that the heat required to bring about this change of state is called latent heat.

The Saturation of Air.

Evaporation of water will occur at any temperature above absolute zero (-273ºC), but the rate of evaporation increases as the temperature of the environment increases. This is because, at higher temperatures, the molecular activity within the water is greater; in other words, the molecules are more mobile, and a change of state is more likely.

However, there is only so much water vapour that a given volume of air can hold, at any given temperature and pressure.

When air is not able to hold any more water vapour it is said to be saturated.

When the air can absorb no more water vapour, the air is said to be saturated. When saturation level is reached, no more evaporation can take place because the air cannot hold any more water vapour.

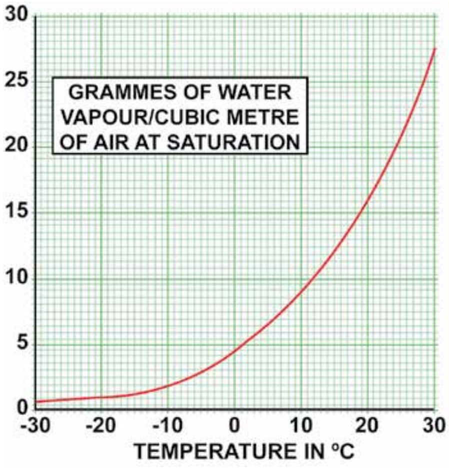

Fig 7.2 The temperature of the air determines how much water can be held.

The graph in *Figure 7.2* shows how much water vapour, in grammes, can be held in a cubic metre of air at any given temperature. The higher the air temperature, the more water vapour can be held in the air.

Air may also become saturated by a process other than evaporation.

It may be easily observed that cold air cannot hold as much water vapour as warm air.

This fact explains why, when our breath cools rapidly on a cold day, as we breathe out, we can "see" our breath. This is because water vapour has condensed to form water droplets.

Air will become saturated when its temperature reduces to its dew point.

So, if a 'parcel' of air which contains a given quantity of water vapour cools down, the air will eventually reach a temperature (called the dew point) where it becomes saturated. Any further cooling will cause water vapour in the air to condense into liquid water droplets which will become visible.

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In the atmosphere, it is condensation through cooling which causes cloud formation. *Figure 7.3* attempts to depict, diagrammatically, the water carrying capacity of air at different temperatures.

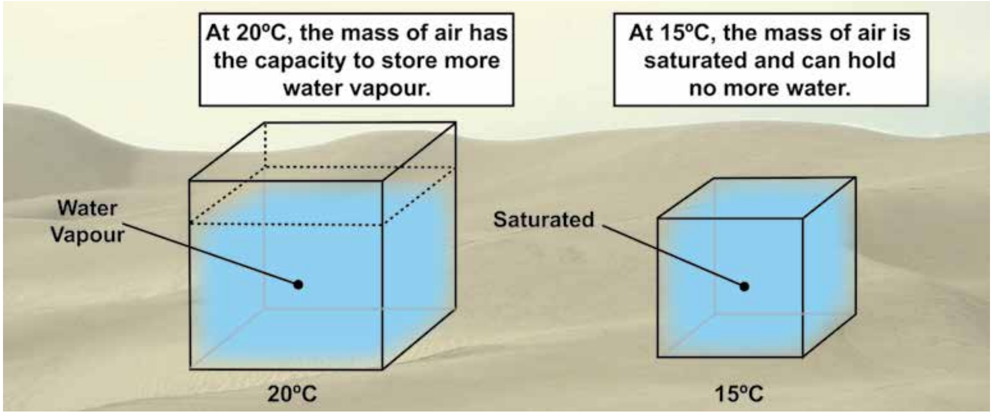

Figure 7.3 Saturation of air can be achieved by cooling the air. At a lower temperature, the air cannot hold as much of water vapour as at a higher temperature.

Condensation.

Condensation is the reverse of evaporation; it is the change of state from gas (water vapour) back to liquid (water).

Condensation describes the change of state from water vapour to liquid water. During condensation, latent heat is released to the surroundings.

As you have learnt, water vapour contains stored latent heat and so, when water vapour condenses and changes into water again, it releases this latent heat back to the surrounding air.

When condensation takes place in the atmosphere, water vapour changes state into visible water droplets, to form dew, clouds and fog.

However, the condensation process is quite complex, usually requiring more than just cooling of the air. For condensation to occur, minute particles must be present in the atmosphere to provide a surface on which the microscopic water droplets can form. These particles are called condensation nuclei. Condensation nuclei may be salt particles absorbed into the atmosphere over the sea, or pollutants from industrial sources, such as dust and smoke.

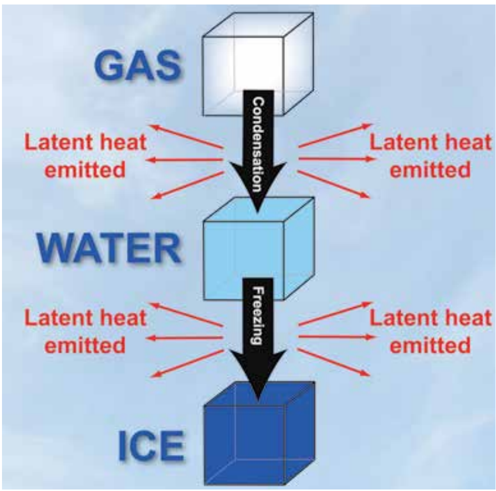

Figure 7.4 Latent heat is emitted during condensation and freezing.

Freezing.

The change of state of water from liquid to solid is known as freezing. When the temperature of water drops below 0ºC, water usually turns to ice, releasing latent heat to the environment. In the free atmosphere, freezing, like condensation, generally requires the presence of minute particles known as freezing nuclei. If there are no freezing nuclei present in the atmosphere, water droplets will <u>not</u> freeze, but remain as supercooled water droplets. Supercooled water droplets are one of the principal causes of formation of ice on aircraft.

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Sublimation and Deposition.

Two other state or phase-changes of water must be mentioned here: sublimation and deposition. They are less common in the atmosphere than condensation or evaporation, but are nevertheless important.

Sublimation describes the change of state of a solid directly to a vapour, without first passing through the liquid state.

When ice changes directly into water vapour, the process is called ***sublimation****, with latent heat being absorbed. If water vapour changes directly into ice, latent heat is released. This process is called* ***deposition****, but in some meteorological texts it is also referred to as sublimation.*

The sublimation of water involves ice changing directly to water vapour. During sublimation, water vapour absorbs latent heat.

When water changes directly from water vapour to ice, the process is called deposition. During deposition, latent heat is released.

Note that both sublimation and deposition miss out the liquid state.

Sublimation takes place when a body of ice has a higher temperature than that of the surrounding atmosphere. Sublimation accounts for the slow mid-winter disappearance of ice and snow at temperatures too low to cause melting.

An example of deposition is the formation of hoar frost on cold surfaces, caused directly by contact between a cold surface and the water vapour in the air.

It is important to note that in meteorology, the term sublimation can also be used to describe deposition.

MEASURING HUMIDITY.

The instrument used to measure humidity is the hygrometer.

As we established at the beginning of this chapter, humidity refers to the amount of water vapour in the air. The instrument that meteorologists use to measure humidity is the hygrometer. This instrument incorporates both a wet-bulb, and a dry-bulb thermometer as pictured in *Figure 7.5*.

The bulb at the bottom of the wet-bulb thermometer is wrapped in a moist muslin cloth. If the surrounding air is unsaturated, water will evaporate from the muslin. During evaporation, latent heat is absorbed from the thermometer, lowering the temperature of the wet-bulb, and causing it to indicate a lower temperature than the dry-bulb thermometer.

If the air is saturated, no evaporation can take place, and the wet-bulb temperature and dry-bulb temperature will be the same.

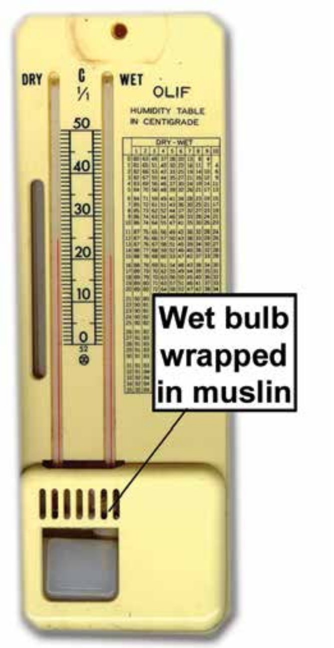

Figure 7.5 A simple hygrometer consists of a wet and dry bulb thermometer.

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From the scale to the right of the two thermometers, the difference between the readings of the wet-bulb and the dry-bulb thermometers indicates the amount of water vapour held in the atmosphere. This measurement is usually expressed as a relative humidity.

RELATIVE HUMIDITY.

Relative humidity is an expression which describes the amount of water vapour held by a given quantity of air. Relative humidity is expressed as a percentage which refers to the actual quantity of water vapour present in a volume of air divided by the maximum amount of water vapour which that volume of air can hold.

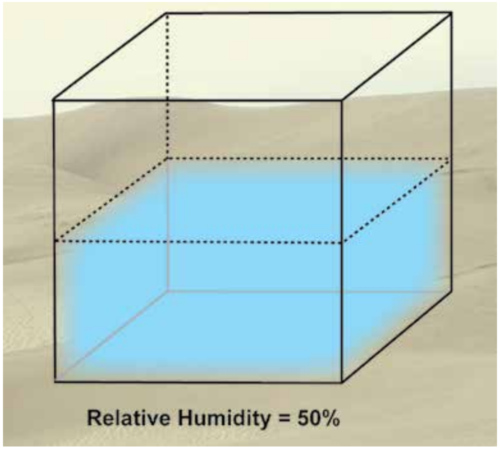

Figure 7.6 This parcel of air contains only half the water vapour that it is able to hold; its relative humidity is 50%.

The Relative Humidity of a given volume of air is an expression of the actual quantity of water vapour present in that volume, divided by the maximum quantity of water vapour that the air can hold. Relative Humidity is expressed as a percentage.

If the air is holding as much water vapour as it can, its relative humidity is said to be 100%, and the air is saturated. If the air contains only half the amount of water vapour it is able to hold, its relative humidity is 50%. *Figure 7.6* depicts a parcel of air with a relative humidity of 50%. Of course, in reality, water vapour in air of 50% humidity is not contained in only half the volume, but spread throughout the volume. *Figure 7.6* is a representation, only.

THE DEW POINT.

The temperature at which the relative humidity reaches 100%, that is, the temperature at which saturation occurs, is known as the dew point.

The dew point is the temperature at which a parcel of air becomes saturated, either through evaporation or cooling, or both. In the atmosphere, clouds or fog will begin to form when the air reaches its dew point.

Figure 7.7 depicts a parcel of air, initially at a temperature of 15°C, which contains a given amount of water vapour. As the air cools down, the capacity of the air to hold water vapour is reduced and the relative amount of moisture in the parcel of air increases. In other words, as the air cools, its relative humidity increases.

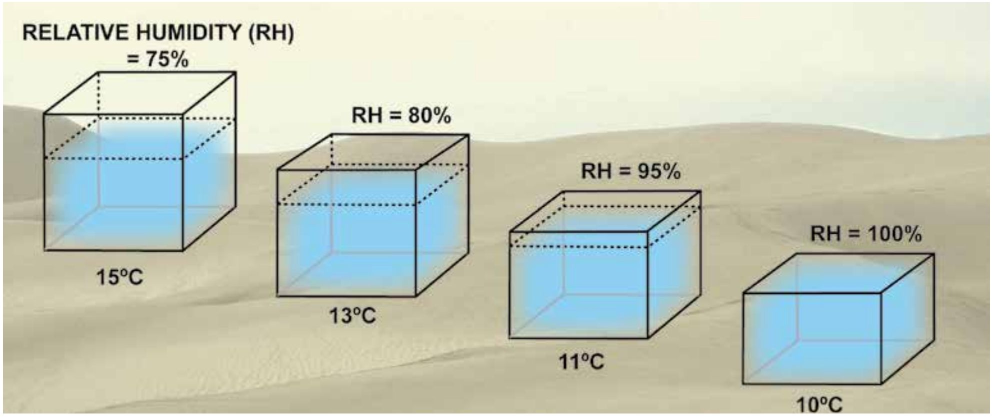

Figure 7.7 As the temperature of the parcel of air decreases, its Relative Humidity rises until the air becomes saturated.

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It may help you understand this phenomenon if you think back to the science you learned at school. The volume of a given mass of air, at constant pressure (in this case, atmospheric pressure), decreases as its temperature decreases. So, if air, at a given temperature, holds a given amount of water vapour, reducing the temperature of the air will decrease its volume. As the volume of air decreases, the constant amount of water vapour takes up an increasing percentage of the decreasing volume until the air become saturated.

At 10°C, the parcel of air in *Figure 7.7* is holding as much water vapour as it can and is, therefore, saturated. The relative humidity of the air is now 100%. 10ºC is, therefore, in this case, the dew point of the air.

If the parcel of air were to cool further, the water vapour would condense into liquid water droplets. In the atmosphere, this condensation would become visible, as clouds or fog.

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Representative PPL - type questions to test your theoretical knowledge of Humidity.

1. Which of the processes listed below can cause air to become saturated?

    a. Melting
    b. Condensation
    c. Heating
    d. Evaporation

2. The instrument used for measuring the humidity in the air is a:

    a. hydrometer
    b. hygrometer
    c. wet bulb thermometer
    d. hygroscope

3. A change of state directly from a solid to a vapour, or *vice versa*, is known as:

    a. insolation
    b. condensation
    c. evaporation
    d. sublimation

4. When condensation takes place, latent heat:

    a. is released
    b. is absorbed
    c. causes a rise in temperature during the change of state
    d. causes a fall in temperature during the change of state

5. In a hygrometer, the wet bulb temperature would normally be lower than the dry bulb temperature because:

    a. condensation causes a release of latent heat
    b. evaporation causes cooling of the wet bulb thermometer
    c. latent heat is absorbed by the wet bulb thermometer
    d. of condensation on the muslin wick on the bulb

6. When water vapour changes to ice:

    a. latent heat is absorbed
    b. specific heat is released
    c. latent heat is released
    d. specific heat is absorbed

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7. The process of change of state from water to water vapour is known as:

   a. condensation in which latent heat is released
   b. evaporation in which latent heat is released
   c. condensation in which latent heat is absorbed
   d. evaporation in which latent heat is absorbed

8. The process of change of state from water vapour to water is known as:

   a. evaporation in which latent heat is absorbed
   b. evaporation in which latent heat is released
   c. condensation in which latent heat is absorbed
   d. condensation in which latent heat is released

9. Which of the processes listed below can cause the air to become saturated?

   a. Heating
   b. Cooling
   c. Digression
   d. Compression

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Answer									

The answers to these questions can be found at the end of the book.

CHAPTER 8
ADIABATIC PROCESSES AND STABILITY

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INTRODUCTION.

An adiabatic process changes the temperature of a gas within a defined system, without any transfer of heat energy across the boundaries of the system. The term 'adiabatic' literally means "an absence of heat transfer." This chapter will explain the concept of the adiabatic processes and their fundamental link to atmospheric stability.

In an adiabatic process, no heat energy flows in or out of the system.

The compression and expansion of 'parcels' of air within the atmosphere are examples of adiabatic processes.

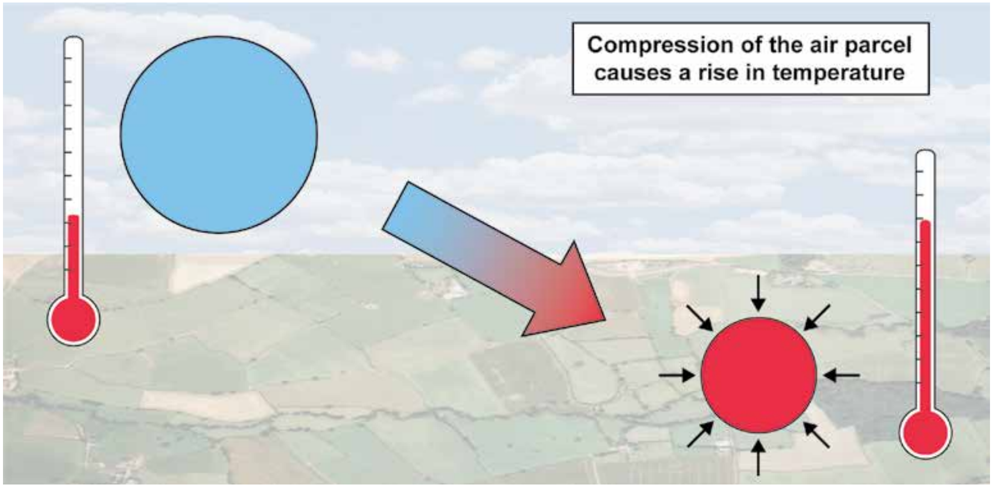

Figure 8.1 When air is compressed, its temperature rises adiabatically.

As a parcel of air descends in the atmosphere, it is compressed and heats up adiabatically.

When a parcel of air is compressed, the potential energy of the air is increased, causing an increase in molecular activity, raising the temperature of the parcel of air.

The important point to note is that this temperature change is not caused by any external heat source, but as a result of the compression of the air.

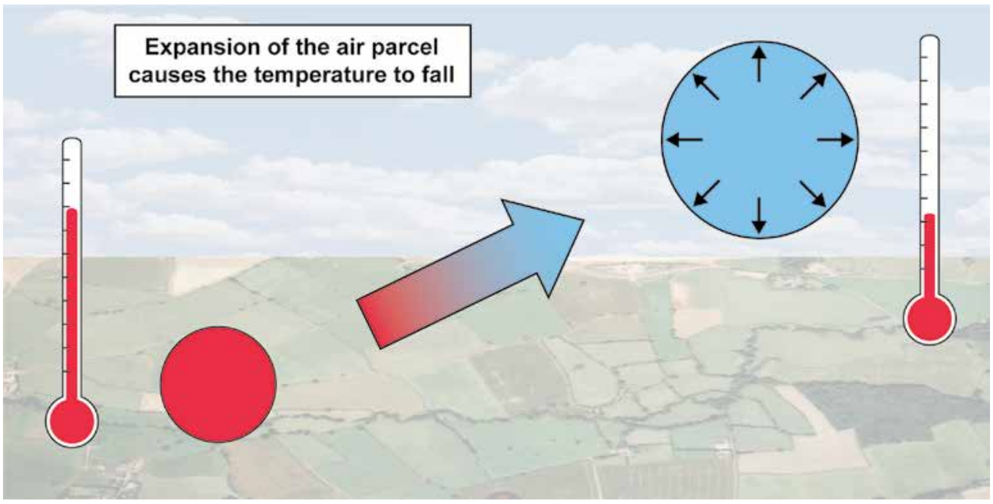

Figure 8.2 When air expands, its temperature falls adiabatically.

As a parcel of air rises in the atmosphere, it expands and cools adiabatically.

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The reverse process takes place if an air parcel expands. During expansion, the molecules lose kinetic energy, and the temperature of the air falls as a consequence.

ADIABATIC TEMPERATURE CHANGES.

Adiabatic temperature changes occur in the atmosphere as air rises and descends.

As you learnt in Chapter 5, pressure decreases with altitude and, so, if a parcel of air were to rise up through the atmosphere, the pressure of the surrounding air would decrease, and the parcel of air would expand. This expansion would cause the temperature within the parcel to fall because of "adiabatic cooling". *(See Figure 8.2.)*

Conversely, when a parcel of air descends, the surrounding pressure increases, and the parcel is compressed, causing the temperature to increase, because of "adiabatic warming". *(See Figure 8.1.)*

ADIABATIC LAPSE RATES.

The rate at which the temperature of a parcel of air rises or falls with height is known as the "adiabatic lapse rate". The value of the adiabatic lapse rate is dependent on the moisture content of the air.

The Dry Adiabatic Lapse Rate.

The Dry Adiabatic Lapse Rate (DALR) is 3°C per 1000 feet.

If unsaturated air (that is, air at less than 100% humidity) is forced to rise or descend within the atmosphere, the temperature of the air parcel changes at a rate of 3°C per 1 000 feet. This is known as the "Dry Adiabatic Lapse Rate". *Figure 8.3* shows a graph of temperature against height representing the Dry Adiabatic Lapse Rate (DALR).

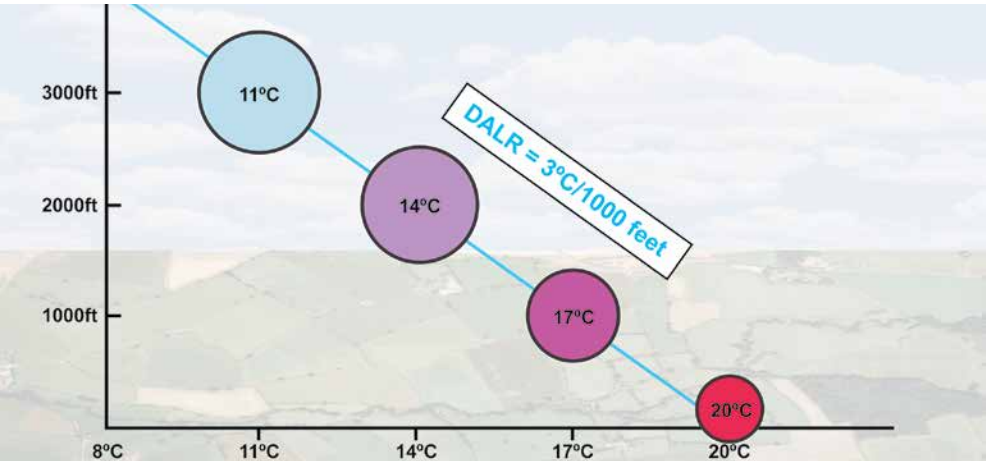

Figure 8.3 The Dry Adiabatic Lapse Rate is 3º C per 1000 ft.

The Saturated Adiabatic Lapse Rate.

If the air is saturated (that is, if the relative humidity of the air is 100%), the rate of change of temperature with height is lower than when the air is unsaturated. The "Saturated Adiabatic Lapse Rate" is 1.5°C per 1 000 feet. However, the Saturated

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Adiabatic Lapse Rate (SALR) is not actually constant, but it varies from 1.2°C per 1 000 feet, close to the Earth's surface, to 2.8°C per 1 000 feet in the upper atmosphere.

Some text books on Meteorology use a figure of 1.8°C per 1 000 feet for the SALR, but, for the Private Pilot's Licence examination, 1.5°C per 1 000 feet is used as a working average of the temperature change with height for saturated air.

The Saturated Adiabatic Lapse Rate (SALR) is 1.5°C per 1000 feet.

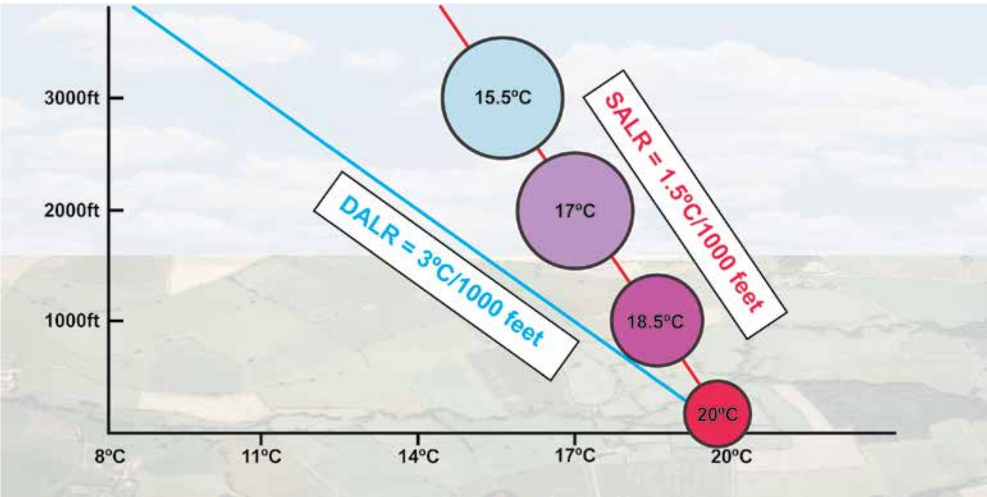

Figure 8.4 The Saturated Adiabatic Lapse Rate is approximately 1.5º C per 1000 ft.

Figure 8.4, shows both the SALR and the DALR.

The SALR is lower than the DALR because of the action of latent heat.

*The SALR is less than the DALR because of the release and absorption of **latent heat**.*

When saturated air cools as it is rising, condensation occurs, and latent heat is released by the water vapour, thus reducing the rate at which the parcel of air cools. When saturated air warms up as it is descending, the water droplets evaporate, absorbing latent heat from the water vapour, thus reducing the rate at which the parcel of air warms up.

ATMOSPHERIC STABILITY.

The adiabatic processes you have just learnt about will help you understand atmospheric stability.

When we speak of the atmosphere as being stable, we are referring to the tendency of air, when displaced, to return to its original position when the force that initially displaced the air is removed.

Atmospheric stability lies behind the process of cloud formation, and, thus, an understanding of atmospheric stability helps us to make predictions about the weather.

If the atmosphere is unstable, air which has been displaced tends to be further displaced, even when the initial force causing the displacement is removed.

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If the atmosphere is stable, air which has been displaced will tend to return to its original location.

Displaced air which is cooler than its surroundings will tend to return to its original position. In such conditions, the atmosphere is stable.

A Stable Atmosphere.

Atmospheric stability, then, is a relatively simple concept; if air, having being raised through the atmosphere is colder than its surroundings, it will naturally tend to descend to its original position when the lifting force is removed, because cold air is denser and heavier than warmer air.

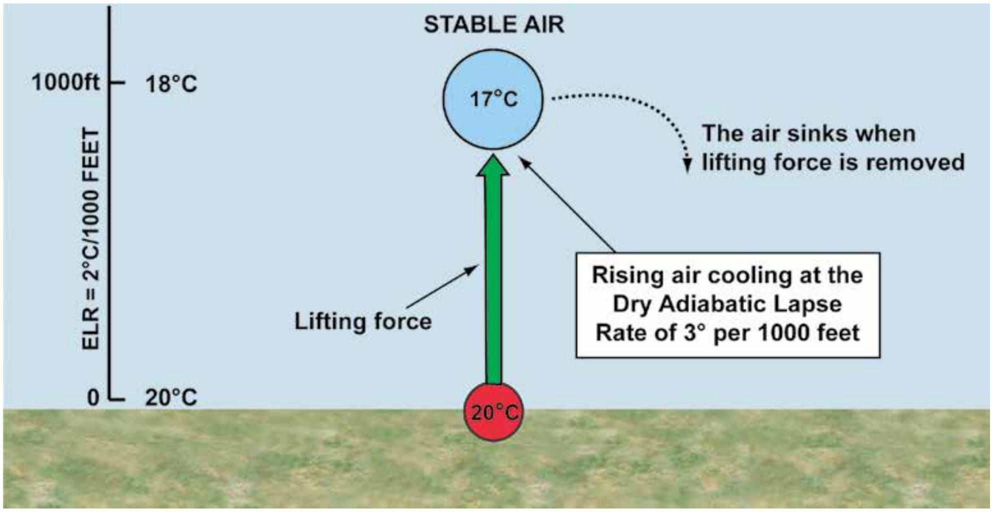

Figure 8.5 If the parcel of rising air cools at a higher rate than the surrounding air, the atmosphere is stable.

Figure 8.5, shows a parcel of unsaturated air ascending, and cooling at the Dry Adiabatic Lapse Rate of 3° per 1 000 feet. The temperature of the air surrounding the parcel is decreasing at the slower ISA Environmental Lapse Rate (ELR) of 2° per 1 000 feet. So, if the air parcel had been at the same temperature as the surrounding air as it begins to rise, it quickly becomes cooler and more dense than its surroundings.

Consequently, if the force that was lifting the parcel is removed, the parcel of air will sink back towards the Earth's surface again.

An Unstable Atmosphere

If a parcel of air were to be raised through the atmosphere, and remains warmer than its surroundings, because the Environmental Lapse Rate is greater than the Dry Adiabatic Lapse Rate, as shown in *Figure 8.6*, the vertical displacement of the rising air will continue and increase, even when the lifting force is removed, because the parcel of air remains less dense, and, therefore, lighter than the surrounding air. In this situation, the atmosphere is said to be unstable.

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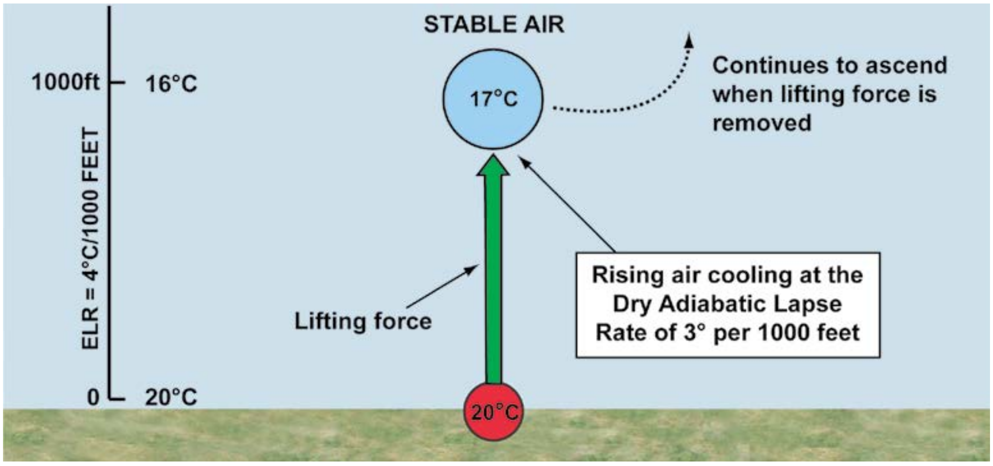
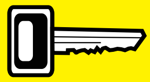


Figure 8.6 If the parcel of air cools a lower rate than the surrounding air, the atmosphere is unstable.

Basic adiabatic processes within the atmosphere, and, therefore, the degree of atmospheric stability are, thus, controlled by the prevailing, and variable, Environmental Lapse Rate (ELR), described in Chapter 7. It follows, then, that if we know the actual Environmental Lapse Rate for a given day, we can predict whether the atmosphere will be stable or unstable.

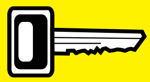


If the Environmental Lapse Rate is known, we can predict whether the atmosphere will be stable or unstable.

The levels of stability of the atmosphere are classified as Absolute Stability, Absolute Instability and Conditional Stability.

ABSOLUTE STABILITY.

A state of Absolute Stability is said to exist when the Environmental Lapse Rate (ELR) is less than the Saturated Adiabatic Lapse Rate (SALR). In other words, when the change of temperature of the environmental air with altitude is less than 1.5°C per 1 000 feet.



Absolute Stability exists when the Environmental Lapse Rate is less than the Saturated Adiabatic Lapse Rate.

Examining the graph in *Figure 8.7,* we see that, given the prevailing ELR, the atmosphere is stable, because rising unsaturated and saturated air will always be cooler than the surrounding environmental air.

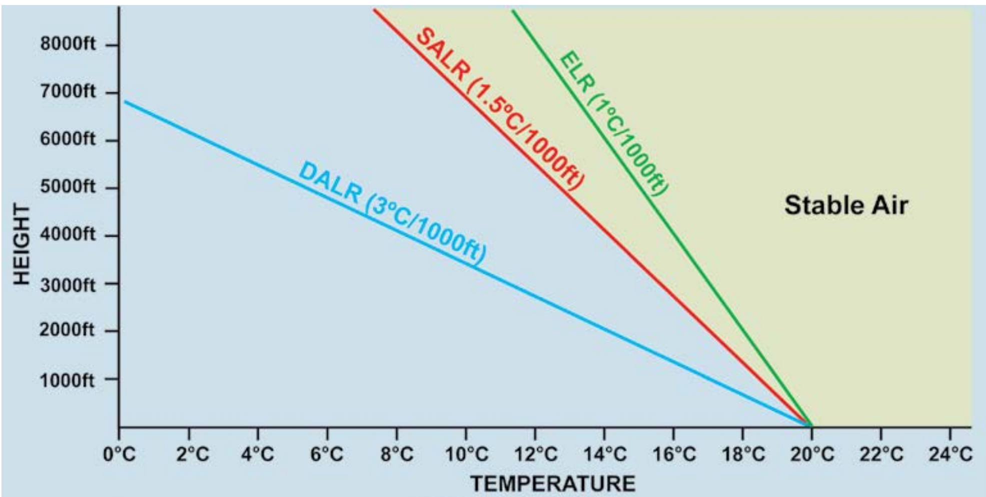


Figure 8.7 Absolute Stability will exist when the Environmental Lapse Rate (ELR) is lower than the SALR.

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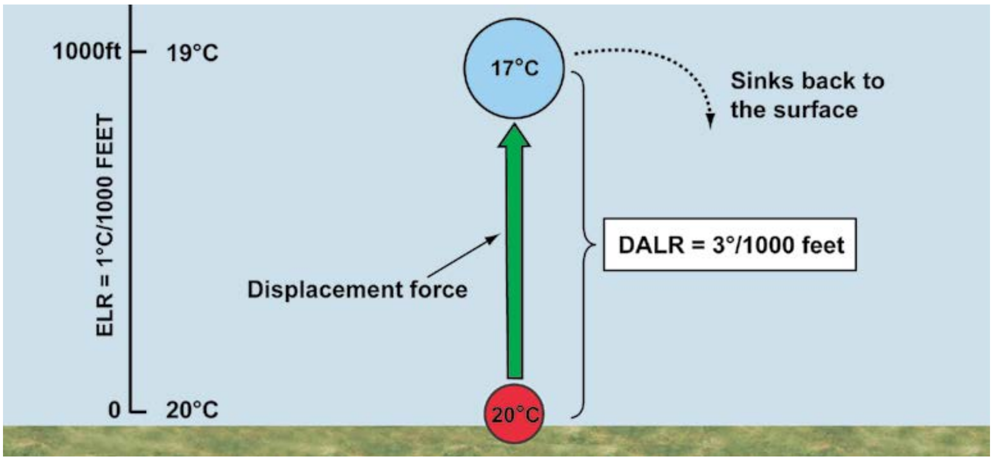

Figure 8.8 In a stable atmosphere, rising unsaturated air will tend to return to its original position when the force causing the air to rise is removed.

If a parcel of unsaturated air were forced to rise to 1 000 feet, as depicted in *Figure 8.8*, the temperature of the air parcel would fall at the DALR, which is 3°C per 1 000 feet. Thus, in the atmospheric conditions represented by *Figure 8.7*, by the time the parcel of dry air, whose temperature at the surface was 20°C, had reached 1 000 feet, it would have cooled to a temperature of 17°C. But, at 1 000 feet, the temperature of the ambient or environmental air would have fallen to only 19°C, because the ELR, in this case, is only 1°C per 1 000 feet.

Consequently, if the displacement force were removed, the parcel of dry air would tend to return to the surface because it is denser and heavier than the environmental air. If the parcel were displaced to 2 000 feet, the difference in temperature between it and the environmental air would be even greater. Therefore, the tendency to return to the surface would be even more pronounced.

Saturated air, when displaced vertically upwards, falls in temperature at the SALR of 1.5°C per 1 000 feet. So, if a parcel of saturated air with a temperature at the Earth's surface of 20° were to be displaced to 1 000 feet, as depicted in *Figure 8.9*, its temperature will reduce to 18.5°C. Just like the unsaturated air, in the atmospheric conditions represented by *Figure 8.7*, where the ELR is 1°C per 1 000 feet, this parcel of air would also be colder than the surrounding air, and would tend to return to the surface when the lifting force was removed.

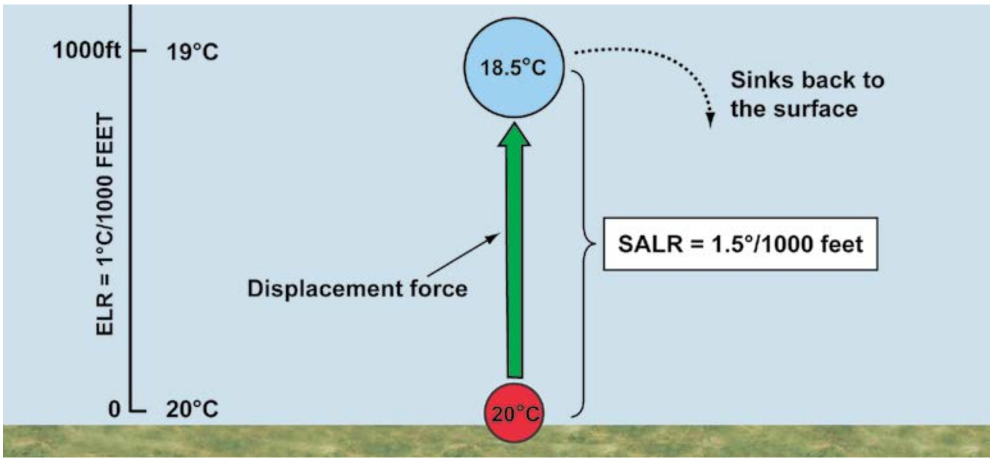

Figure 8.9 In a stable atmosphere vertically displaced saturated air will also tend to return to its original position.

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Again, if the displacement were continued to 2 000 feet, the temperature difference between the parcel of air and its surroundings would increase, and the tendency to return to the surface would be more pronounced.

These examples show that whenever the Environmental Lapse Rate is less than 1.5°C per 1 000 feet the atmosphere is stable.

Isotherms and Inversions are Associated with a Stable Atmosphere.

There are two particular examples of ELR which have special significance in marking a stable atmosphere.

An isotherm occurs when temperature remains constant with increasing height. *(See Figure 8.10.)* An isotherm will always contribute to a stable atmosphere which is why the Tropopause limits vertical air movement and is, effectively, the 'top of the weather'. As you have learnt, in the lower levels of the Stratosphere, the ELR is isothermal.

The other significant type of ELR, also depicted in *Figure 8.10,* is the inversion. An Inversion is characterised by temperature increasing with height. An inversion makes for a very stable atmosphere.

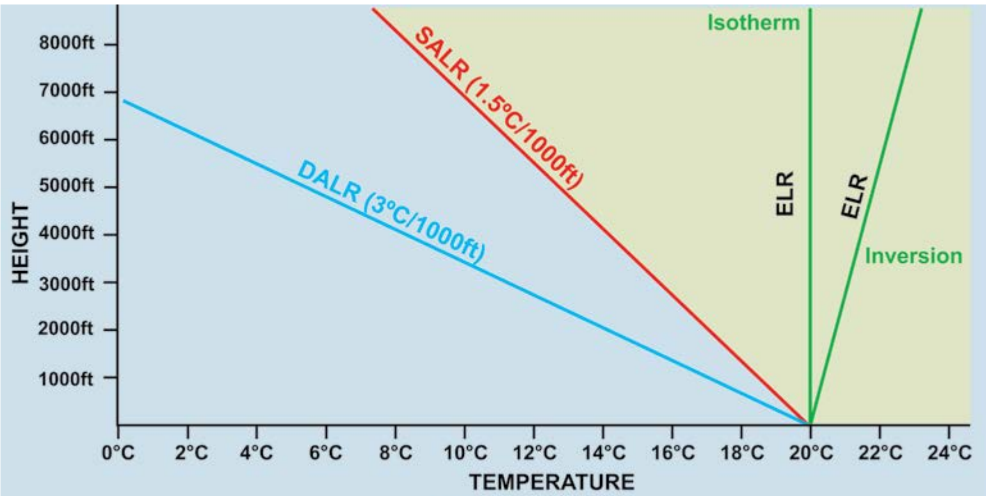
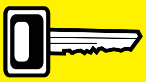


*Figure 8.10 The pale green shaded area, in which **ELRs** are all less than the **SALR**, denotes stable atmospheric conditions. In the shaded area are examples of special cases of **ELR**: an **isotherm** and an **inversion**.*

The Characteristics of a Stable Atmosphere.

The effect of a stable atmosphere is to suppress vertical displacement of air, so preventing air rising any significant distance through the atmosphere, even if convection is present. A stable atmosphere, then, prevents any significant cumuliform cloud formation. If any cloud is produced in a stable atmosphere, it is predominately stratiform-type cloud, although cumulus of small vertical extent may also form.

Stable air resists vertical displacement. Therefore any clouds formed will be stratiform rather than cumuliform, and visibility will be poor.



A stable atmosphere can also have a marked effect on surface visibility. Because a stable atmosphere suppresses vertical movement of air, any pollution, such as dust or smoke, will be trapped near the surface and accumulate, creating very hazy conditions with poor surface visibility.

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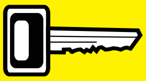
ABSOLUTE INSTABILITY.

Absolute Instability is said to exist when the Environmental Lapse Rate (ELR), is greater than the DALR; in other words, when the rate of change of temperature with altitude is higher than 3°C per 1 000 feet. The graph at *Figure 8.11* depicts atmospheric conditions in which the atmosphere is absolutely unstable.



Absolute Instability exists when the ELR is greater then the DALR.

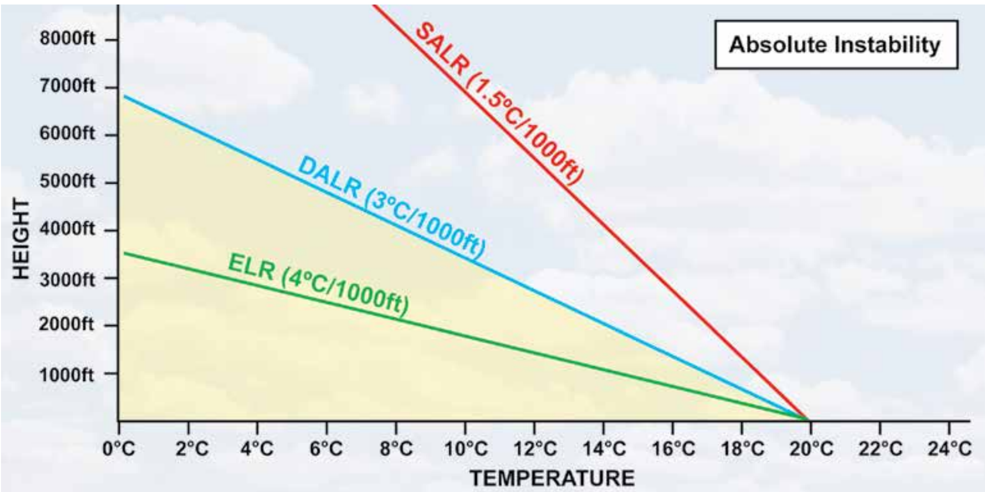


Figure 8.11 Absolute Instability of the atmosphere. Absolute Instability exists when the ELR is higher than the DALR.

Figure 8.11 depicts an unstable atmosphere with an ELR of 4°C per 1 000 feet, and a surface temperature of 20°C. If, as shown in *Figure 8.12,* a parcel of unsaturated air were forced to rise to 1 000 feet, its temperature would fall by the DALR, which is 3°C per 1 000 feet. Therefore, by the time the air parcel reached 1 000 feet, the temperature of the parcel of air would be 17°C. But at 1 000 feet, in the unstable atmosphere that we are considering, the temperature of the environmental air would be 16°C.

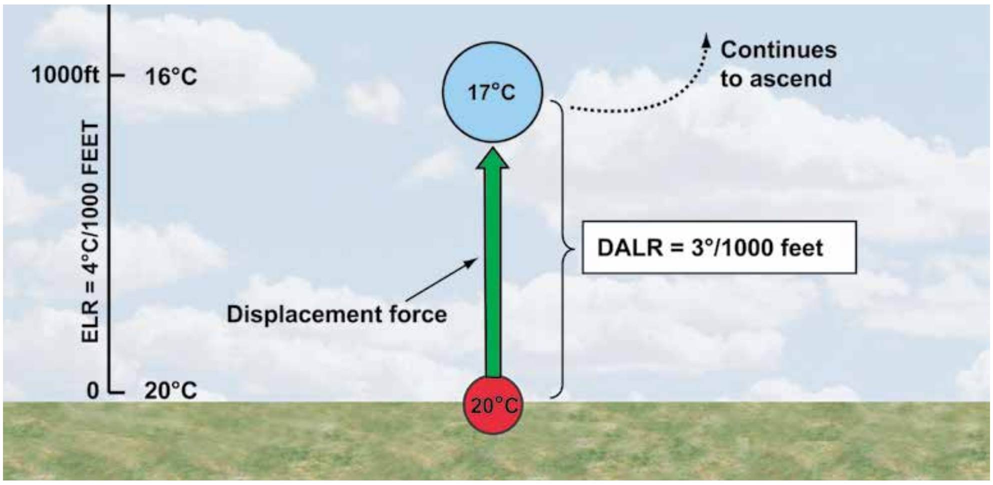


Figure 8.12 Absolute Instability. Any displaced unsaturated air will continue to rise when the ELR is greater than the DALR.

The parcel of displaced air, therefore, is now warmer than the environmental air. It follows, then, that even if the displacement force were to be removed, the parcel of air would continue to rise, because it is less dense and, therefore, lighter than the environmental air.

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If the parcel of air were displaced to 2 000 feet, the difference in temperature between it and the environment would be even greater, and therefore the tendency to rise would increase.

If, as depicted in *Figure 8.13,* a parcel of saturated air were lifted to 1 000 feet, in the same unstable atmospheric conditions, its temperature would reduce to 18.5°C. Just like the unsaturated air, the parcel of saturated air is warmer than the surrounding environmental air at 1 000 feet, and will continue to rise after the original displacement force is removed.

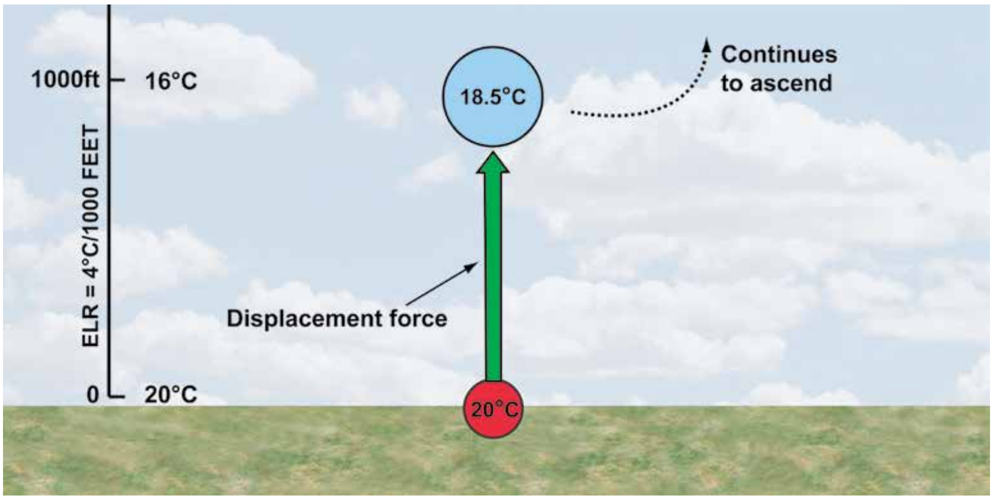

Figure 8.13 Any displaced saturated air will continue to rise when the ELR is greater than the DALR.

The Characteristics of an Unstable Atmosphere.

In an unstable atmosphere, whether the air is saturated or not, air, once displaced vertically upwards, continues to rise and accelerate upwards into the atmosphere. This process generates significant vertical air currents, and, as a result, if any cloud forms, it is cumuliform-type cloud which, if no inversion is present at higher atmospheric levels, may develop into cumulonimbus clouds. Cumulus clouds of significant vertical development may present a hazard to flight as described in Chapter 5, Pressure Systems.

Unstable air gives rise to strong upward vertical movement creating cumuliform clouds which, if no inversion is present, may develop into cumulonimbus. Visibility, outside cloud and showers, will be good.

The rising air which causes the formation of cumulus clouds is exploited by glider pilots to gain altitude. Glider pilots call these upcurrents thermals.

In an unstable atmosphere, pollution will be raised away from the Earth's surface, due to the active upcurrents. Consequently, in an unstable atmosphere, visibility is often excellent.

On warm, clear, summer days, as the surface temperature rises rapidly, the ELR will increase, creating an unstable atmosphere, and active cumuliform clouds can be seen scattered around the sky. This is especially so in the tropics, in Florida for example.

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CONDITIONAL STABILITY.

The atmosphere is Conditionally Stable when the ELR lies between the SALR and the DALR. The air is stable if dry air is displaced, and unstable if saturated air is displaced.

If the ELR lies between 1.5°C per 1 000 feet and 3°C per 1 000 feet, the atmosphere is described as being in a state of conditional stability. This state implies that the stability of the atmosphere is now dependent on conditions other than the ELR. Let us examine *Figures 8.14 and 8.15*, which assume an ELR of 2°C per 1 000 feet.

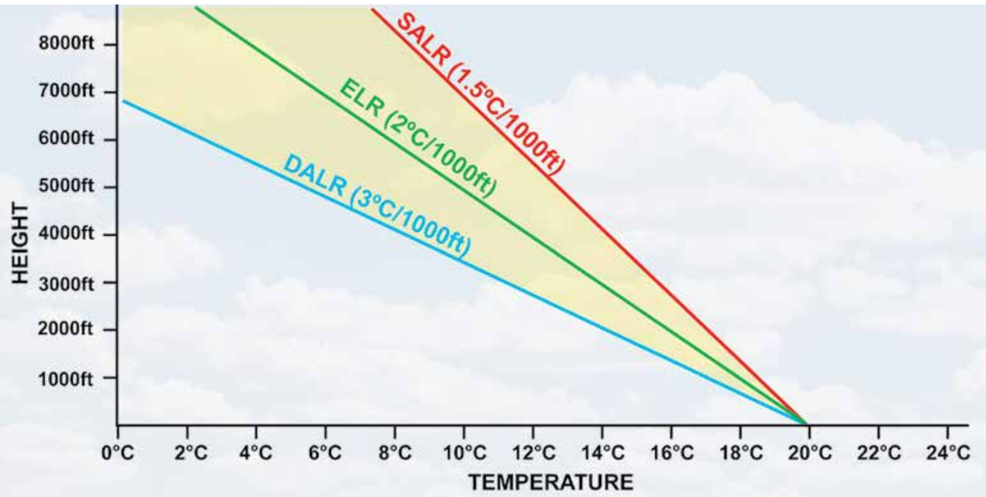

Figure 8.14 Conditional Stability exists when the ELR lies between the SALR and the DALR.

If a parcel of unsaturated air, at the surface, has a temperature of 20°C, and is forced to rise, in the atmospheric conditions represented in *Figure 8.14*, it will have cooled to 17°C at 1 000 feet. At 17°C, the parcel of air is colder than the environmental air at 1 000 feet (which will be 18°C), and will tend to return to the surface when the lifting force is removed. So, if it is unsaturated air which is rising, as depicted on the left of *Figure 8.15,* the atmosphere is stable. However, if the air were saturated and was displaced to 1 000 feet, it would cool to 18.5°C which is warmer than the environmental air at that level. This air would now have a tendency to continue rising when the displacing force was removed, thus making for an unstable atmosphere. *(See right hand example in Figure 8.15.)* We see, then, that in the atmospheric conditions defined by *Figure 8.14*, the degree of stability of the atmosphere is

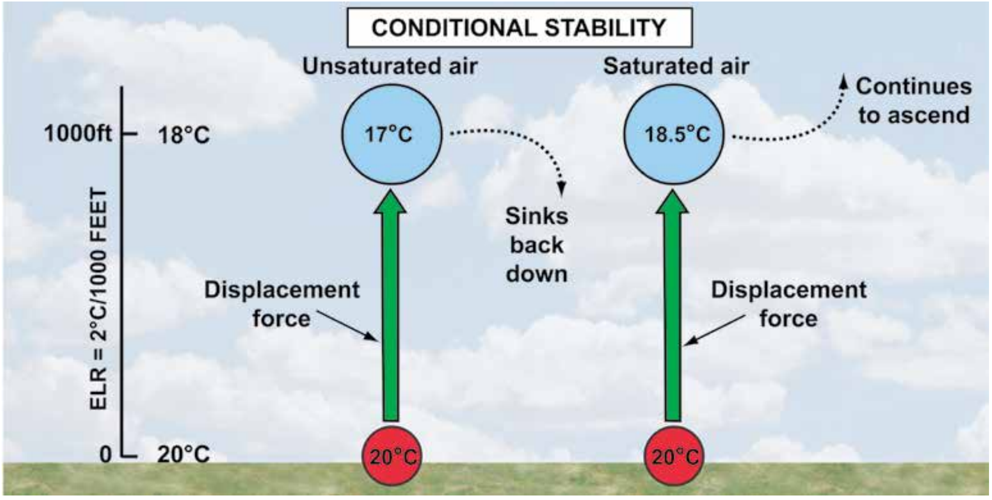

Figure 8.15 When the ELR lies between the DALR and the SALR, unsaturated air creates stable conditions, while saturated air makes for unstable conditions.

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dependent on the amount of water vapour in the air; in other words, stability is now conditional on the air's humidity.

When the ELR lies between the SALR and DALR, saturated air will give rise to an unstable atmosphere, whereas unsaturated air causes the atmosphere to be stable.

NEUTRAL STABILITY.

The atmosphere may also be neutrally stable. Neutral stability is described as being the condition of the atmosphere in which a parcel of air, if disturbed, will tend to remain at the level to which it is displaced. Neutral atmospheric stability can only occur when the Environmental Lapse Rate is the same as the Adiabatic Lapse Rate of the displaced air.

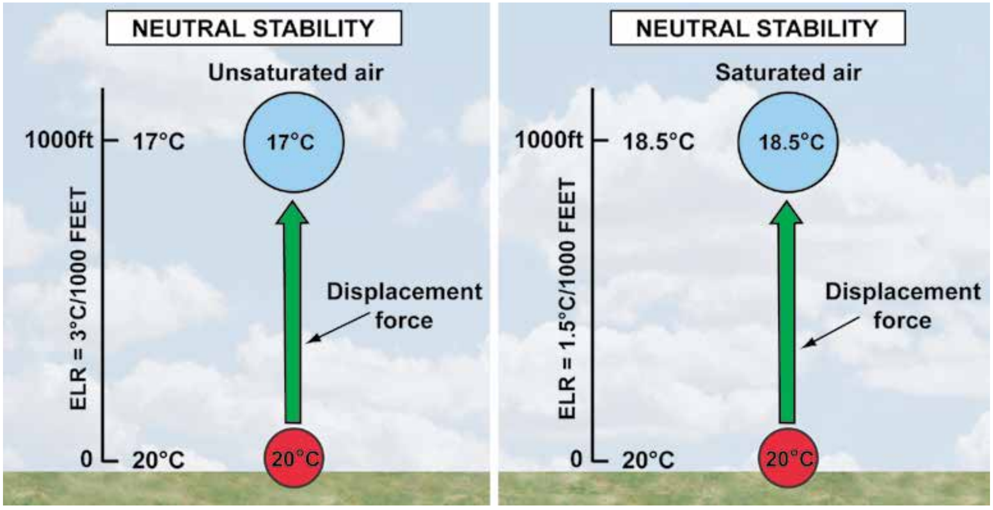

Figure 8.16 In a neutrally stable atmosphere, a vertically displaced parcel of air will remain at the displaced location. There are two conditions for this: 1. If the ELR is the same as the DALR and the air is unsaturated 2. If the ELR is the same as the SALR and the air is saturated.

Air is neutrally stable when the ELR equals the appropriate adiabatic lapse rate.

If the ELR is 3°C per 1 000 feet as shown on the left hand side of *Figure 8.16*, and unsaturated air were displaced, the displaced air would cool at the same rate as the environmental air, and, therefore, would remain at the level to which it was displaced, tending neither to sink nor rise.

The atmosphere would also be neutrally stable if the ELR were 1.5°C per 1 000 feet and saturated air were to be displaced vertically.

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SUMMARY.

Figure 8.17, summarises the relationship between atmospheric stability and the Environmental Lapse Rate (ELR). The stability of the atmosphere is determined by the zone in which the Environmental Lapse Rate lies.

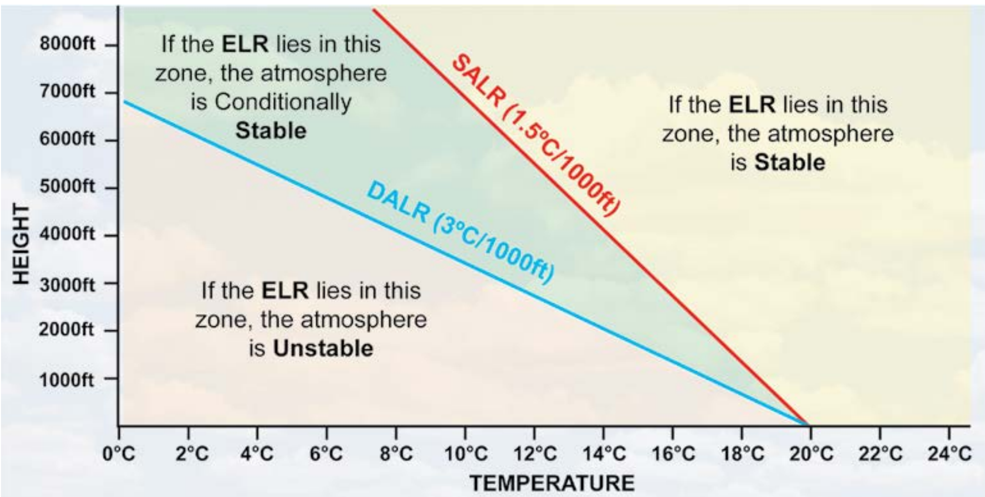

Figure 8.17 The stability of the atmosphere depends on the value of the Environmental Lapse Rate.

In summary, then, with the Dry Adiabatic Lapse Rate (DALR) and the Saturated Adiabatic Lapse Rate (SALR) being constant, the stability of the atmosphere is determined by the prevailing, and variable, Environmental Lapse Rate (ELR).

We can summarise the relationships explored during this chapter thus:

For **Absolute Stability,**	**ELR < SALR**
For **Absolute Instability,**	**ELR > DALR**
For **Conditional Stability,**	**ELR between DALR & SALR**
For **Neutral Stability,**	**ELR = DALR if air is dry**
	ELR = SALR if air is saturated

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Representative PPL - type questions to test your theoretical knowledge of Adiabatic Processes and Stability.

1. Air is stable if:

   a. it moves very little
   b. there are few changes in pressure
   c. when the lifting force is removed, the air tends to return to its original position
   d. when the lifting force is removed, the air continues to rise

2. Absolute instability occurs when:

   a. DALR > ELR
   b. ELR > DALR
   c. SALR > ELR
   d. SALR < ELR

3. Given atmospheric conditions in which the Relative Humidity is 60% and the ELR is less than the DALR, if air is forced to rise it will be:

   a. unstable and carry on rising
   b. stable and will carry on rising
   c. unstable and will tend to regain its former position
   d. stable and will tend to regain its former position

4. _______ instability exists when the _______ is _______ than the DALR.

   a. Conditional, SALR, less
   b. Conditional, ELR, greater
   c. Absolute, ELR, greater
   d. Absolute, SALR, less

5. Which of the following weather descriptions characterises unstable air:

   a. Layered cloud with showers and generally poor visibility
   b. Layered cloud with good visibility and drizzle
   c. Cumulus cloud with continuous precipitation and poor visibility
   d. Cumulus cloud with showers and generally good visibility outside the showers

6. If saturated air is forced to rise it will:

   a. tend to regain its former position if the ELR is less than the SALR
   b. tend to regain its former position if the ELR is greater than the SALR
   c. carry on rising if the ELR is less than the SALR
   d. be classified as stable air when the ELR is greater than the SALR

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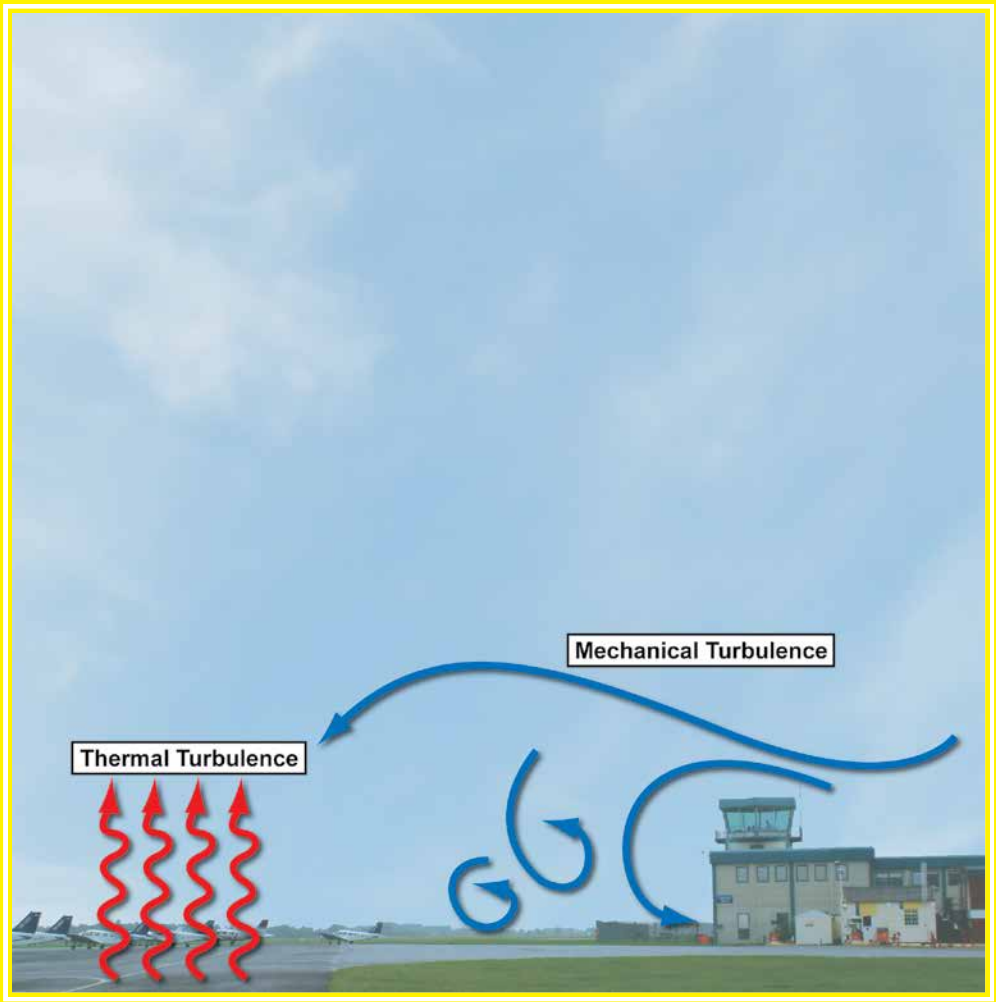
7. The change of ambient air temperature with height is known as:

   a. the environmental lapse rate
   b. the adiabatic lapse rate
   c. the temperature curve
   d. the tephigram

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Answer							

The answers to these questions can be found at the end of the book.

CHAPTER 9
TURBULENCE



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INTRODUCTION.

This chapter will examine turbulence and windshear, the atmospheric conditions which give rise to turbulence and windshear, and their likely effect on an aircraft in flight.

The expression turbulence is generally taken to refer to disturbed or rough air whose movement is of a disordered, swirling nature, causing air to move out of its immediate environment and mix with other layers of air. Turbulence will have an effect on an aircraft's in-flight attitude, but will generally allow the aircraft to maintain its flight path.

Windshear is a similar phenomenon to turbulence, but its effects are far more severe. Windshear is air flow in which there are marked variations in speed and/or direction in the vertical or horizontal plane. Windshear differs from turbulence in that it is able to displace an aircraft abruptly from its intended flight path, so that substantial control action may be required from the pilot in order to maintain heading, speed and height. Chapter 25 covers windshear in more detail.

Windshear is able to displace an aircraft abruptly from its intended flight path.

LOW LEVEL TURBULENCE.

One of the most common causes of low level turbulence is disturbance of the air as it flows over irregularly shaped surfaces, such as hills, buildings, trees etc. The layer of air in which this type of disturbance is likely to take place is known as the friction layer. Above the friction layer, the flow of air is unaffected by the surface. The upper boundary of the friction layer is called the friction level.

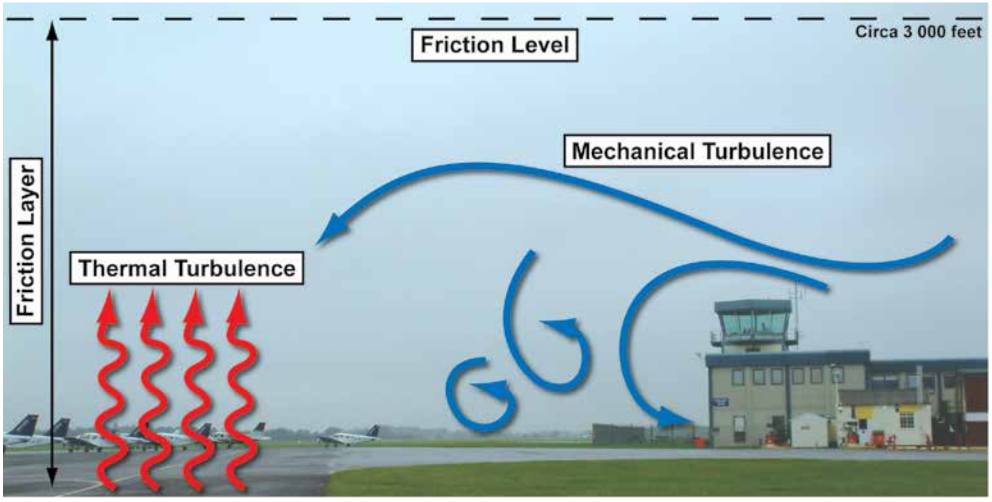

Figure 9.1 Low Level Turbulence is generated by mechanical and thermal means.

Turbulence caused by air flow disturbed by surface features is called mechanical turbulence. The depth of the friction layer will be influenced by the extent of mechanical interference from trees and buildings.

Low level turbulence is also generated as air overlying hot spots on the Earth's surface is heated to a higher temperature than the surrounding air and ascends thermally. This type of turbulence is called thermal turbulence.

On hot summer afternoons, the friction level will be found at a greater height than on cooler days. Generally, the friction level varies from 2 000 feet to 5 000 feet above ground level.*

** Students preparing for the various levels of pilot's licence should check with their national aviation authority whether a particular value for the thickness of the friction layer has been assumed for examination purposes.*

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TURBULENCE WITHIN CLOUDS.

Turbulence occurs within cumuliform clouds because of the upcurrents and downdraughts within and around the clouds.

Turbulence is also found in and around significant cloud developments, especially in cumuliform cloud, which are convective clouds created by rising air currents.

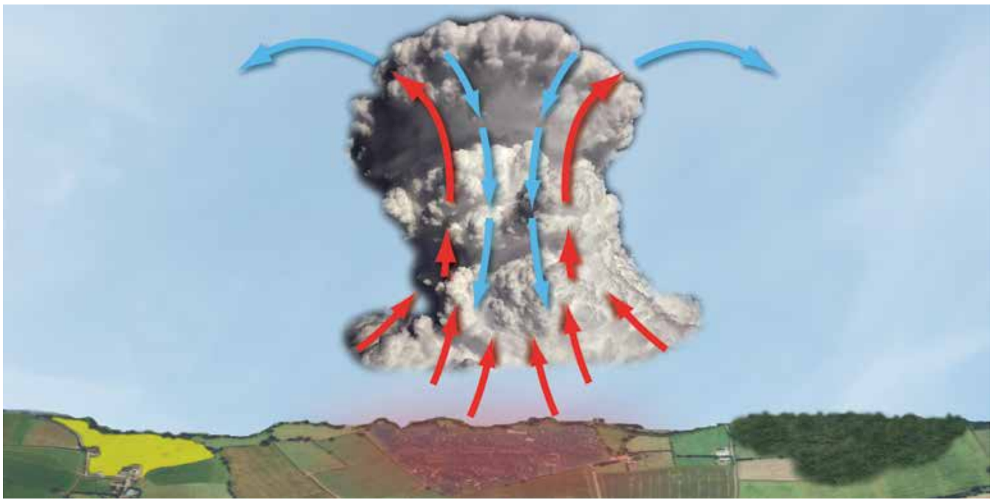

Figure 9.2 Turbulence within clouds is generated by rising air.

The vertical extent of a cumulus cloud is therefore a very good indication of the intensity of the vertical air flow beneath and within the cloud, and, consequently, the intensity of the turbulence in and around the cloud. For this reason, pilots must treat large cumuliform clouds with caution. Cumulonimbus clouds generate the most violent turbulence. In cumulonimbus clouds, and well developed cumulus cloud, both upcurrents and downdraughts are present within the cloud, itself.

TURBULENCE SURROUNDING CLOUDS.

Around well developed cumulus cloud, (cumulus congestus), and cumulonimbus, downdraughts are active at some distance from the cloud itself. These downdraughts cause severe turbulence.

Treat cumulus congestus and cumulonimbus clouds with great caution. Severe turbulence will almost certainly be present within and around these clouds.

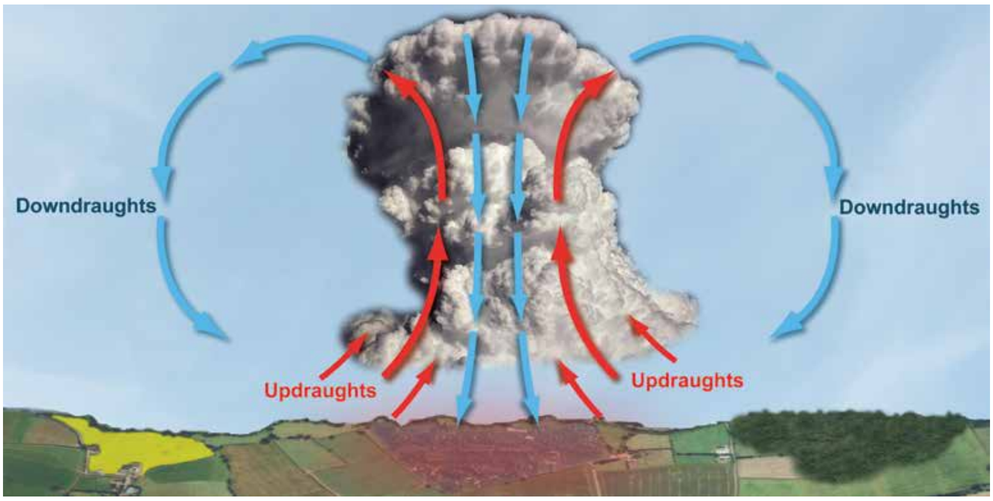

Figure 9.3 Downdraughts can cause severe turbulence at some distance from the cumulus congestus and cumulonimbus.

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TURBULENCE BENEATH CLOUDS.

Beneath the base of cumulus congestus and cumulonimbus, convective upcurrents are also very strong. Downdraughts can be met beneath the cloud base, too.

The most severe downdraughts occur in precipitation.

When precipitation falls from clouds, it tends to drag air down with it, creating downdraughts within, and underneath the cloud.

A microburst measures approximately 5 kilometres across and lasts for around 5 minutes. If the phenomenon is of a greater scale than that, it is called a macroburst.

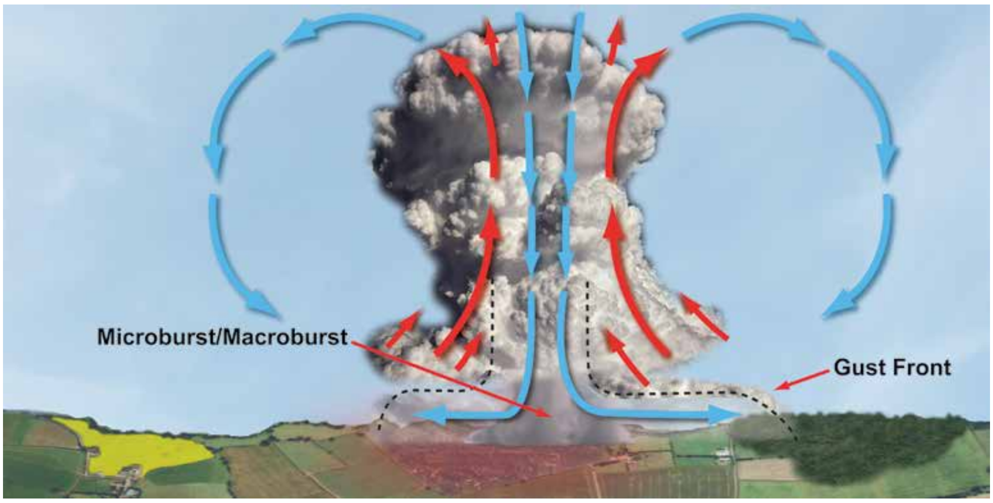

Figure 9.4 Heavy downdraughts of air under clouds are called microbursts, or macrobursts.

If the mass of air descending from the cloud is significant enough, a phenomenon known as a microburst, or, on a larger scale, a macroburst, is created.

If the downdraught descends from beneath a cumulonimbus or cumulus congestus, it will usually come into contact with the ground, and then spread out from the cloud, sometimes up to distances from the cloud of 15 - 20 miles. This type of phenomenon causes large changes in the direction and speed of the wind in the vicinity of the cloud, both vertically and horizontally, and may thus give rise to dangerous low level windshear.

The strong downdraughts from large cumuliform clouds, especially cumulonimbus, give rise to low level wind shear, which can extend up to 15 - 20 miles ahead of a fast moving thunderstorm.

Because of the weather phenomena such as microbursts and windshear associated with them, cumulonimbus clouds are extremely hazardous to aircraft. Flight below, and in the immediate vicinity of, large cumuliform clouds, especially cumulonimbus, should be avoided.

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AIR FLOW OVER HILLS AND MOUNTAINS.

Hills and mountains are able sufficiently to disturb the flow of air passing over them to generate significant turbulence at certain levels, which may present a major hazard to pilots. *(See Figure 9.5.)*

In certain wind conditions, the velocity of downdraughts on the leeward side of hills and mountains may exceed an aircraft's maximum rate of climb.

The most immediate hazard that a light aircraft pilot should note is that, on the downward (leeward) side of hills or mountains, strong downdraughts will be encountered with a velocity of sink which may exceed the maximum climb rate of the aircraft. Such downdraughts can literally fling a light aircraft onto the leeward slopes of the high ground. On the immediate windward side of high ground, strong upcurrents can be encountered.

Visual clues to the type of airflow over a hill or mountain may be seen from cloud produced by the air flow. Cloud which forms when air is forced to rise by high ground is called orographic cloud (from the Greek, oros, meaning mountain). Orographic cloud may shroud the mountain or hill top making it difficult to see from the air. When it covers the summit itself, orographic cloud is called cap cloud. *(See Figure 9.5.)*

MOUNTAIN WAVE.

As stable air flows over a hill or mountain, it begins to oscillate in a wave-like pattern. The crests of these oscillations are known, generally, as mountain waves, lee waves, or standing waves. Mountain waves can reach high up into the atmosphere, creating disturbances which reach well into the Stratosphere. Mountain waves are generally stationary, with the oscillating air molecules maintaining their mean position, hence the term standing wave.

The conditions required for mountain waves to form are: a stable air mass, and a wind of at least 15 knots, increasing with altitude, which blows more or less at right angles to the range of hills or mountains.

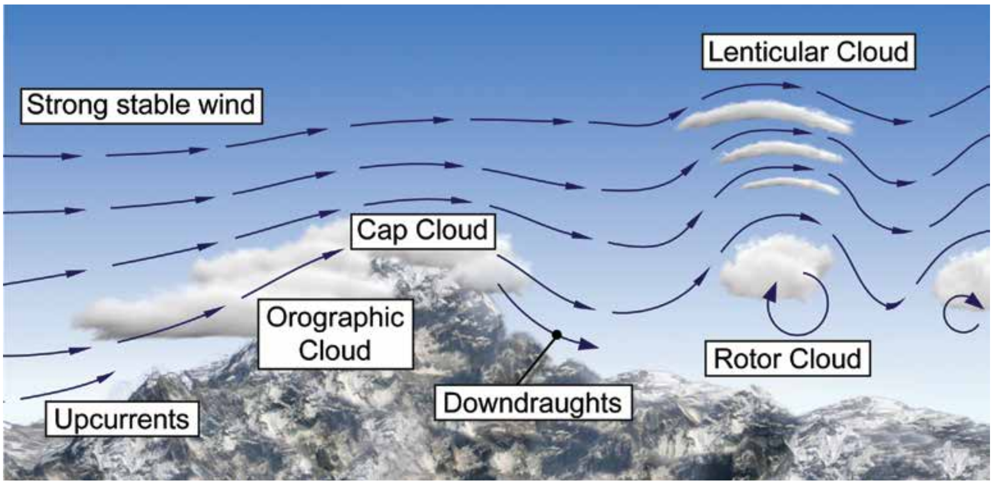

Figure 9.5 Turbulence associated with hills and mountains. Downdraughts on the leeward side of a hill or mountain can pose great danger to aircraft. The most severe turbulence is in the area of the rotor cloud.

The creation of mountain waves requires specific atmospheric conditions to prevail. Firstly, the air must be very stable, otherwise the air flow, when reaching the mountain, would simply rise vertically, and the oscillation pattern would not establish itself. Also, the wind speed at the level of the mountain's ridge must be of sufficiently high speed, and this speed must increase with altitude. A further crucial factor is the direction of the wind in relation to the orientation of the range of mountains or hills. The wind direction must be roughly across the range of hills or mountains.

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If all these conditions are met, a mountain wave will develop.

Often, mountain waves may become visible, because they can create very distinctive cloud formations. As the air rises, in the up-going part of the oscillation associated with mountain wave, it will cool adiabatically. This adiabatic cooling may cause condensation to take place, and cloud to form. However, when air descends during the second half of the oscillation, it will be compressed and warm up, causing the newly formed cloud to evaporate. As shown in *Figure 9.5,* cloud formed in this way takes on a lens-like shape. This is the reason why mountain wave clouds are called altocumulus lenticularis or, more commonly, lenticular cloud.

Because the cloud is continuously forming at the leading edge and dissolving at the trailing edge in the oscillating wave, mountain wave clouds are stationary.

Lenticular clouds, themselves, do not present a significant hazard to aircraft, since the airflow within them is fairly laminar.

Although the flow of air within mountain waves is laminar and smooth, severe turbulence may be present beneath the wave. The flow of air underneath the peaks of the waves is often rotating turbulently. This zone can pose significant danger to aircraft since the wind direction is changing constantly within a very confined area. Cloud, called rotor or roll cloud, is often formed by this turbulent airflow. *(See Figure 9.5.)* But the severe turbulence caused by the rotor is not always made visible by the presence of cloud.

Mountain waves may be detected visually by lenticular cloud and rotor cloud downwind of the high ground. Turbulence will be at its most severe in the rotor cloud.

The best way for pilots to avoid the danger zones associated with air flow over hills and mountains, is to avoid flying downwind of a range of mountains or hills, especially below the ridge line.

Do not fly downwind if a range of hills or mountains, especially below the ridge line, when there is any significant wind blowing over the range.

If it is necessary to fly over a mountain, pilots must do so with adequate separation from the crest or peak in order to avoid rotor turbulence in the lee of the mountain. Mountain waves will be present at the higher altitude, even though the cloud signs may not be there, but rotor cloud should not be encountered.

Significant lift can be experienced in the up-going part of mountain wave oscillations, especially forward of the leading edge of lenticular cloud. Glider pilots are able to soar to great altitude by exploiting the lift associated with mountain waves, which is propagated far up into the Stratosphere. The world glider altitude record stands at around 49 000 feet. The greatest altitude attained by a glider in soaring flight in Britain is over 31 000 feet. This record was gained over the Black Mountains in Wales where the highest peak is below 3 000 feet.

WINDSHEAR CAUSED BY TEMPERATURE INVERSION.

A further atmospheric phenomenon which can give rise to turbulence and windshear is temperature inversion, in which temperature increases with altitude. Temperature inversions in the troposphere tend to be confined to the very lowest layers of the atmosphere, close to the Earth's surface.

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Low level wind shear may be found in the inversion created by surface mixing.

If the temperature inversions are strong enough, there may be significant changes in wind direction and speed across the boundary of the inversion because of changes in atmospheric density. This phenomenon is, of course, a type of windshear. Pilots should exercise caution if a destination airfield issues a Marked Temperature Inversion warning.

Temperature inversions in the lower atmosphere may be caused by mixing, as described below.

On the left, in *Figure 9.6*, is depicted a sample depth of atmosphere with an Environmental Lapse Rate (ELR) of 1ºC/1 000 feet, with turbulent mixing occurring up to 3 000 feet. The turbulent mixing causes air within the mixing layer to rise and sink. The middle section of Figure 9.6 shows the air at 3 000 feet being forced down and warming at the Dry Adiabatic Lapse Rate (DALR) of 3ºC/1 000 feet. Consequently, the air at the surface will be forced up to replace the sinking air and, thus, cool at the DALR of 3ºC/1 000 feet. This differential heating and cooling within the mixing layer now alters the average temperature change with height and produces a new ELR, after mixing, whose value is shown on the right hand side of the diagram. This new ELR clearly shows that, at the top of the mixing layer, a temperature inversion has been created. As in any other type of inversion, changes in wind speed and direction can give rise to windshear at the inversion boundary.

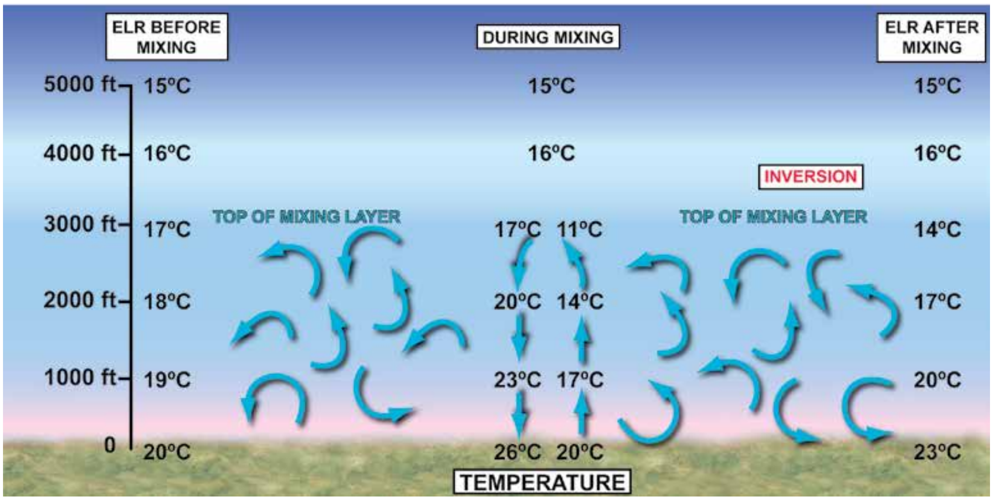

Figure 9.6 Temperature inversion resulting from thermal mixing. Windshear may occur at the inversion boundary.

AVOIDING TURBULENCE AND WINDSHEAR.

Turbulence of any kind should be avoided by pilots.

Windshear and turbulence are particularly hazardous on the approach to land. Make sure that you have learned from your flying instructor how to deal with windshear.

Windshear is especially hazardous to aircraft during the approach and landing phases of flight, because of the aircraft's low forward speed, low altitude and high level of drag.

During the approach and landing phases, if he suspects that turbulence and/or windshear are present, a pilot must fly with great caution, respond very promptly to the turbulence, and monitor airspeed closely.

In order to cope with turbulence and windshear after take-off and on the approach, the pilot should consider using a slightly higher initial climb or approach speed, to ensure a greater safety margin above stalling speed.

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Representative PPL - type questions to test your theoretical knowledge of Turbulence.

1. In a mountain wave situation, the worst of the turbulence is most likely to be found when flying:

    a. at about mid-height between the lenticular and roll cloud
    b. in or just below the roll cloud
    c. in the cap cloud
    d. in the lenticular cloud

2. Complete the following sentence: Low level windshear:

    a. is rare where there is a strong inversion level close to the surface
    b. is found only under the core of the anvil of a thunderstorm
    c. is only ever found on the fringes of a micro-burst
    d. may be experienced 15 to 20 miles ahead of a fast-moving thunderstorm

3. A light aircraft flying at low level near a mountain range across which a strong wind is blowing may expect:

    1. severe turbulence below or within the rotor zone
    2. downdraughts on the leeward side of the mountain, below ridge level, which may exceed the climb rate of the aircraft
    3. strong smooth upcurrents on the windward side of the mountain wave
    4. lenticular cloud

    a. Only 1 and 3 are correct
    b. Only 1 and 2 are correct
    c. 1, 2, 3 and 4 are correct
    d. Only 1, 2 and 4 are correct

4. The pilot of an aircraft which is approaching a mountain from the downwind, or leeward, side, a few hundred feet above ridge level, observes lenticular cloud above. Which of the following conditions would the pilot expect to encounter as the flight continues?

    a. Strong thermal upcurrents at the top of the ridge
    b. Strong downdraughts and turbulence after passing over the ridge
    c. Strong downdraughts immediately before the ridge of the mountain is reached, with strong updraughts after passing the ridge to the windward side
    d. Strong updraughts before the ridge is passed and strong downdraughts after the ridge is passed

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5. An aircraft is flying in the vicinity of a range of hills, lying North/South, across which a wind is blowing from the West to the East. Which of the following situations might cause the aircraft to encounter dangerous downdraughts?

   a. When flying East towards the hills from the West
   b. When flying West towards the hills from the East
   c. When flying North towards the hill from the South
   d. When flying South towards the hill from the North

6. A low level temperature inversion may produce:

   a. windshear at the inversion boundary
   b. an on-shore breeze
   c. a decrease in stability
   d. good visibility by day because of the steep temperature lapse rate

Question	**1**	**2**	**3**	**4**	**5**	**6**
Answer						

The answers to these questions can be found at the end of the book.

CHAPTER 10
CLOUDS AND PRECIPITATION

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INTRODUCTION.

This chapter deals with clouds, their formation and characteristics, their relevance to aviation, and the type of precipitation which may be associated with them. A discussion of precipitation and how it is produced will then follow.

CLOUDS.

Cloud Amounts.

Meteorologists often measure cloud amounts in units called OKTAS, literally meaning eighths of the sky. So, if half of the sky were covered with cloud, the cloud amount would be reported as 4 oktas. *Figure 10.1* represents a typical sky for which the cloud would be reported as 4 oktas.

Figure 10.1 Four oktas or scattered cloud cover.

In aviation weather reports, the extent of cloud cover is normally expressed using the following words.

FEW	=	1-2 **oktas**
SCATTERED	=	3-4 **oktas**
BROKEN	=	5-7 **oktas**
OVERCAST	=	8 **oktas**

Figure 10.2 The extent of cloud cover.

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In TAFs and METARs, cloud bases are given as heights above aerodrome level; in area forecasts, they are given above mean sea level (AMSL).

Cloud Base.

Cloud base may be defined in several ways. One definition is: "the lowest zone in which the type of obscuration perceptibly changes, from that corresponding to clear air haze, to that corresponding to water droplets or ice crystals". A further definition of cloud base is given as: "for a given cloud layer, the lowest level in the atmosphere at which the air contains a perceptible quantity of cloud particles."

In Terminal Area Forecasts (TAFs) and Meteorological Aerodrome Reports (METARs), cloud base is given as height above aerodrome level. In area forecasts, cloud base is shown as altitude above mean sea-level.

There are several ways of determining the cloud base.

- Cloud base can be reported by aircraft in flight, *(see Figure 10.3).*

Figure 10.3 Cloud base can be observed in flight.

- Cloud base may be measured by timing a balloon with a known rate of ascent, in order to calculate the vertical distance between the ground and the cloud, *(see Figure 10.4).*

Figure 10.4 Cloud base may be determined by timing a balloon's ascent.

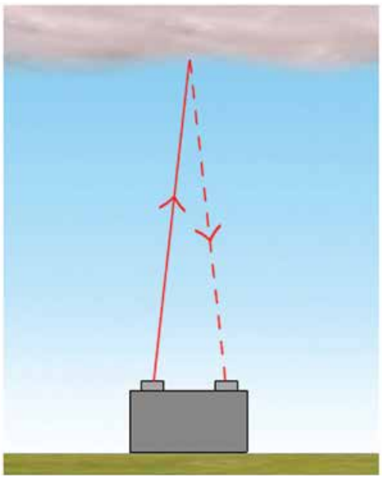

Figure 10.5 Cloud base may be measured using a laser device.

- The most common modern tool used by aviation meteorologists to measure cloud base is the laser cloud base recorder.

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Cloud Tops.

The heights of the cloud tops are much more variable than the level of cloud base.

Cloud growth ceases when the air within the cloud is no longer rising or when there is no longer sufficient water vapour in the air for saturation to occur. The vertical growth of cloud comes to a halt when the temperature of the air within the cloud reaches the same temperature as that of the environmental air. We may see from a graph showing both Environmental Lapse Rate (ELR) and Saturated Adiabatic Lapse Rate (SALR) *(see Figure 10.6)* that the vertical growth of cloud will cease where the ELR and SALR lines intersect. This point quite often lies on a temperature inversion, which is also shown in *Figure 10.6*.

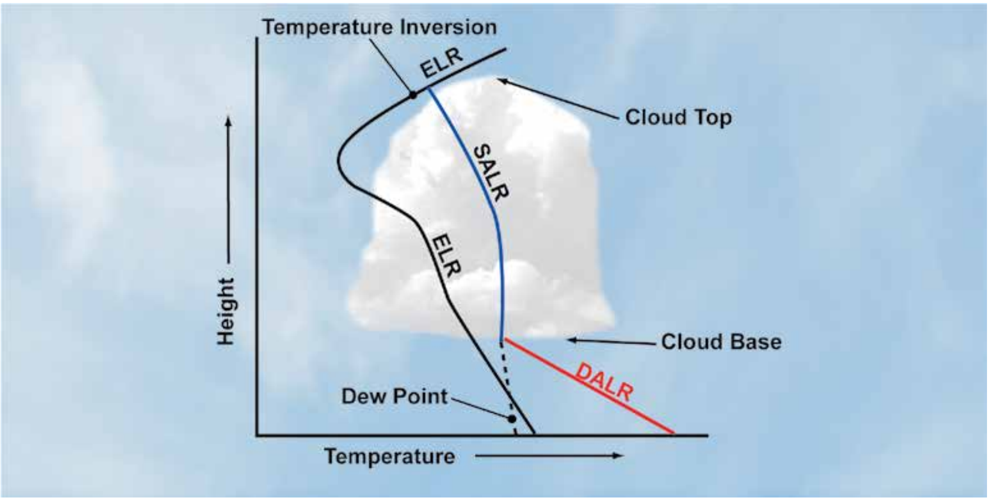

Figure 10.6 The cloud tops may be predicted from graphs showing the ELR and the SALR.

CLOUD TYPES.

Classification of cloud type is based primarily on the shape or form of the cloud. The basic forms of cloud are stratiform, cumuliform and cirriform.

Stratiform cloud, *see Figure 10.7*, is a layered type of cloud of considerable horizontal extent, but little vertical extent.

Figure 10.7 Stratiform Cloud.

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Cumuliform cloud is heaped cloud, displaying a marked vertical extent, of greater or lesser degree. *(See Figure 10.8.)*

Figure 10.8 Cumuliform Cloud.

Cirriform cloud is a cloud which is fibrous, wispy or hair-like in appearance. This type of cloud is found only at high levels in the Troposphere.

Figure 10.9 Cirriform Cloud.

Clouds are classified initially by their shape or form. Stratiform cloud is layered cloud with little vertical extent. Cumuliform cloud is heaped cloud with a large vertical extent. Cirriform cloud is wispy and fibrous, being present only at high level.

Clouds are also identified by reference to the height at which they occur. There are 3 distinct cloud levels within the troposphere.

Low-level clouds are those which are found between the surface and 6 500 ft. These clouds may be stratus, stratocumulus, cumulus and cumulonimbus. (The suffix nimbus implies "rain bearing".) However, cumulus and cumulonimbus will have significant vertical development and will extend from low level to higher levels. Cumulonimbus clouds may even extend up to the Tropopause and, in the tropics, possibly above it if they have enough vertical energy.

Medium-level clouds are found between 6 500 feet and 23 000 feet.

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The names of medium-level clouds are characterised by the prefix "alto-": such as altostratus and altocumulus. Nimbostratus is also a medium-level cloud, but it may also extend into both the lower and upper levels of the atmosphere.

Clouds are also classified by the level at which they occur. Low-level cloud occurs between the surface and 6 500 ft, medium-level cloud between 6 500 ft and 23 000 ft, and high-level cloud from 16 500 ft to the Tropopause.

High-level clouds are generally found between 16 500 feet and the Tropopause. The names of high-level clouds are prefixed by "cirro-": cirrostratus, cirrocumulus, and cirrus. (Latin cirrus means curl.)

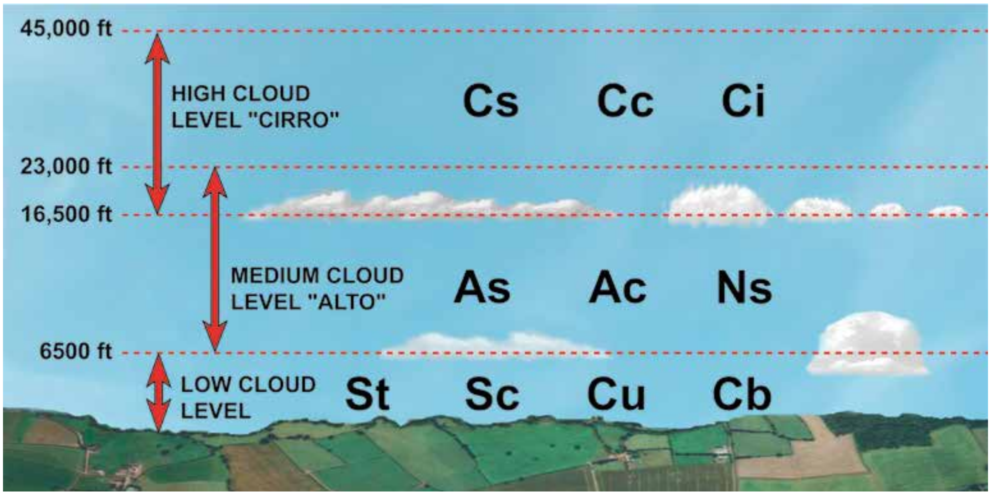

Figure 10.10 Low-Level Cloud:- Stratus (St), Stratocumulus (Sc), Cumulus (Cu), Cumulonimbus (Cb).
Medium-Level Cloud :- Altostratus (As), Altocumulus (Ac), Nimbostratus (Ns).
High-Level Cloud:- Cirrostratus (Cs), Cirrocumulus (Cc), Cirrus (Ci).

Stratus.

Stratus (from Latin stratum, meaning layer) is generally a grey, layered cloud with a fairly uniform base, which may produce drizzle, or light snow. Stratus cloud is generally no more than 1 000 - 1 500 ft thick, and is often much thinner. Stratus is usually the lowest of all cloud types. The main hazard associated with stratus is that it often covers high ground, concealing hill tops from pilots. When stratus is at its thinnest, the sun can be clearly seen through the stratus layer.

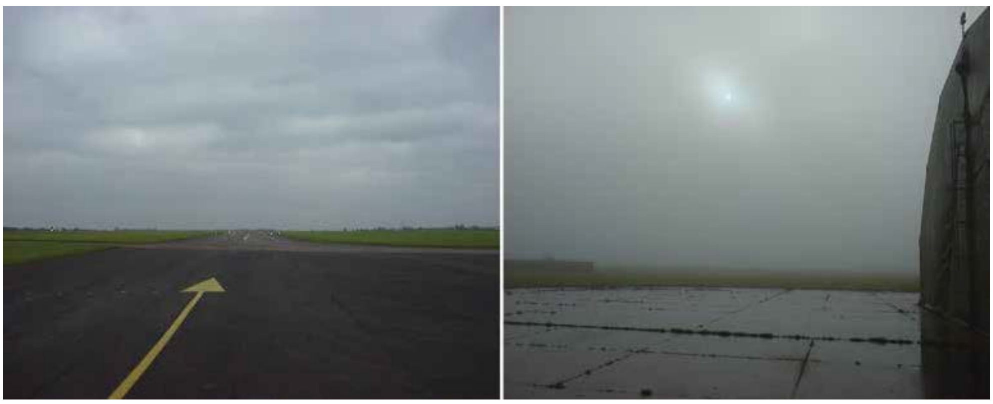

Figure 10.11 Stratus (St).

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Nimbostratus.

Nimbostratus, *see Figure 10.12*, is a dense, dark-grey, rain-bearing, stratiform cloud, producing extensive and long-lasting precipitation.

Figure 10.12 Nimbostratus (NS).

Cumulus.

Cumulus cloud, see *Figure 10.13*, is the most common form of convective cloud, being classified as heaped cloud, from Latin cumulare meaning to heap up. For glider pilots, a developing cumulus is regarded as a reliable indication of the presence of thermal upcurrents which, if skilfully exploited, can enable the glider to gain height. Pilots of light aircraft, on the other hand, will note that, on a day when the sky is peppered with fine-weather cumulus, as depicted in *Figure 10.13*, flight below cloud base is turbulent, whereas, above the cloud tops, the air is likely to be very smooth. A developed cumulus cloud is generally dense, with sharp outlines. As it continues to develop vertically, a cumulus cloud forms mounds, domes or towers, of which the upper parts often resemble the head of a cauliflower. The sunlit parts of cumulus clouds are brilliant white, but their bases are relatively dark.

Flight below the base of cumulus cloud is often turbulent, while above the cloud tops, conditions are smooth.

Figure 10.13 Fine-weather cumulus (Cu).

Cumulus clouds of small vertical development can appear benign, but they can grow rapidly when the atmosphere is unstable, with no upper-air inversion, and may develop into cumulonimbus clouds, with their tops reaching the Tropopause.

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Stratocumulus.

Stratocumulus cloud, *see Figure 10.14*, is probably the most common form of cloud in the skies of the United Kingdom. It appears grey, or whitish, but usually always has distinct dark parts. Stratocumulus can be seen as patches, or in a continuous layer. Stratocumulus is usually no more than 2 000 to 3 000 feet thick, but may become 5 000 to 6 000 ft deep in certain conditions.

Figure 10.14 Stratocumulus (SC).

Cumulonimbus.

Cumulonimbus clouds, *see Figure 10.15*, are clouds that the aviator should avoid. Cumulonimbus clouds consist of vigorous convective cloud cells of great vertical extent. In the later stages of their development, cumulonimbus clouds display a characteristic anvil top, as the upper part of the cloud hits the Tropopause. The upper parts of a cumulonimbus cloud often consist of supercooled water droplets and ice crystals. The base of cumulonimbus clouds is often very dark, with ragged cloud appearing beneath the main cloud cell.

Figure 10.15 Cumulonimbus (CB).

The risk of icing and turbulence is always severe in, and in the proximity of, cumulonimbus.

The risk of icing and turbulence associated with cumulonimbus is always severe. Within cumulonimbus, very strong upcurrents and downdraughts are continually at play, producing severe precipitation in the form of heavy showers of rain and hail. Other hazards associated with cumulonimbus are lightning and static discharge, which may lead to airframe damage and erroneous instrument readings.

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Moist unstable air throughout a deep layer of the atmosphere is necessary for the formation of cumulonimbus cloud. A 'trigger' to set off the lifting process is also required, and could be convection, frontal or orographic lifting or convergence.

Altocumulus.

Altocumulus, *see Figure 10.16,* takes the form of speckled white or grey cloud. The patches of cloud appear as rounded masses of fibrous or diffuse aspect. Altocumulus usually occur between 8 000 and 15 000 ft with tops on some occasions as high as 23 000 ft.

There are two forms of altocumulus which are of particular significance, namely: altocumulus lenticularis and altocumulus castellanus; both types are illustrated in *Figure 10.17*.

Figure 10.16 Altocumulus (AC).

Altocumulus lenticularis are signposts of the presence of mountain wave. In the lee of mountains, below altocumulus lenticularis, severe turbulence may be encountered, sometimes marked by rotor cloud.

Figure 10.17 Altocumulus Lenticularis and Altocumulus Castellanus.

Altocumulus lenticularis, also known as lenticular cloud, is found downwind of mountainous or hilly areas, and is indicative of the presence of mountain wave activity. (See Chapter 9.) Because of its position downwind of high ground, moderate or even severe turbulence may be found beneath altocumulus lenticularis. However, the air in the lenticular clouds, themselves, is always smooth.

Altocumulus castellanus is a "bubbly" form of normal altocumulus. The "towers" that form in altocumulus castellanus are like battlements on castles, hence the name. These clouds are significant because they often herald a change to showery, thundery weather and are a feature of summer weather in temperate latitudes.

Cumulonimbus clouds sometimes develop from altocumulus castellanus, when instability is present at medium levels of the Troposphere.

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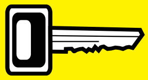
Altostratus.

Altostratus *(Figure 10.18)* is a grey or bluish sheet, or layer of cloud, which can be fibrous or uniform in appearance. Sometimes, altostratus covers the whole sky, giving a "ground glass" effect around the Sun or Moon.

Altostratus is usually found between 8 000 and 15 000 feet and can be from around 2 000 to 8 000 feet thick. But despite its thickness, altostratus is not a dense cloud, and the sun is usually perceptible through the cloud layer.

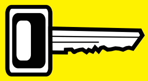
Figure 10.18 Altostratus (As).



The Sun or Moon may be visible through altostratus, appearing with a halo round it.

Cirrus.

Cirrus (from Latin cirrus, meaning curl) is the highest of all the cloud types and is composed entirely of ice crystals. Cirrus clouds take the form of white delicate filaments, in patches or narrow bands. They may also be described as fibrous or hair-like. Cirrus clouds can be found between 16 500 and 45 000 ft. They often herald the approach of a warm front. *(See Figure 10.19.)*



There are several qualifying words which are used in cloud names: - "nimbo" or "nimbus" meaning rain-bearing, "alto" which indicates "middle level" and, lastly, "cirro" which indicates "high level".

Figure 10.19 Cirrus (CI).

Cirrostratus.

Cirrostratus *(see Figure 10.20)* is a transparent, whitish cloud-veil of fibrous or smooth appearance, totally or partially covering the sky.

Cirrostratus is made up of ice crystals, and lies between 18 000 and 45 000 ft. Cirrostratus is a further warning of an approaching frontal system, and, like altostratus, may cause the Sun and Moon to appear with a halo.

Figure 10.20 Cirrostratus (CS).

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Cirrocumulus.

Cirrocumulus *(see Figure 10.21)* is probably the cloud which is least often seen in the sky. Cirrocumulus is a thin, white and patchy layer of cloud, with ripples, more or less regularly arranged. Cirrocumulus consists of ice crystals and is generally found between 20 000 and 30 000 feet.

Figure 10.21 Cirrocumulus (Cc).

THE FORMATION OF CLOUD.

Clouds are made up of either minuscule droplets of liquid water, or, at high altitudes, minuscule ice crystals.

For cloud to form, water vapour must be condensed into liquid water, a process which occurs when saturated air is cooled.

So, in order to generate clouds in the atmosphere, air must be cooled to dew point. This may come about in various ways. In the formation of low-level cloud, an airmass may be cooled when it passes over a cooler surface than that of the area in which the airmass originated. Air may also be cooled by mixing.

Cloud is most frequently created by being lifted and cooling adiabatically.

Most commonly, though, cloud is created by being lifted and cooling adiabatically.

Adiabatic cooling is dealt with in Chapter 8.

Cloud Formation through Turbulent Mixing.

In the lower atmosphere, air may be cooled, and cloud created, by turbulent mixing. This method of cloud formation was mentioned briefly in Chapter 9. On the left of *Figure 10.22,* the environmental air temperature is shown falling with altitude, at an Environmental Lapse Rate (ELR) of approximately 1°C per 1 000 ft. Notice that the temperature at 2 000 ft is 18°C, and at 3 000 ft is 17°C.

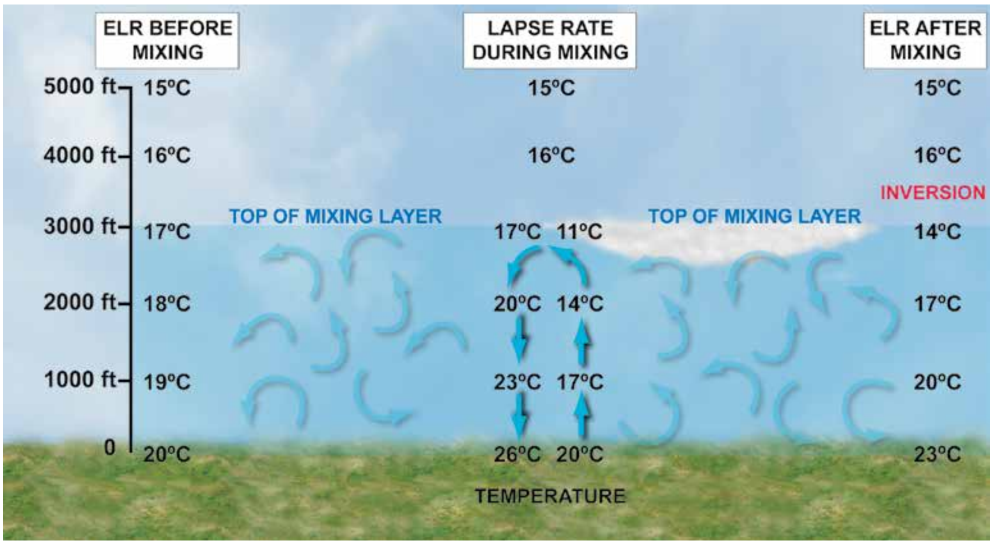

Figure 10.22 Turbulent mixing can lower the temperature near the top of the mixing layer sufficiently for condensation to occur and cloud to form.

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During mixing, the temperature within the mixing layer is modified by air either being forced up or down at the Dry Adiabatic Lapse Rate (DALR) of 3°C per 1 000 feet. After mixing, the average temperatures within the mixing layer create a new ELR, as shown to the right of *Figure 10.22*. Notice that, now, the temperature at 3 000 ft has decreased to 14°C, and the temperature at 2 000 feet has decreased to 17°C. If there is sufficient moisture, the dew point may be reached and turbulent cloud will form.

No cloud will be formed in this way above the mixing layer, because the temperature will not have fallen and an inversion will exist. Cloud generated by turbulent mixing is usually layered-type cloud, in other words, stratiform. *(See Figure 10.22.)* Stratiform cloud which is formed by mixing has a very characteristic flat top.

MECHANISMS OF LIFTING.

The most common form of cloud formation is that where air is lifted and cooled adiabatically to its dew point. There are several natural mechanisms for lifting air within the atmosphere from its original level to higher levels; the most common of these processes is convection.

Convection.

During the day, the Earth's surface will heat up, with some types of surfaces heating up more than others. The air overlying the warmer surfaces will, itself, be heated to a temperature higher than that of the surrounding air, becoming less dense, and, therefore, lighter than the environmental air, in the process. The warmer air will thus rise, and, as it does so, it will cool adiabatically. When the air has risen sufficiently to cool to the dew point, condensation will occur and cloud will form, as depicted in *Figure 10.23*.

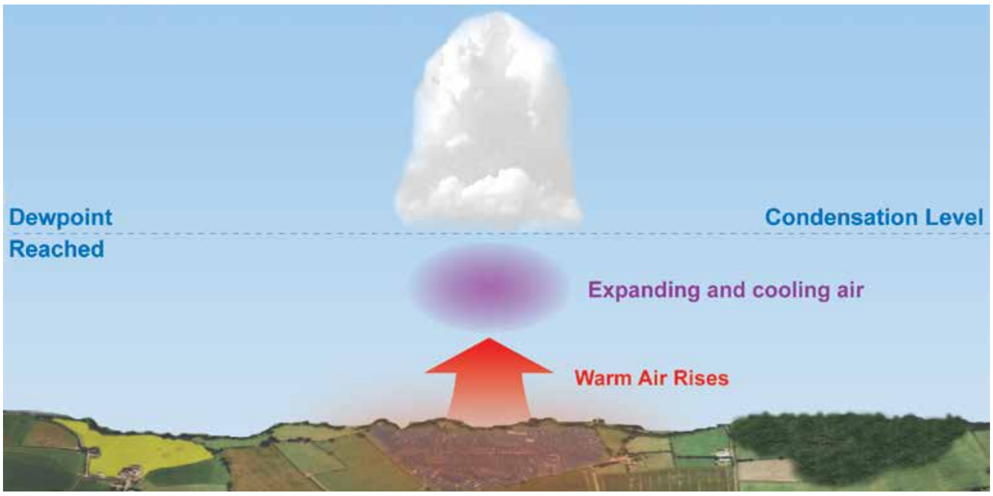

Figure 10.23 Lifting due to convection.

Cloud generated by convection is known as convective cloud. Convective cloud develops vertically, and takes the form of cumuliform cloud. Convection normally takes place on a small scale laterally, but, in certain atmospheric conditions, such as those which favour cumulonimbus cloud, convection may be much more extensive.

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Convective Cloud Base.

If air is very dry, it has a relatively low dew point temperature. Therefore, dry air will have to rise to quite a high altitude in order for it to be cooled to the dew point, compared to air which is more humid. A relationship, therefore, exists between the height of cloud base, and the relative humidity.

Figure 10.24 depicts two situations where the differences of temperature between surface air temperature and dew point are dissimilar. The cloud on the right has a higher cloud-base, because of the greater difference between surface temperature and dew point.

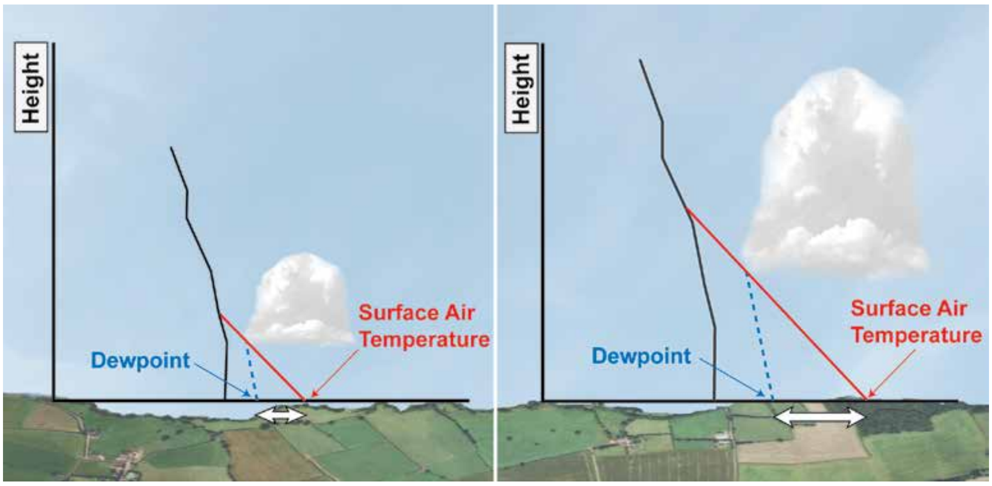

Figure 10.24 Cloud base is at the height where the lifted parcel of air has cooled to the dew point. The greater the difference between surface temperature and dew point, the higher the cloud-base.

In order to calculate cloud base, UK CAA examiners use the formula, (Temp º Celsius - Dew Point º Celsius) / 3 x 1 000 = cloud base in feet.

The United Kingdom Civil Aviation Authority (UK CAA) currently uses an approximate method of cloud base calculation. This is, simply, to take the difference between the surface temperature, and dew point, in degrees Celsius, divide that difference by the Dry Adiabatic Lapse Rate (3° per 1 000 feet), then multiply by 1 000 in order to obtain the height of cloud base above ground level, in feet.

For instance, if the surface temperature is 20°C and the dew point is 8°C, the base of cumulus cloud would be 4 000 feet.

$$\frac{(20 - 8) \times 1\,000}{3} = \frac{12}{3} \times 1\,000 = \textbf{4 000 feet above ground level}$$

Note that cloud base is calculated as height above ground level and that, consequently, the cloud base of convective cloud will be at a greater altitude (vertical distance above sea-level) over high ground than over low-lying terrain.

There are other, more accurate, methods of cloud base calculation, but the UK CAA method gives a good approximation of cloud base height above ground level. However, the derivation and use of these more accurate methods are outside the scope of this book. If you are a student based outside the United Kingdom, your national aviation authority may use a different method for cloud base calculation in pilot licence examinations.

Cloud base figures can be obtained from aerodrome TAFs and METARs.

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Convergence.

If two masses of moving air (winds) converge with each other, the air will be forced to rise where the two air masses meet. This forced ascent will cause the air to cool adiabatically, possibly leading to condensation and the formation of cloud.

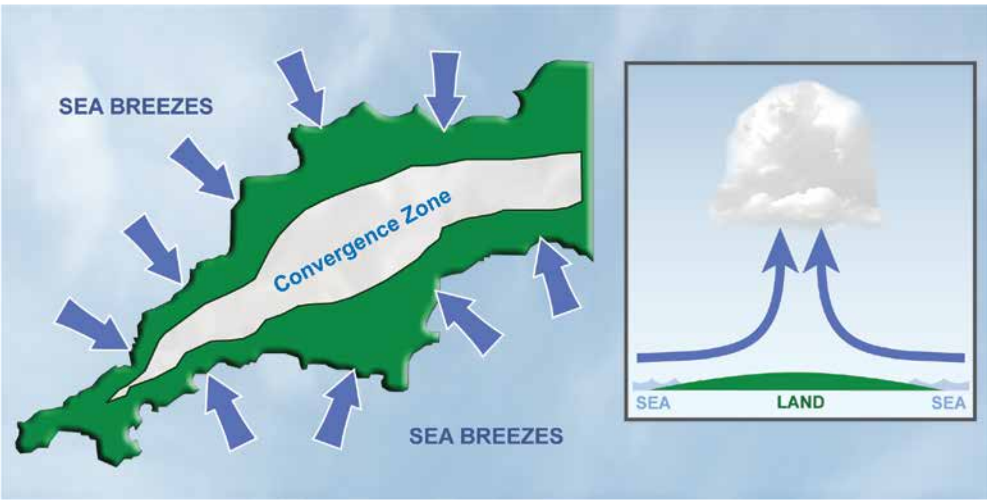

Figure 10.25 Lifting due to convergence on the Cornish peninsula.

The cloud formed within the zone of convergence will be of cumuliform type, similar to cloud formed by convection. An example of convergence is shown in *Figure 10.25*, caused by sea breezes on the Cornish peninsula, in Great Britain.

Frontal Lifting.

You have already learnt about how cloud forms in frontal systems. When a warm air mass meets a colder, denser air mass, the warm air will be forced to rise. In a warm front, the warm air rises over the cold air, and, in a cold front, the warm air is forced to rise by being undercut by the faster moving cold air mass. The rising warm air will cool, and its water vapour content will condense to create cloud.

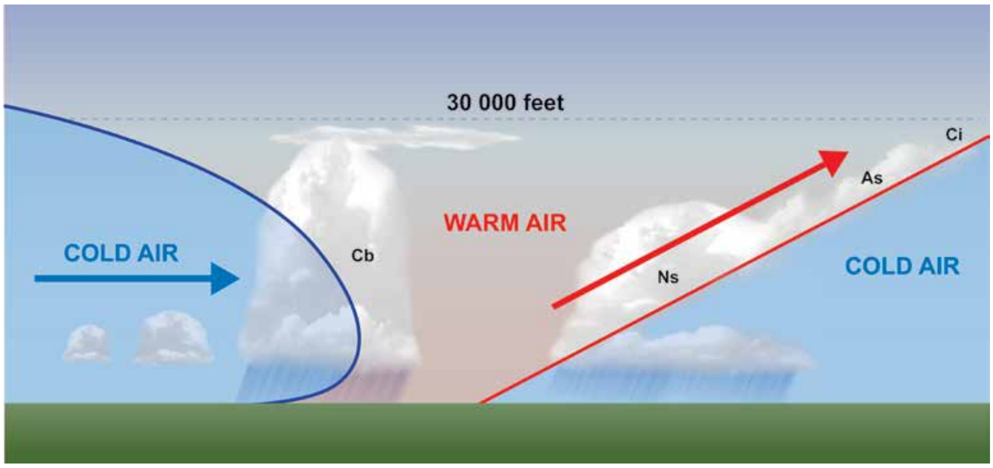

Figure 10.26 Cloud formation.

Figure 10.26 depicts both the warm and cold fronts which are associated with a polar depression. As you have learnt, cumulus and cumulonimbus are often created in advance of the cold front.

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Orographic Cloud.

High ground, hills and mountains will also force air to rise when wind is present, causing cloud to form over the hills if the air is cooled to its dew point. This type of cloud is called orographic cloud (from Greek oros meaning mountain). The type of orographic cloud which forms will depend on the stability of the air. In an unstable atmosphere, orographic cloud will continue to develop vertically to form cumuliform cloud, and even cumulonimbus. *(See Figure 10.27.)*

If unstable air is forced to rise up the side of a mountain, it will continue to rise once it has reached the peak, and cumuliform cloud will be created.

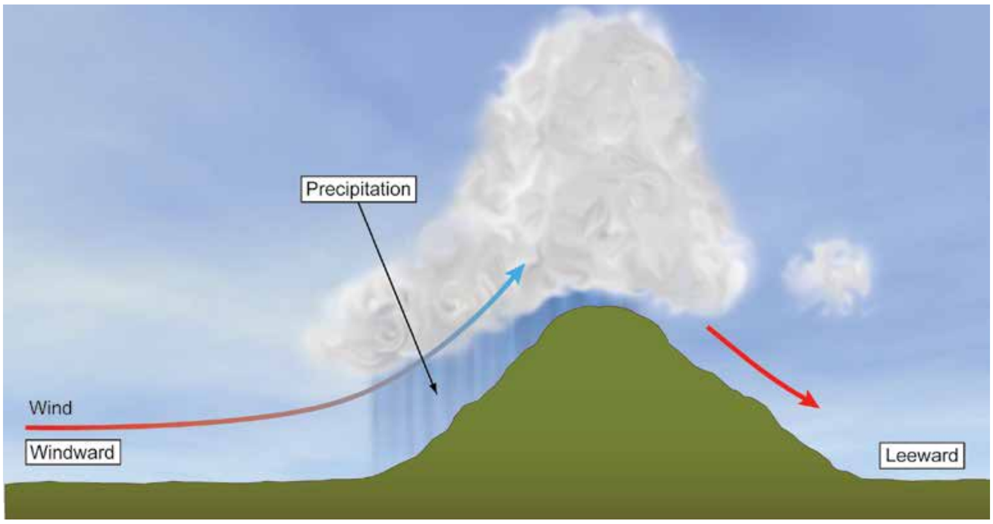

Figure 10.27 Cumuliform cloud may be embedded in orographic cloud, in unstable conditions.

In stable conditions, orographic cloud will not develop vertically, but will tend to hug the high ground forming what is known as cap cloud. *(See Figure 10.28.)*

In stable atmospheric conditions, orographic cloud remains stratiform, producing what is known as cap cloud on hill and mountain tops.

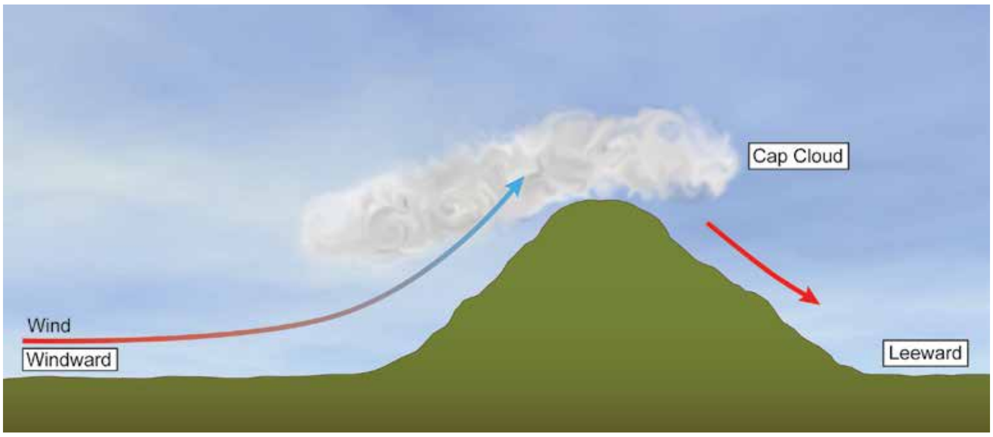

Figure 10.28 In stable air cap cloud will be formed.

Lenticular and Rotor Clouds.

When an air mass moves over hills or mountain ranges, stable conditions can create standing waves, with their associated lenticular and rotor clouds. You learnt about this phenomenon in Chapter 9.

Figure 10.29 illustrates the different types of cloud associated with hills and mountains, in stable atmospheric conditions.

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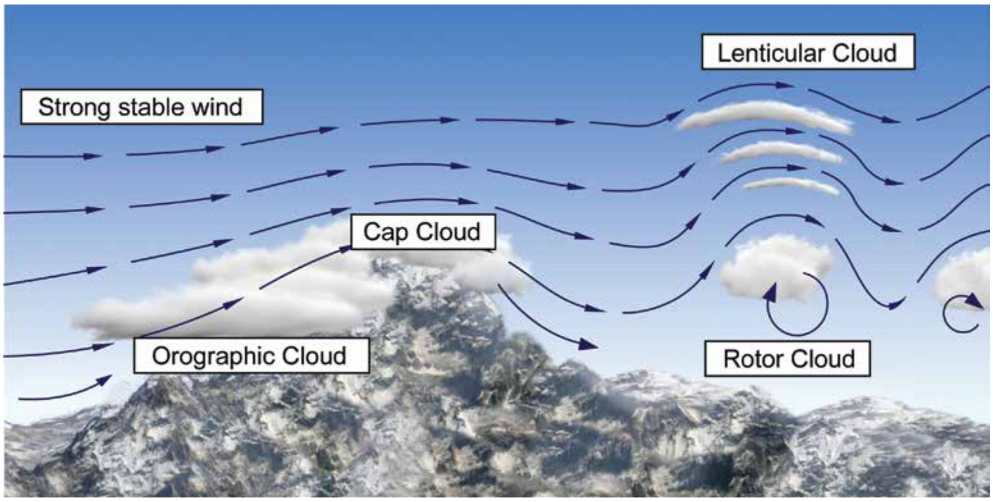

Figure 10.29 Cloud associated with airflow over a mountain, in stable conditions.

THE FÖHN EFFECT.

Stable air flowing over a mountain may also give rise to what is known as the Föhn Effect and its associated cloud and wind. The term Föhn wind describes a wind blowing down the lee of a mountainside, and which is warmer and drier than the air moving up the windward side of the mountain, at the same height.

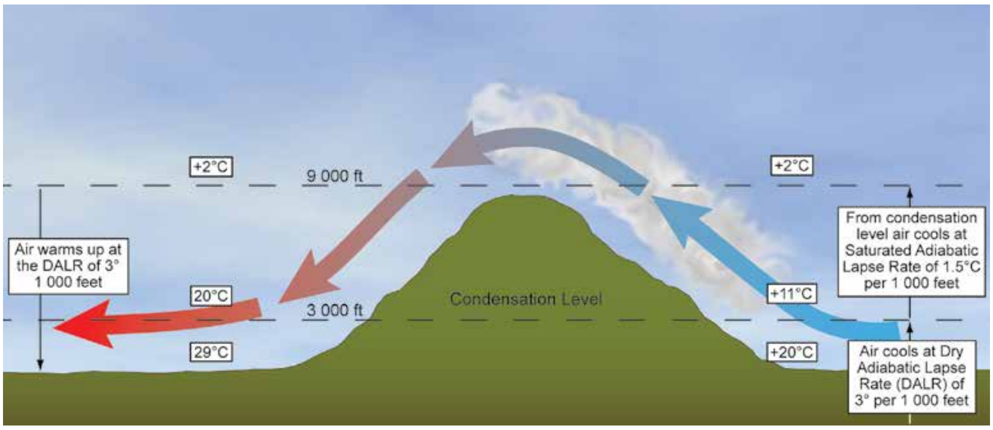

Figure 10.30 The Föhn wind and the Föhn effect.

Figure 10.30 depicts moist air moving up the windward side of the mountain. First of all, the air is unsaturated and, as it rises up the mountainside, it cools at the Dry Adiabatic Lapse Rate (DALR) of 3° per 1 000 feet. When the air becomes saturated, however, cloud will form, possibly accompanied by precipitation, and, from that point, the air will continue to cool at the lower Saturated Adiabatic Lapse Rate (SALR) of 1.5°C per 1 000 ft. When the air descends on the leeward side of the mountain, it will have lost much of its water vapour content through the formation of cloud, and precipitation. Consequently, the descending air will heat up at the DALR of 3° per 1 000 feet, giving rise to warm, dry valley winds.

Föhn winds and the Föhn Effect are common phenomena in the Alps.

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PRECIPITATION.

Precipitation is the name given to liquid and solid water particles which fall to the Earth's surface from clouds. Precipitation may take the form of drizzle, rain, snow or hail. As you have learnt, clouds are formed when water-vapour condenses and forms water droplets. The only real difference between the water droplets which make up the cloud and the water particles which fall from cloud as precipitation is one of size and weight.

Condensation and Coalescence.

In order for precipitation to occur, condensation must first take place. Condensation requires the presence of condensation nuclei (see Chapter 8). As the air cools, water vapour condenses into visible water droplets around these nuclei. However, these droplets frequently remain very very small, and are retained in the cloud, itself, by upcurrents. These minute droplets are, of course, essentially, the very substance of the cloud, itself. If they grow heavy enough so that they are just able to fall from the cloud, precipitation may result in the form of fine drizzle. The cloud commonly producing drizzle is stratus. Stratus has very little vertical development and contains only weak updraughts, so the water particles which fall from stratus are always very fine.

Drizzle is the type of precipitation most commonly associated with stratus.

Water droplets produced by condensation, however, frequently continue to grow, because of processes within the cloud, itself. Droplets frequently collide and merge to form larger droplets which may be held suspended in cumuliform cloud until they are heavy enough to fall as rain. The process of water droplet growth through collisions is called coalescence. The size that droplets grow to before falling as rain will depend on the strength of the up-currents within the cloud. Powerful vertical upcurrents will support much larger droplets, and produce heavier rain. Cumulonimbus contain the strongest upcurrents and produce the heaviest, most intense, precipitation.

Though it is a generalisation, the average raindrop may be considered to possess a mass of about 1 000 000 times greater than a water droplet which forms a cloud.

Rain and Snow - The Bergeron Process.

The Bergeron Process (named after the physicist Tor Bergeron) describes the process whereby, in those parts of a cloud where the temperature is lower than 0°C, water vapour sublimates directly into ice crystals. Ice crystals continue to grow and eventually become heavy enough to fall through the cloud. The ice crystals may then start to melt, and amalgamate into large clusters of ice crystals to form snow. As the snow falls, the air temperature may rise above freezing level, causing the snow to melt to become rain.

*The type and intensity of precipitation depends largely on the strength and extent of the vertical air movement inside a cloud. Hence, **stratus** will produce drizzle, **cumulus** will produce rain and **cumulonimbus** will produce heavy rain or hail. Precipitation falls as snow if the temperature is below zero.*

The Formation and Growth of Hail.

Hail is formed when rain droplets are carried by strong updraughts rapidly to the top of a cloud, usually cumulonimbus, causing the droplets to freeze into hail stones.

The small hail stones will then begin to fall again, before being swept back upwards as they are caught in the stronger upcurrents feeding the base of the cloud. In this way, hail stones will grow through collision with other water droplets, by the process of coalescence.

Hailstones grow layer by layer, through the process of coalescence, and may become very large indeed before they fall to Earth from the cloud. Hailstones weighing up

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to 1 kg have been known to form in cumulonimbus, posing a real hazard to aviation. As has been stated several times in this book, pilots should give cumulonimbus a wide berth.

Virga.

Virga is precipitation which is falling, but not reaching the ground, and looks like tendrils hanging beneath the cloud.

Figure 10.31 Virga.

The Nature of Precipitation.

Precipitation may take on various forms, such as rain, hail, snow etc, and may also fall to the Earth's surface in different ways, either steadily, over a long period of time (dynamic precipitation), or intensely and briefly as a shower.

Showers develop in unstable atmospheric conditions and fall from large cumulus (cumulus congestus) and cumulonimbus clouds. As you have already learnt, these clouds have active, powerful updraughts within them, helping to support large water and ice particles. This fact explains why showers of rain tend to consist of large rain droplets.

The convective cells making up cumulus congestus and cumulonimbus move over the surface at the speed of mid-altitude winds causing showers to have a relatively sharp onset and cessation. Showers can be of rain, snow or hail.

Dynamic precipitation is characterised by its more gentle onset, its duration of several hours, and gradual cessation. Dynamic precipitation falls from layered cloud, as opposed to showers which fall from convective cloud. Dynamic precipitation may take the form of drizzle, rain, snow or sleet. Dynamic precipitation can be described as being intermittent, falling from time to time for usually less than 60 minutes, or continuous, lasting for 60 minutes or more at any one location.

Classification of the Intensity of Precipitation.

The intensity of precipitation is described using the words: light, moderate and heavy.

Light rain is described as less than 0.5 mm per hour, whereas heavy rain is greater than 4 mm (1/6 of an inch) per hour.

Snow fall is measured in centimetres, or inches, of accumulation per hour.

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Representative PPL - type questions to test your theoretical knowledge of Clouds and Precipitation.

1 Unstable air is forced to rise up the side of a mountain. What weather might you expect to see on the windward slopes?

- a. Cloud of extensive vertical development embedded in orographic cloud
- b. Thick stratiform cloud, possibly nimbostratus
- c. None, as the air will subside and warm adiabatically after passing over the summit
- d. Cap clouds with possible altocumulus lenticularis

2. Meteorological textual information defines the height of the cloud base as follows: (agl = above ground level; amsl = above mean sea-level)

- a. METAR – agl, TAF – amsl, Area Forecast – amsl
- b. METAR – agl, TAF – agl, Area Forecast – amsl
- c. METAR – amsl, TAF – amsl, Area Forecast – agl
- d. METAR – amsl, TAF – agl, Area Forecast – agl

3. The use of the suffix “nimbus” or prefix “nimbo” means:

- a. dark and threatening
- b. wispy, detached or fibrous
- c. medium cloud
- d. rain bearing

4. The precipitation produced by stratus is normally:

- a. heavy showers
- b. heavy rain
- c. drizzle
- d. light showers

5. Hail is most likely to fall from which type of cloud?

- a. NS
- b. AC
- c. CB
- d. AS

6. Which of the following clouds is most closely associated with extensive light rain?

- a. Nimbostratus
- b. Cumulus
- c. Cumulonimbus
- d. Cirrostratus and stratocumulus

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7. From the list below, select the Low, Medium and High clouds in ascending order.

   a. Stratus, altocumulus, cirrus
   b. Nimbostratus, cumulonimbus, cirrus
   c. Altostratus, altocumulus, cirrus
   d. Cirrus, cumulonimbus, stratus

8. Given a surface temperature of +21° C and a dew point of +6° C, at approximately what height will the cloud base of a cumulus cloud be? Use the UK CAA's formula for calculating height of cloud base.

   a. 560 ft
   b. 56 000 ft
   c. 4 000 ft
   d. 5 000 ft

9. One or more coloured rings around the Sun or Moon may indicate the presence of which type of cloud?

   a. High
   b. Cirrostratus
   c. Stratus
   d. Cirrocumulus

10. What type of weather phenomenon would you expect in a valley on the leeward side of a mountain over which a Föhn wind was blowing?

   a. Heavy precipitation
   b. A warm, dry wind
   c. A cold, moist wind
   d. Valley fog

11. Lenticular clouds observed in the lee of a range of hills indicate the possibility of what type of meteorological phenomenon?

   a. Strong upcurrents in the lee of the hills
   b. Severe downdraughts on the immediate windward side of the hills
   c. Severe downdraughts in the immediate lee of the hills and turbulent rotor clouds beneath the lenticular cloud
   d. the imminent development of cumulonimbus

12. An unstable atmosphere where the Environmental Lapse Rate is greater than the Saturated Adiabatic Lapse Rate, is characterised by:

   a. clear skies and heat haze
   b. a predominance of cirrostratus and altostratus with no low level cloud
   c. fog with an almost complete absence of wind
   d. extensive cumulus or cumulonimbus cloud with frequent showers and otherwise good visibility

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13. Heavy showers of rain and the possibility of thunderstorms are most often associated with cloud:

    a. in advance of a cold front
    b. behind a warm front
    c. in advance of a warm front
    d. within a ridge of high pressure

14. A stable air mass which is subject to orographic lifting will most likely produce:

    a. cloud of extensive vertical development
    b. stratiform cap cloud at the summit of the high ground
    c. no cloud because the air is stable
    d. warm, dry, valley winds

Question	1	2	3	4	5	6	7	8	9	10	11	12
Answer												

Question	13	14
Answer		

The answers to these questions can be found at the end of the book.

CHAPTER 11
THUNDERSTORMS

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INTRODUCTION.

This chapter deals with the formation of thunderstorms, and the hazards they pose to pilots.

Well-developed cumulonimbus clouds produce thunderstorms. However, in order for the cumulonimbus to reach the state of development necessary for thunderstorms to occur, certain meteorological criteria must be met. These are:

The conditions required for the formation of a thunderstorm cell are an unstable atmosphere, a plentiful supply of moisture and a triggering action.

- The atmosphere must be unstable. The Environmental Lapse Rate (ELR) must be greater than the Saturated Adiabatic Lapse Rate (SALR), and that condition must extend to well above the 0ºC level.
- The air must hold sufficient water vapour to form, and sustain, the cumulonimbus cloud.
- A trigger mechanism must be present in order to produce the initial uplift of air.

TRIGGER MECHANISMS.

There are a number of trigger mechanisms within the atmosphere and on the Earth's surface, which will cause air to ascend and, under the conditions mentioned above, begin the vigorous convective activity, required to form cumulonimbus cloud.

- Unequal surface heating is a trigger mechanism. As the surface of the Earth heats up unequally, air lying in contact with the warmer surfaces will begin to rise. This is called convection. Convection is one of the main triggers for thunderstorms, especially over land in summer.

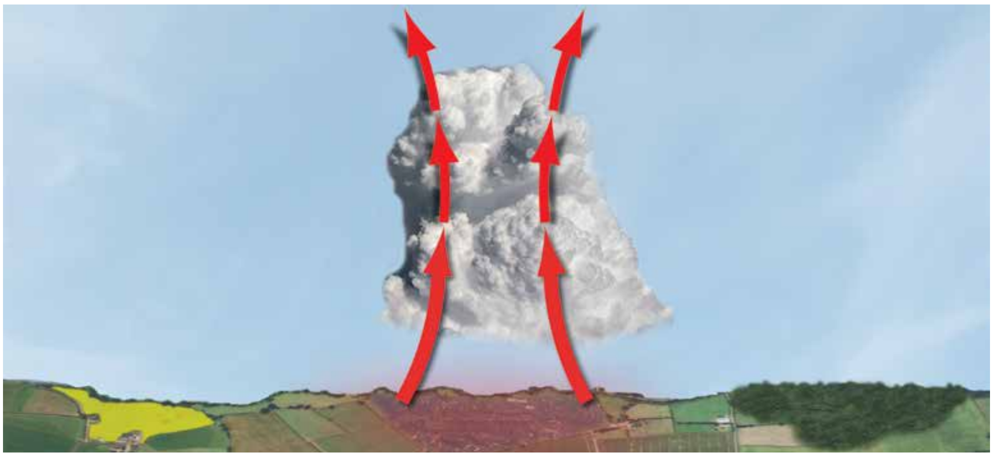

Figure 11.1a Convection.

- In mountainous areas, the trigger for thunderstorms can be the forced ascent of air as it flows up the windward side of mountains and hills. This is called orographic uplift. *(See Figure 11.1b.)*
- If two air masses move together, air will be forced to rise through convergence. *(See Figure 11.1c.)*
- Air is also forced to rise by frontal uplift. Cumulonimbus thunder clouds are commonly associated with the vigorous uplift of air in advance of a cold front. But, very rarely, cumulonimbus may also be embedded in warm-front stratiform cloud, too.

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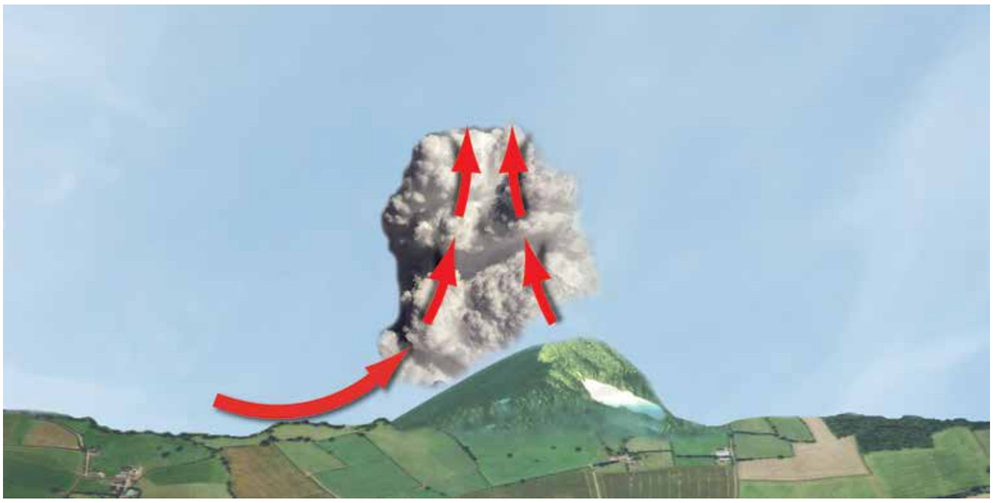

Figure 11.1b Orographic uplift in an unstable atmosphere may trigger a thunderstorm.

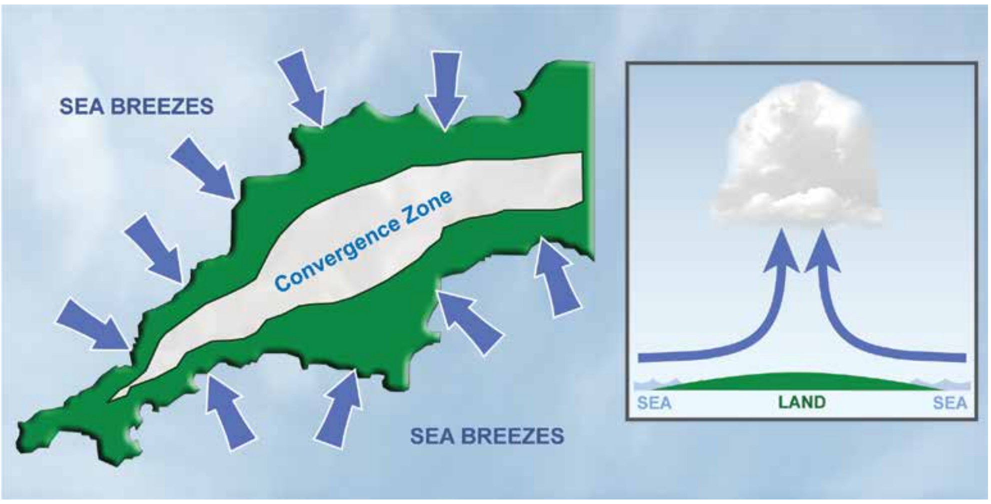

Figure 11.1c Convergence in an unstable atmosphere may trigger a thunderstorm.

In frontal thunderstorms, cumulonimbus are often embedded in the stratiform clouds found on fronts. Embedded cumulonimbus pose a great hazard to aviation because they are difficult to see.

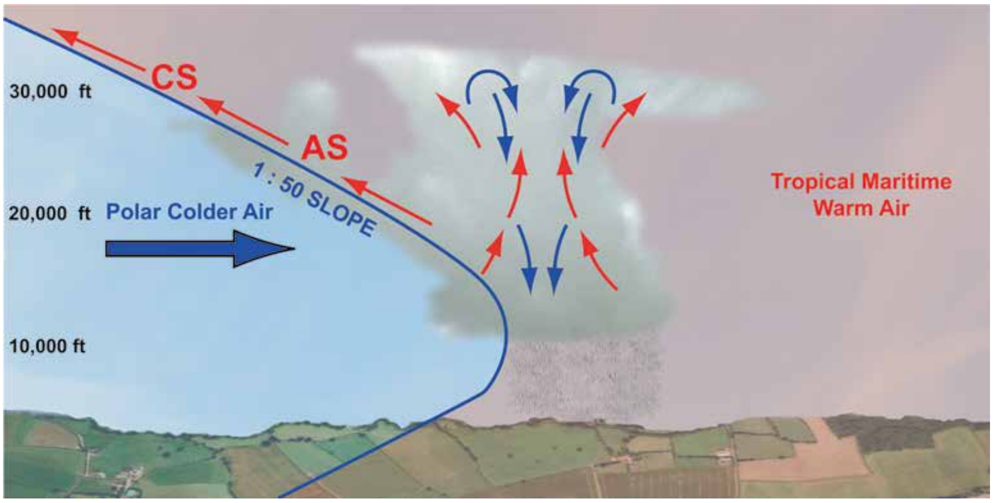

Figure 11.1d Thunderstorms may form ahead of a cold front.

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THUNDERSTORM CLASSIFICATION.

There are generally two different types of thunderstorms: those which occur in a single air mass, called heat-type thunderstorms or air mass thunderstorms, and those which are associated with frontal action, called frontal thunderstorms.

Heat type thunderstorms are triggered by convection, convergence or orographic uplift in an unstable atmosphere, and are generally isolated, although it is not unknown for lines of such storms to form lines or groups. Heat type thunderstorms normally occur in the summer.

In the summer months, thunderstorms can be caused by convection, convergence, or orographic uplift in an unstable atmosphere. This heat-type of thunderstorm is most frequent over land, and generally forms by day. Although mainly isolated, heat-type thunderstorms may, on occasion, form into lines or large groups.

Thunderstorms also occur at cold fronts, or very occasionally, at occlusions. On such occasions, they are often embedded in layered cloud, which makes them particularly hazardous to aircraft. Frontal thunderstorms form mainly over the land, and are more common in winter months. *Figure 11.1d* depicts the way in which a frontal thunderstorm is formed. The triggering action for a frontal thunderstorm is the lifting of the warm air by the advancing cold air.

THE STAGES OF DEVELOPMENT OF THUNDERSTORMS.

There are three main stages in the development of a thunderstorm: the initial or cumulus stage, the mature, cumulonimbus stage and the dissipating stage.

The Initial Stage.

The initial stage, depicted in *Figure 11.2*, is characterised by strong updraughts and by the rapid growth, both horizontally and vertically, of a cumulus cloud. Strong updraughts produce clouds of great vertical extent, as air is drawn into the cloud from beneath and from the sides. This initial stage usually lasts for around 20 minutes can produce a cloud up to 5 nm across and 25 000 ft high. The rapidly developing cumulus is often called cumulus congestus or towering cumulus.

The initial stage of a thunderstorm is characterised by strong updraughts and rapid vertical cloud growth.

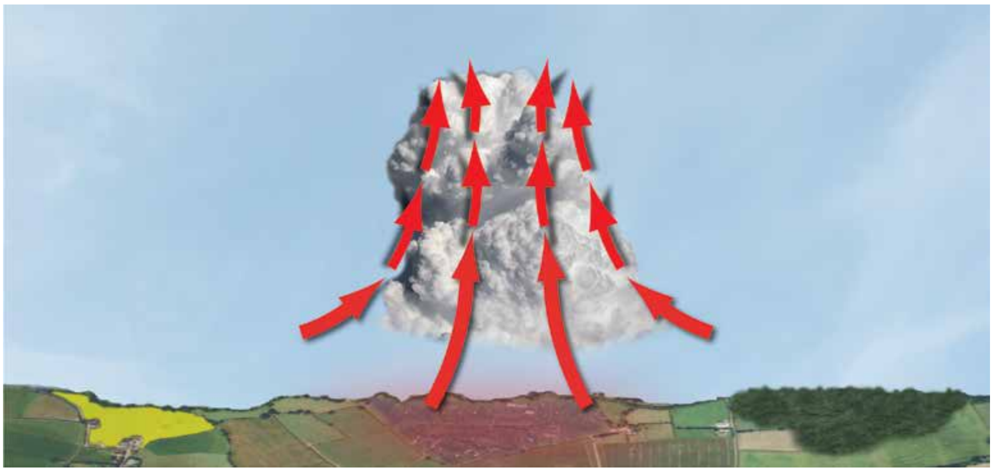

Figure 11.2 The initial stage of a thunder cloud characterised by strong upcurrents. These clouds are sometimes referred to as cumulus congestus.

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The mature stage of thunderstorm development is characterised by up and downdraughts, and the onset of precipitation.

The Mature Stage.

The mature stage, depicted in *Figure 11.3*, is characterised by strong up and down draughts, within what has become a cumulonimbus cloud, which are accompanied by precipitation in the form of rain or hail. Downdraughts can attain 2 000 fpm or more, bringing cold heavy air down to lower levels within, and below, the cloud. These downdraughts are frequently colder than the surrounding air beneath the cloud, causing the air to sink at an even faster rate. They thus present a major hazard to aircraft caught beneath the cloud.

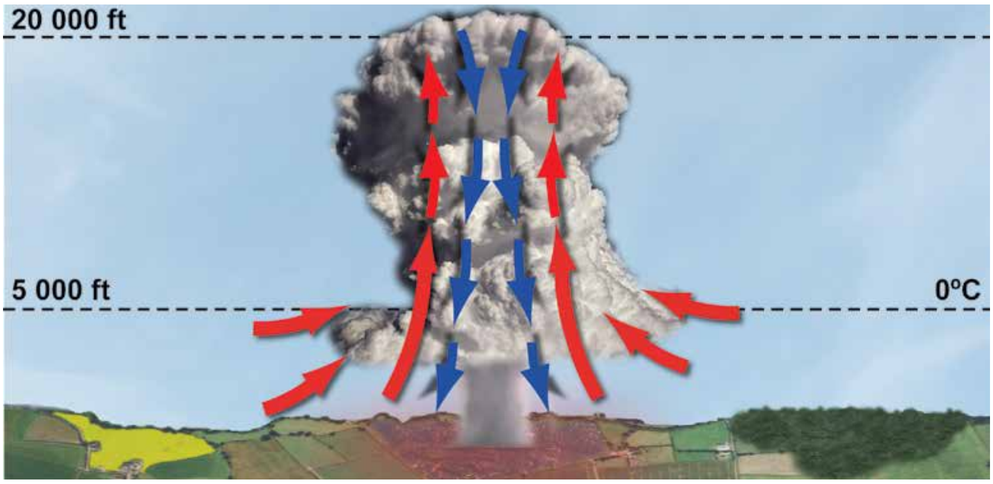

Figure 11.3 The mature stage of a cumulonimbus thunder cloud is characterised by strong up and down draughts, and is accompanied by precipitation.

The upcurrents within a mature cumulonimbus can attain 10 000 feet per minute, while the cloud top may grow upwards by as much as 5 000 feet per minute. In the later part of the mature stage, the cumulonimbus may begin to develop the characteristic fibrous anvil top, thought this is not always the case. Sometimes the characteristic anvil may not be seen until the cumulonimbus has begun to decay. *(See Figure 11.7.)*

The rising and falling particles of rain, hail and snow cause a build up of static electricity within the cumulonimbus. The top of the cumulonimbus becomes positively charged while the lower part negatively charged. The negative charge at the base of the cumulonimbus induces a net positive charge on the Earth's surface beneath the cloud base.

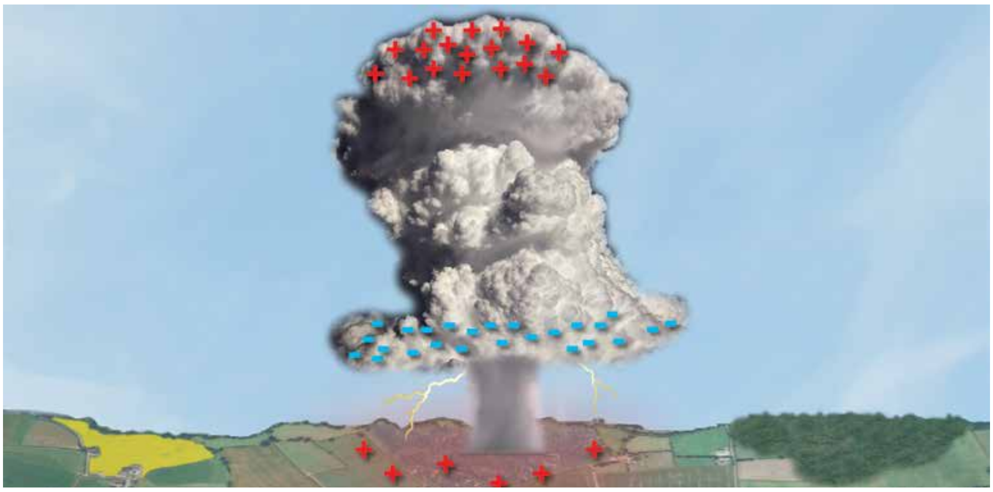

Figure 11.4 The difference in electrostatic charge between the bottom of the cloud and the surface is the cause of lightning.

The difference in charge between the base of the cumulonimbus and the Earth's surface eventually leads to lightning discharge, and the characteristic boom of explosively heated air, which we call thunder.

In the mature stage differences in electrostatic charge at the bottom of the cloud and the surface create lightning while the severe downdraughts create micro-bursts, gust fronts and roll cloud.

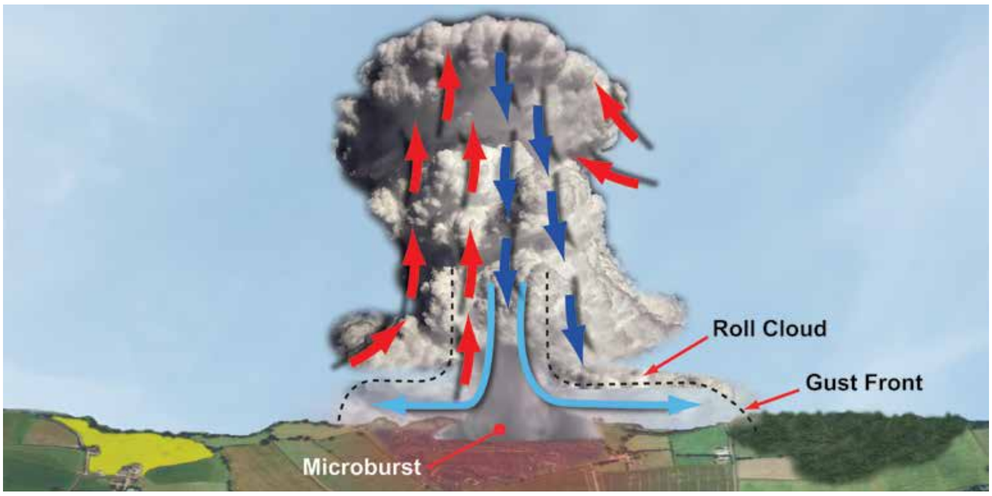

Figure 11.5 Microbursts, gust fronts and roll cloud are further hazards created by thunderstorms.

Microbursts and gust fronts, depicted in *Figure 11.5*, are other features of the mature stage of the cumulonimbus thunder cloud.

Microbursts are created when strong, cold downdraughts, beneath the cloud, spread out as they reach the surface. Microbursts can be very dangerous, because the rate of sink of the air may exceed the climb performance of aircraft, thereby forcing them to the ground.

Figure 11.6 Virga.

A good visual clue to microburst activity is the presence of virga. Virga is precipitation which is falling, but not reaching the ground, and looks like tendrils hanging beneath the cloud.

As indicated in *Figure 11.5*, the leading edge of this out-flowing colder air beneath a mature thunder cloud is known as a gust front. The gust front marks a rapid change in wind direction and speed, and is accompanied by a noticeable temperature drop. Gust fronts are often made visible as the colder air undercuts the warm air, forcing it to rise to create cloud known as roll, or shelf clouds.

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Once developed, cumulonimbus clouds and the associated thunderstorms move in the same direction as the winds at around 10 000 ft. However, the horizontal development of a maturing cumulonimbus can easily extend upwind.

The Dissipating Stage.

The dissipating stage of a cumulonimbus thunder cloud, shown in *Figure 11.7,* begins as the anvil top becomes fully formed. The dissipating stage is characterised predominately by downdraughts. However, updraughts may still prevail at the summit of the cumulonimbus, feeding the growing anvil. Precipitation at this stage is usually heavy, but more widespread and less intense than at the mature stage.

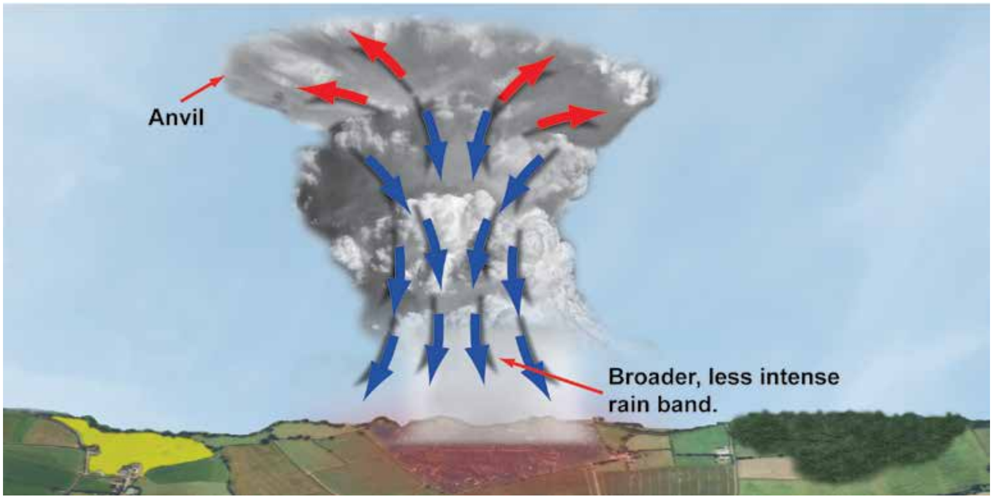

Figure 11.7 The dissipating stage of the cumulonimbus thunder cloud is characterised by the thundercloud's anvil top, downdraughts and continuing precipitation.

The dissipating stage may last for between 1½ and 2½ hours, during which time, lightning and thunder may continue to occur.

Isolated thunderstorms, although on occasions quite large, do not last long, because the severe downdraughts which accompany the precipitation suppress the up-currents necessary to sustain the cloud. Isolated thunderstorms, then, effectively begin to dissipate once precipitation commences.

THUNDERSTORM HAZARDS.

The hazards to aviation created by thunderstorms are turbulence, windshear, icing, microbursts, hail, and lightning. Most of these hazards can be encountered in the vicinity of the cumulonimbus as well as within the cloud, itself.

Turbulence.

Severe turbulence can occur in, and around, any cumulonimbus clouds, and particularly around thunderstorms. The violent up and downdraughts within cumulonimbus are especially hazardous. The downdraughts, and associated windshear which accompany microbursts, are particularly dangerous during take-off and landing, because, at those times, aircraft are in a configuration of high drag and low forward speed. Wind shear can reduce airspeed to stalling speed as well as lead to loss of control by the pilot. In extreme turbulence, structural damage and even structural failure may be suffered by airframes.

Icing.

Severe icing may occur in cumulonimbus at temperatures between 0ºC and -45ºC. High concentrations of large, supercooled water droplets can lead to severe, clear icing accumulating on the airframe very quickly. Pilots should avoid icing conditions by remaining clear of cloud above the freezing level.

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Carburettor and engine icing can occur at temperatures between - 10ºC and + 30ºC, in the high humidity associated with any cloud.

Light aircraft should avoid thunderstorms by 10 nm because most of the hazards associated with thunderstorms can be encountered outside the cloud itself.

Hail.

Hail may be encountered at any height in, and underneath, a thunderstorm. Hail can also be experienced beneath the anvil of a cumulonimbus, outside the cloud. Severe damage to the skin of an airframe may be caused by hail.

Lightning.

Lightning is most likely to occur 5 000 ft either side of the freezing level, in a part of the cloud that usually has a temperature between - 10ºC and + 20ºC. Lightning within the vicinity of an aircraft can cause the following effects:

- Temporary blindness.
- Erroneous compass reading.
- The ADF becoming unreliable, often pointing in the direction of the storm itself.
- Skin damage to an aircraft struck by lightning, especially composite aircraft.
- Ignition of the fuel vapour if the fuel tanks are nearly empty.

Pressure Variations.

Large and rapid pressure variations can occur in, and around cumulonimbus, which may lead to errors in indicated altitude of up to plus or minus 1 000 feet.

Inaccurate height indications and severe downdraughts can potentially create very dangerous conditions. If the altimeter is fluctuating, a pilot should not try to maintain level flight, because there is a danger of overstressing the aircraft. It is more important to maintain attitude rather than altitude inside the storm.

GUIDANCE FOR THE AVOIDANCE OF HAZARDS.

Light aircraft should avoid thunderstorms by at least 10 nautical miles horizontally and 5 000 ft vertically.

Thorough pre-flight planning is particularly crucial before flying in weather where strong convection is expected. Low Level Significant Weather Charts (see Chapter 19), and Terminal Aerodrome Forecasts (TAFS) (see Chapter 17), should give a good indication of the timing and location of cumulonimbus and/or thunderstorm development.

Thunderstorms pose a significant danger to the safety of aircraft and it is a frightening experience for a pilot and passengers to be caught in one. Cumulonimbus clouds must be treated with extreme caution and, before a flight, the pilot should analyse weather reports and forecasts carefully, to ensure he is able to avoid cumulonimbus during the planned flight.

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Representative PPL - type questions to test your theoretical knowledge of Thunderstorms.

1. Thunderstorm activity is most likely to be associated with which of the following:

    a. A ridge of high pressure
    b. Stable anticyclonic conditions
    c. The presence of mountain wave
    d. A cold front

2. Which of the following combinations of weather-producing variables would be most likely to result in the formation of cumulonimbus cloud?

    a. Stable moist air combined with the Föhn effect
    b. Unstable air and no lifting mechanism
    c. Stable dry air and orographic uplifting
    d. Unstable moist air and orographic uplifting

3. For cumulonimbus clouds to develop, which of the following atmospheric conditions must be present?

    a. A deep layer of stable moist air
    b. A shallow layer of stable moist air at the Earth's surface
    c. A deep layer of very unstable moist air with an appropriate trigger mechanism
    d. A conditionally stable dry air

4. What stage of a thunderstorm is characterised mainly by downdraughts?

    a. Initial stage
    b. Dissipating stage
    c. Mature stage
    d. Cumulus stage

5. What stage of a cumulonimbus is most likely to be characterised by a fibrous anvil shape at the cloud's summit?

    a. Dissipating stage
    b. Initial stage
    c. Mature Stage
    d. Cumulus stage

6. Hazards of the mature stage of a thunderstorm cell include lightning, turbulence and:

    a. a decreasing intensity of precipitation
    b. icing, micro-burst and wind-shear
    c. icing, drizzle and micro-burst
    d. wind-shear, hail and fog

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7. Which of the following are most likely to produce thunderstorms?

   a. A high moisture content with the ELR greater than the SALR
   b. A high moisture content with the ELR less than the SALR
   c. A low moisture content with the ELR less than the SALR
   d. A low moisture content with the DALR greater than the SALR

8. What stage of a thunderstorm is characterised by updraughts only?

   a. Mature stage
   b. Initial stage
   c. Dissipating stage
   d. End stage

9. The atmospheric conditions which must exist to allow a thunderstorm to develop are:

   a. a trigger action, a plentiful supply of moisture and a very stable atmosphere
   b. a steep lapse rate and a stable atmosphere through a large vertical extent
   c. a high moisture content with the ELR greater than the SALR through a large vertical extent of the atmosphere, together with a trigger action
   d. a steep lapse rate through a large vertical extent, a low relative humidity and a trigger action

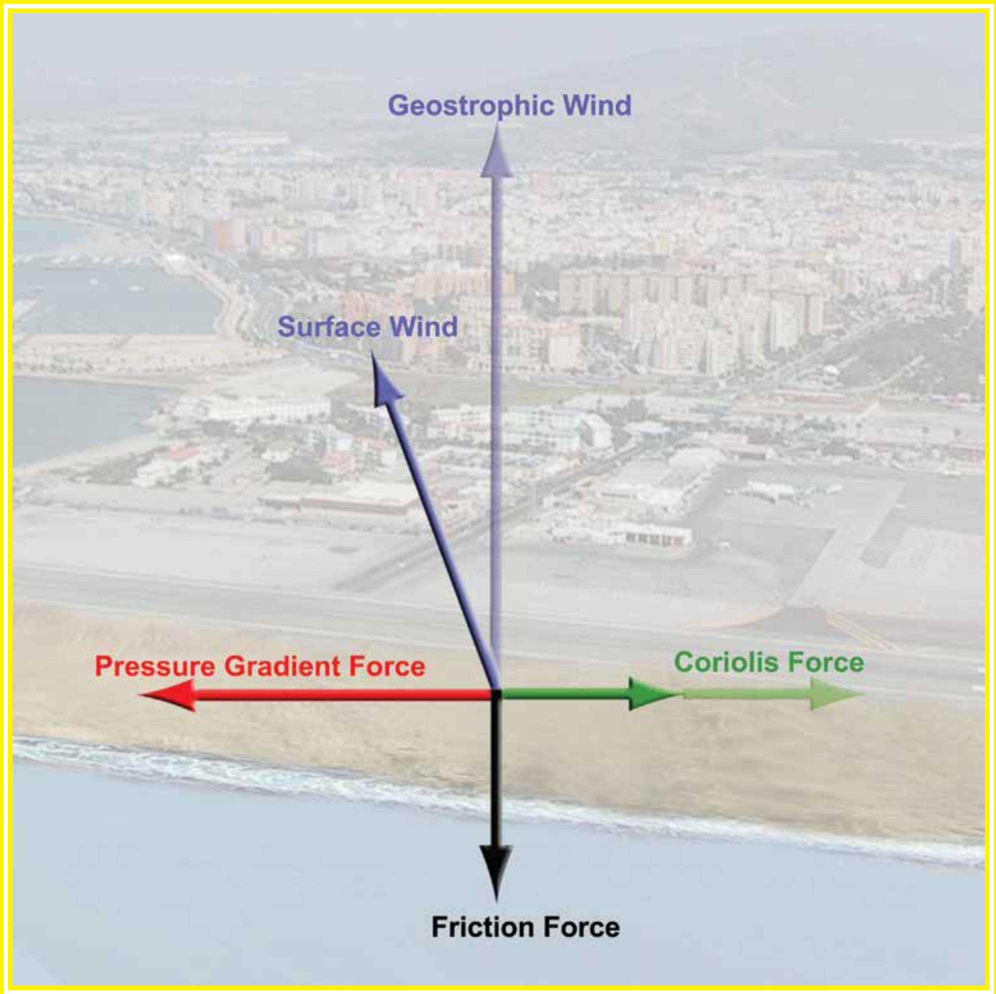
10. Hazards to an aircraft caused by the presence of cumulonimbus thundercloud may be experienced:

   a. only when the aircraft is within the cloud
   b. only when the aircraft is within or beneath the cloud
   c. when the aircraft is within 10 nm of the cloud
   d. when the aircraft is within 5 nm of the cloud

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Answer										

The answers to these questions can be found at the end of the book.

CHAPTER 12
LOW LEVEL WINDS



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INTRODUCTION.

This chapter concentrates on those winds which blow within the first few thousand feet of the surface. It examines what creates wind, what the forces involved are, and, how these change as the wind interacts with its environment, particularly the surface over which it flows. Wind is defined as the sustained horizontal flow of air over the earth. To begin with, the measurement of wind velocity and its units will be examined.

WIND DIRECTION.

Wind is usually represented as a velocity indicating both wind direction and wind speed. The direction of movement of any object is usually given in degrees from north. This scale starts from zero, which is north, all the way through to three hundred and sixty degrees, which is another way of expressing north. Wind direction is given, not as the heading of the wind, but rather as an indication of where the wind is coming from.

For example, a wind blowing towards the east is called a westerly wind and would therefore be shown as having a direction of 270 degrees. This is all shown diagrammatically in *Figure 12.1*.

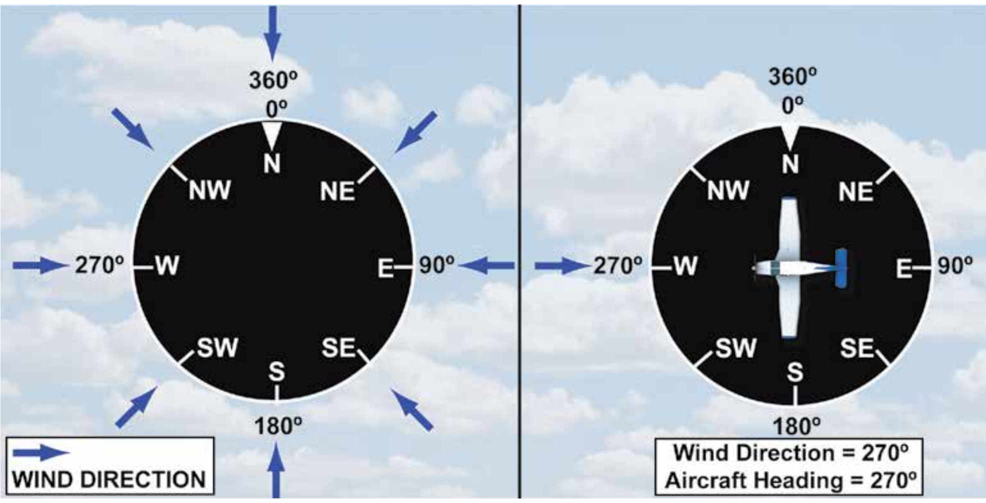

Figure 12.1 Wind Direction - reported from where the wind is coming from and measured in degrees from true north (sometimes magnetic north).

Normally in meteorology the wind direction is given relative to true north. When using such wind directions in flight planning be careful to adjust them using the relevant variation so that their direction is relative to magnetic north although typically navigation planning is usually done in degrees true and the variation is factored in at the end by adding it to, or subtracting it from, the true heading that is the result of the calculation of the triangle of velocities.

The wind velocity has both direction and magnitude. The direction of the wind is always quoted as that from which the wind is coming and reference to true north, except on ATIS broadcasts and transmissions from airfields.

There are two occasions when the reported winds are given as magnetic directions and not true directions. These are whenever wind is reported by an air traffic controller from a tower, on take off and landing for instance, (or an AFISO or A/G radio operator) and in the recorded aerodrome terminal information service or ATIS.

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The wind direction is given by reference to true north on all weather reports and forecasts except when it is given by Air Traffic Control, AFISO or Air/Ground Operator over the R/T or when it is broadcast on ATIS.

Changes in the direction of the wind are expressed using the terms backing and veering. A wind that is veering is changing direction in a clockwise manner. For example, a wind that was zero nine zero degrees and is now one eight zero degrees would be described as veering. A wind is said to be backing if the direction change of the wind is anticlockwise. For example, a wind that was two seven zero degrees, and is now one eight zero would be described as backing. *See Figure 12.2.*

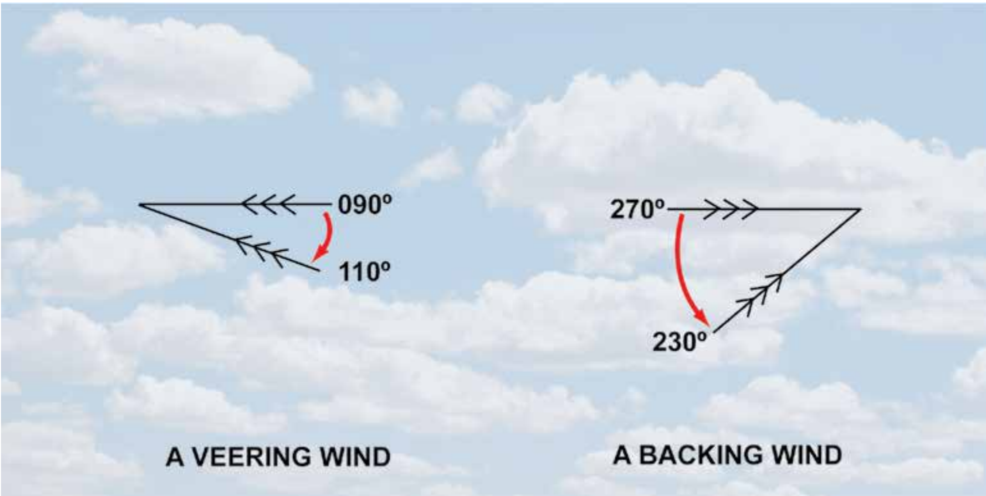

Figure 12.2 (Left) Veering - a clockwise change in direction (Right) Backing - an anti-clockwise change in direction

WIND SPEED.

The wind is reported as a velocity that is, both its direction and speed are given. The standard unit of speed is the metre per second. More generally however, the unit adopted for operational purposes in aviation is the knot; one knot equals one nautical mile per hour.

INSTRUMENTS FOR MEASURING WIND VELOCITY.

Measuring wind velocity is quite simple. The most commonly used instrument is the cup anemometer and wind vane which is shown in *Figure 12.3*. The three cups capture the wind and, as a result, rotate about a spindle. The direction of the wind is measured by a remote transmitting wind vane. These instruments are used around airfields to calculate the approximate surface wind velocity for aircraft either taking off or landing.

The definition of the surface wind is one that blows at 10 metres above ground level. Consequently, these instruments are placed 10 metres above ground level and clear of any nearby obstacles that may unduly disturb the flow of air and give misrepresentative readings.

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Figure 12.3 Wind Instruments. Speed - Cup anemometer. Direction - wind vane. Airfield surface wind measurements are measured 10m above the ground.

WIND SYMBOLS ON CHARTS.

On some weather charts wind speed and direction are shown by symbols. *Figure 12.4* shows an example of how they are presented. The circle denotes the point of observation or the location of the reading. The direction is shown by a straight line coming from the circle. This line points towards the direction from which the wind is blowing.

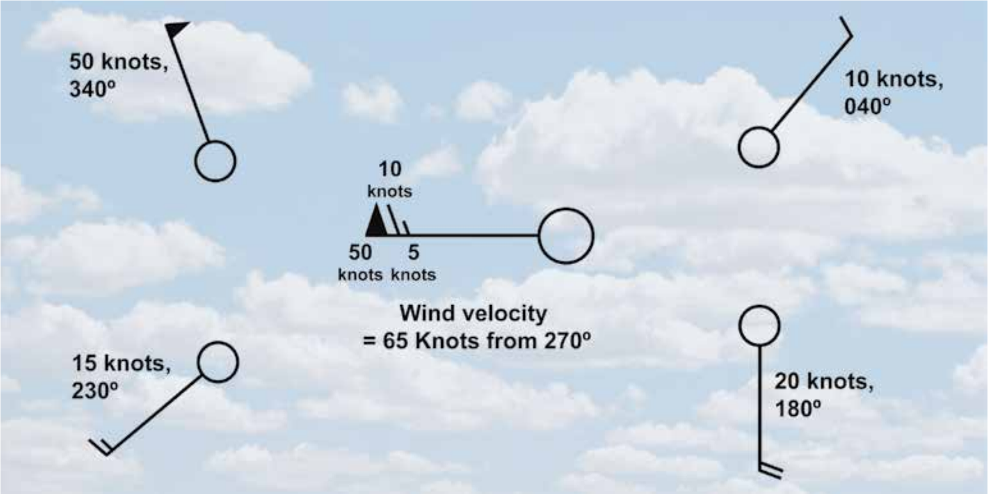

Figure 12.4 Wind representation and coding on some charts.

Shown here is a wind from 270 degrees, in other words a westerly wind. The wind speed coding is attached to the line emanating from the circle. A thin straight line or 'feather' represents 10 knots, a short line or feather represents 5 knots and the triangle a speed of 50 knots. So this example gives the speed as 65 knots.

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THE GEOSTROPHIC WIND.

The study of air flow is complex and in order to understand it certain conditions must be assumed and simplified models constructed. The first of these is the Geostrophic Wind. This is the wind that blows above the friction layer and is unaffected by surface frictional forces, as shown in *Figure 12.5.*

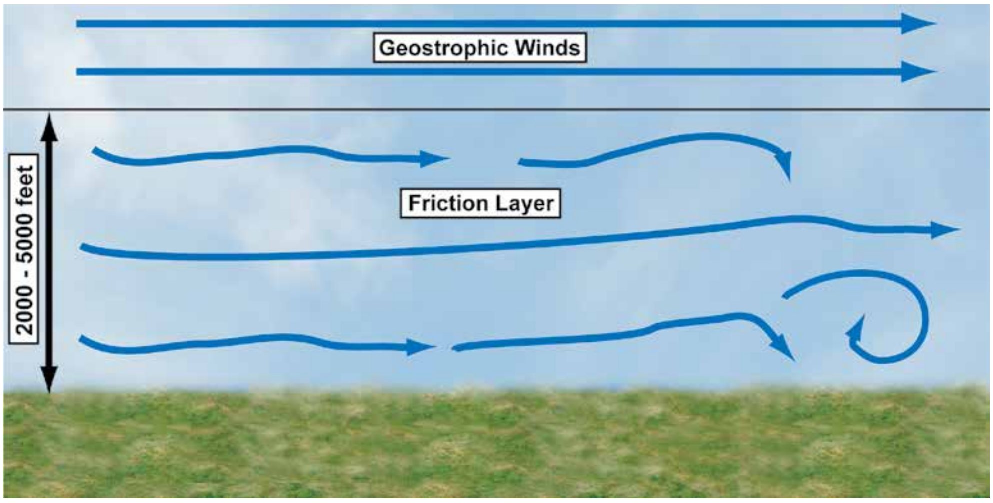

Figure 12.5 The geostrophic wind blows above the friction layer..

The Geostrophic wind blows in a constant direction, parallel to straight isobars. The geostrophic wind is subject to two forces. These forces are in balance and work opposite to each other.

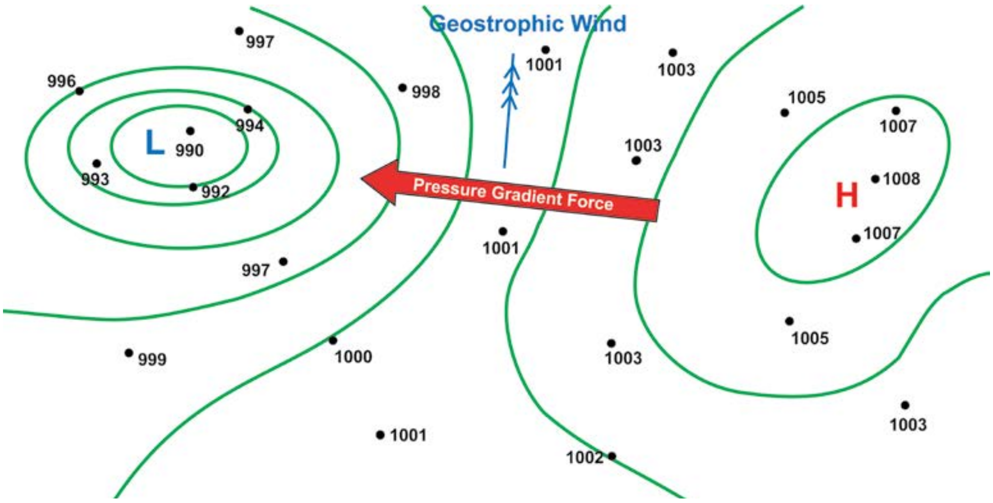

Figure 12.6 The Pressure Gradient Force. This force acts from high to low pressure and determines the wind strength. Isobar spacing tells us its strength.

The first force is the Pressure Gradient Force (PGF); this is the force that acts from high to low pressure. Closely spaced isobars tell us that the PGF is strong. This situation is common in low pressure systems. Widely spaced isobars tell us that the pressure gradient force is weak. This is common in most high pressure systems. It is the pressure gradient force that determines the strength of the wind.

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If the PGF is very large, then there will be a rapid movement of air and the resulting winds will be very strong. However, if the PGF is very weak, then the air will move slowly resulting in light winds. *Figure 12.6* shows high and low pressure patterns with the PGF indicated by the red arrow.

The force which balances the PGF is the Coriolis force (CF). Coriolis force arises from the rotation of the earth on its axis in space; it is at a maximum at the poles and is at zero at the equator. (This statement is sufficient for this level of knowledge; a detailed explanation including the mathematical formula is available on the Oxford Aviation Academy CD ROM, Aviation Meteorology at ATPL level)

Coriolis force deflects the wind to the right in the northern hemisphere. It is directly proportional to the wind speed and the latitude.

In the northern hemisphere the Coriolis force acts at 90 degrees to the wind direction, deflecting it to the right. This results in a wind diagram like the one shown in *Figure 12.7* The two forces are acting opposite to each other and in balance. The PGF pulling air to the left and the Coriolis force pulling to the right.

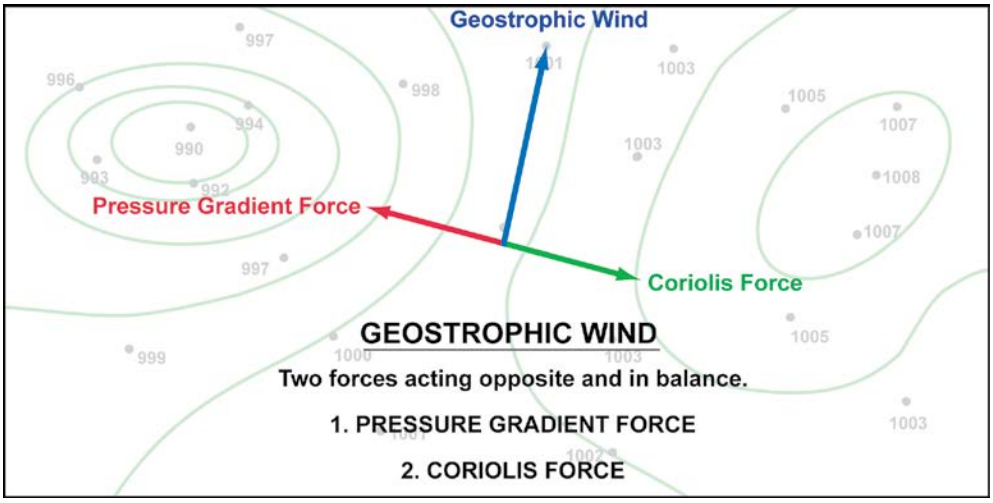

Figure 12.7 The balance of forces in the Geostrophic Wind with Pressure Gradient Force and Coriolis force perfectly opposing each other.

The geostrophic wind blows parallel to straight isobars but how does it get that way? Looking at the *Figure 12.8, overleaf,* it can be seen that the pressure gradient will cause the air to flow towards the low, but, as the air moves, the Coriolis force in the northern hemisphere deflects the air to the right, causing the wind to blow parallel to the isobars.

The Coriolis force is directly proportional to the wind speed and so as the pressure gradient force accelerates the air from the area of high pressure towards the area of low pressure the Coriolis acting at right angles to the wind direction deflects it to the right in the northern hemisphere until the pressure gradient force and the Coriolis force are balancing each other as in *Figure 12.7*. and the wind is blowing along the isobars.

The development of this situation is shown in *Figure 12.8, overleaf*. To remember which way the wind is blowing around pressure systems use Buys-Ballot's law, which states that if an observer's back is to the wind in the northern hemisphere, the low pressure will be on the left.

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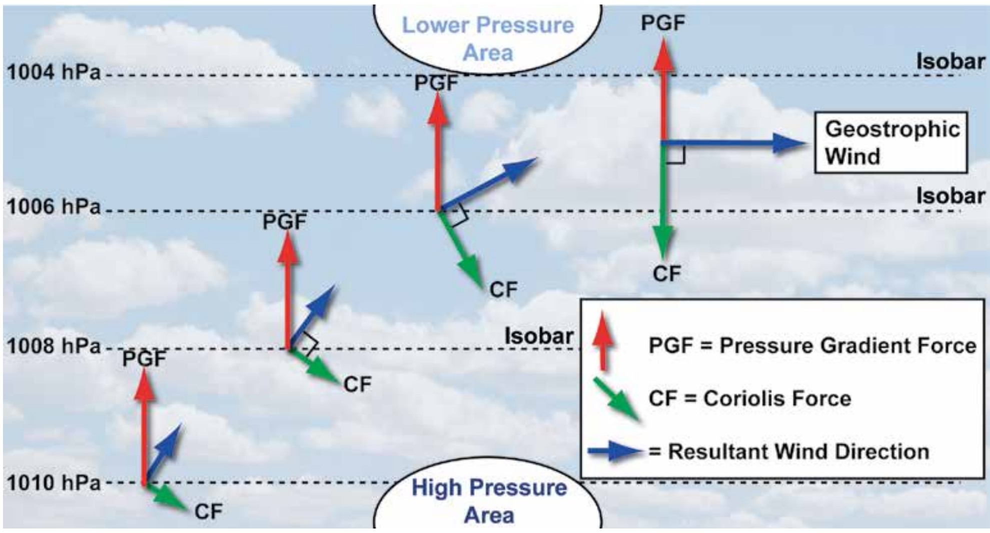

Figure 12.8 CF always acts at 90º to the wind direction, and increases with increasing wind speeds.

Buys-Ballot's law states that with observer's back to the wind in the northern hemisphere low pressure will be on the left.

To calculate the wind speed using a surface pressure chart, measure the spacing between two isobars and use that spacing on the geostrophic wind scale to read off the speed. When calculating the distance between the isobars ensure you note the approximate latitude so that you may use the part of the Geostrophic Wind Scale that corresponds to that latitude. Shown in *Figure 12.9* is an isobar spacing taken from 65°N that when used on the Geostrophic Wind Scale at 65°N gives a Geostrophic wind speed of 50 knots

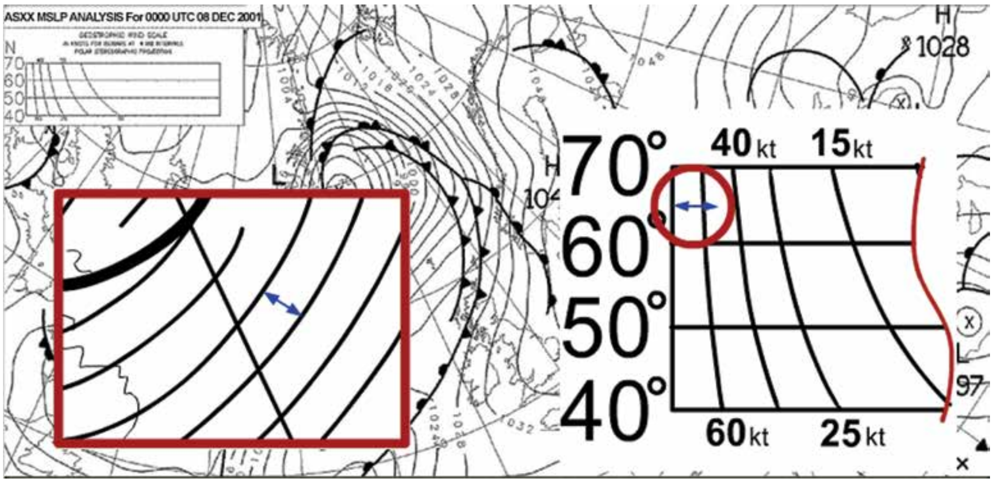

Figure 12.9 To calculate the speed of the geostrophic wind use the geostrophic wind scale, remembering to use the appropriate latitude.

The geostrophic wind blows above the friction layer, as shown in *Figure 12.5.* Friction is another force acting on the wind and because the geostrophic wind only has two forces, there can be no geostrophic wind within the friction layer.

The height of the friction level changes, depending on the time of day and the nature of the surface and so now the wind in the friction layer will be described; this is generally known as the surface wind.

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SURFACE WINDS.

The concept of the geostrophic wind is a useful benchmark in understanding other effects. In *Figure 12.7* the geostrophic wind in the northern hemisphere is the result of the two forces opposing each other and in balance, with the Coriolis force acting at 90 degrees to the right of the wind direction. The geostrophic wind is the blue line pointing straight up.

The speed and direction of the geostrophic wind are modified by the reduction of the wind speed by friction with the surface and as speed reduces, so does the Coriolis force. The forces are now not balanced; the pressure gradient is now the stronger force, and will cause the wind to be deflected as shown. This deflection is purely as a result of the friction. *Figure 12.10* shows how the forces and subsequent wind direction and speeds are changed as a result of surface interaction

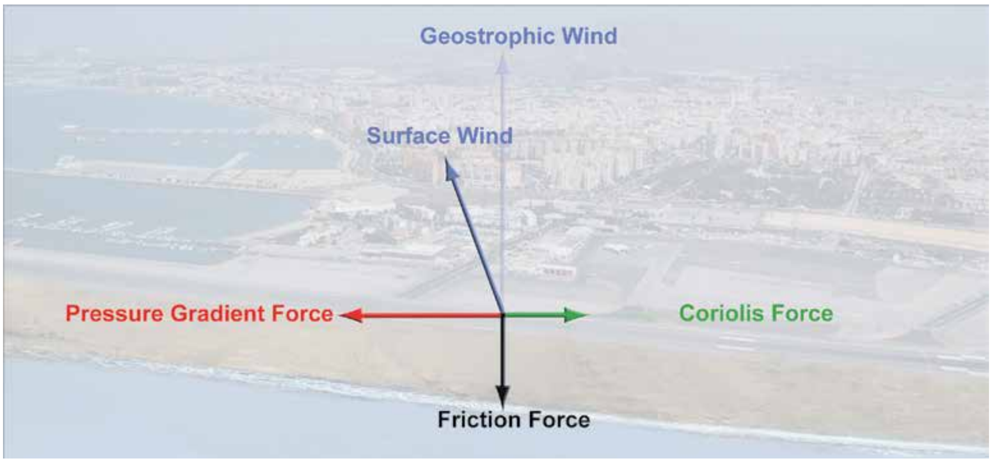

Figure 12.10 Friction will reduce wind speeds. This reduces Coriolis force. The surface wind is deflected towards the Pressure Gradient Force.

The greater the surface friction the more the surface wind is deflected from the geostrophic. You see from *Figure 12.11,* that over land the deflection is approximately 30° and the speed at the surface about half that of the geostrophic wind.

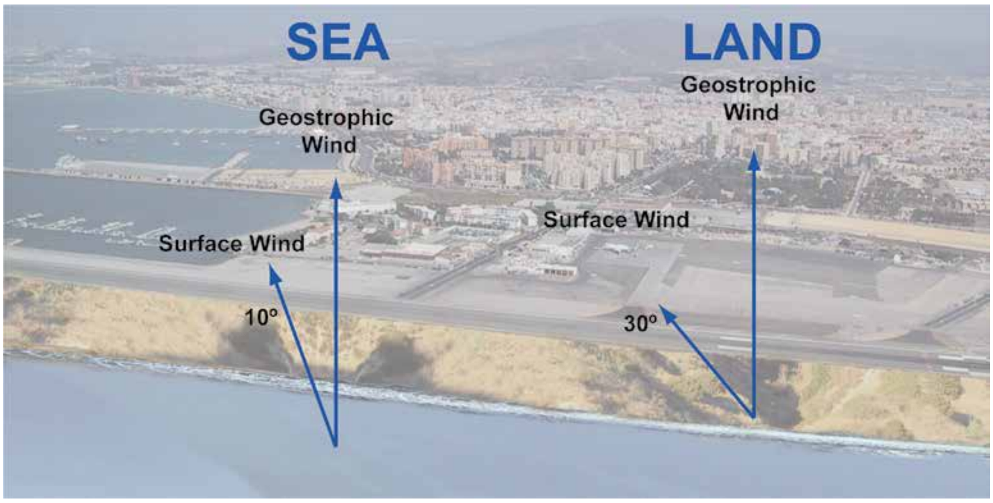

Figure 12.11 There is greater friction from the land than there is from the sea, and so the difference between the geostrophic wind and the surface wind is greater over the land.

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Over the sea, which is smoother, the deflection is only approximately 10° and the surface wind speed about two thirds of the geostrophic wind.

COMPARISON OF GEOSTROPHIC AND SURFACE WINDS.

Coriolis force is proportional the wind speed; the surface wind speed is reduced by friction and so, therefore, is the Coriolis force with the result that the surface wind is not deflected as much as the geostrophic wind. When an aircraft descends towards the surface the wind that it experiences is backed and decreased from the geostrophic wind; in a climb from the surface the wind will veer and increase.

Look at *Figure 12.11* and notice that the surface wind is backed and decreased with respect to the geostrophic wind. Therefore in a climb from the surface to the geostrophic wind level, the wind speed will increase and veer. This is a fundamental diagram to remember.

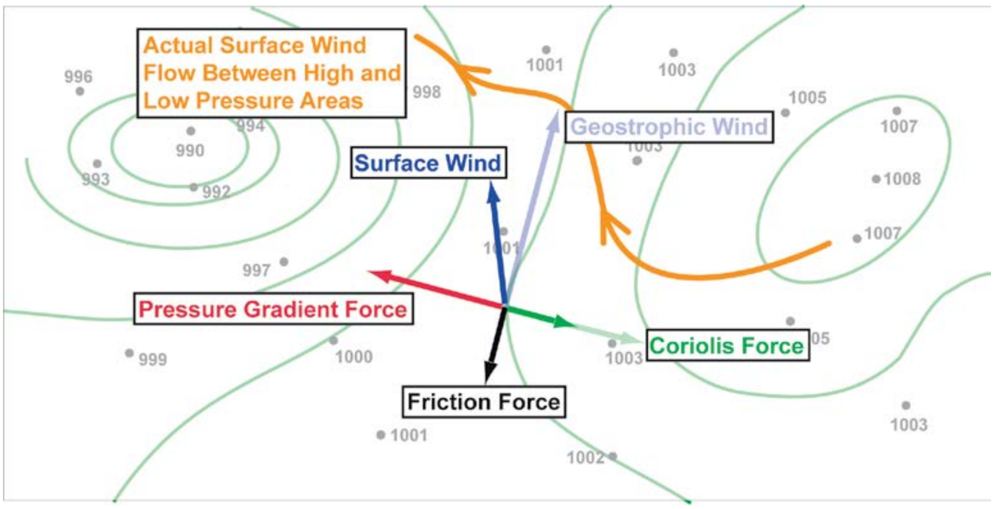

Figure 12.12 Surface wind in the northern hemisphere is reduced in speed and backed compared to geostrophic.

When using the diagram it is important to understand how the speed and direction of the wind varies from the surface to the friction level where the geostrophic wind is found.

Figure 12.12 is the surface pressure chart from *Figure 12.6* but it now has the diagrammatic representation of the modification of the geostrophic wind into the surface wind on it. The geostrophic wind is blowing parallel to the isobars but the surface wind is blowing slight across the isobars into the area of low pressure.

DIURNAL VARIATION.

The diurnal variation of temperature affects the process described above and so there is a diurnal variation in the surface wind velocity. Again, the geostrophic wind and its forces act as a benchmark to understand what is happening.

At approximately 1500 hours the surface wind speed will be at its highest. This is due to thermal mixing with higher level, faster winds. Therefore the surface wind will only be a little slower than the geostrophic, and the Coriolis force will only be slightly less than for the geostrophic wind.

But at 0600 hours, the surface wind is at its slowest because of the lack of any thermal mixing. Since the surface wind is so slow, the Coriolis force is significantly less than that experienced by the geostrophic wind and the surface wind at 0600 will be deflected by a greater amount from the geostrophic wind.

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Put simply the surface winds will move between these two extremes depending on the time of day. From 0600 onwards the surface wind will increase in strength and move towards the 1500 position. But after 1500 hours the wind will slowly decrease and move towards the 0600 position. *(See Figure 12.12a).*

As thermal mixing increases during the day the surface wind speed becomes closer to the geostrophic wind speed and so does the Coriolis force affecting it. As these both increase the surface wind will veer towards the direction of the geostrophic wind. As the thermal mixing decreases over night the surface wind speed is reduced by friction; this reduces its Coriolis force and the wind backs and decreases.

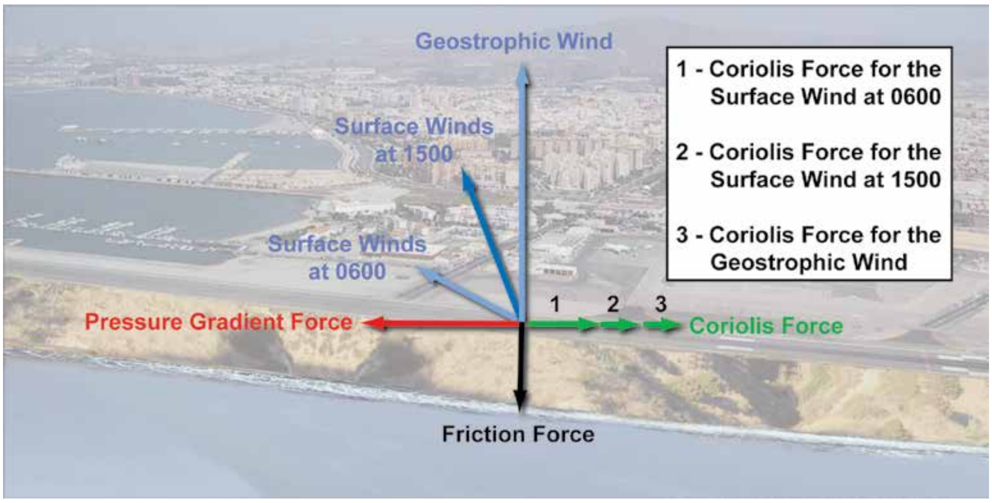

Figure 12.12a Diurnal Variation of the Surface Wind.

LOCAL WINDS.

The rest of this chapter deals with more localised winds. The first of these are land and sea breezes. Land and sea breezes are local winds that can be found along coastlines, particularly, but not exclusively, in the tropics. Land and sea breezes only occur when the general wind conditions are slack and there are no major pressure systems dominating the coastal regions.

Sea Breezes.

Figure 12.13 shows a cross section of the land and sea during the day. The land will heat up faster than the sea and will therefore be warmer. As a result there will be warmer, less dense air above the land surface than above the surface of the sea.

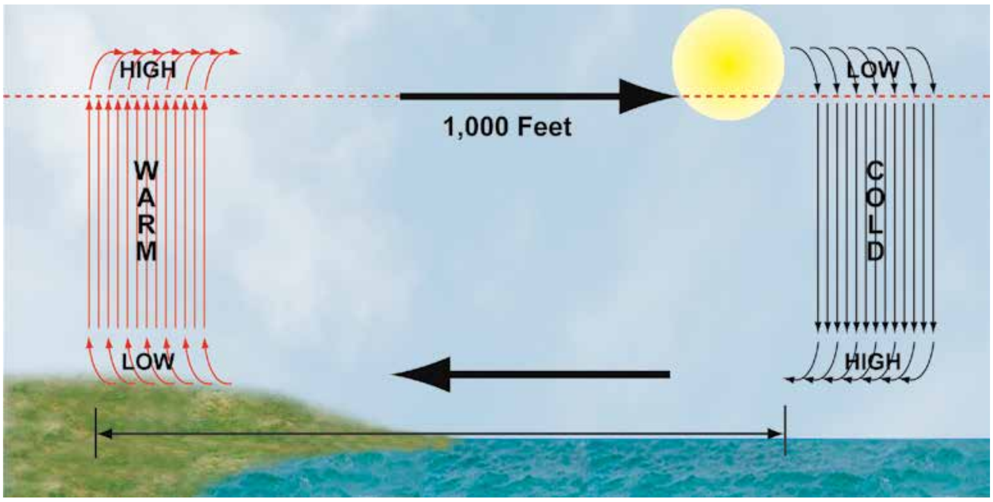

Figure 12.13 The Sea Breeze.

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This warm air over the land will start to rise and the cooler air over the sea will tend to sink. This will gradually set up a small scale cycle of air up to about 1 000 ft as shown. Notice that at the surface the wind will blow from the sea to the land, and hence be called a “sea breeze”. This wind will reach its maximum strength when the lands is hottest which will be at about 15:00 local time.

Land Breezes.

The process is reversed at night. *Figure 12.14* shows a cross section of the land and sea during the night.

During the day the land surface becomes warmer than the sea and the surface wind blows form sea to land, a sea breeze. At night the situation is reversed and the breeze blows from land to sea, a land breeze.

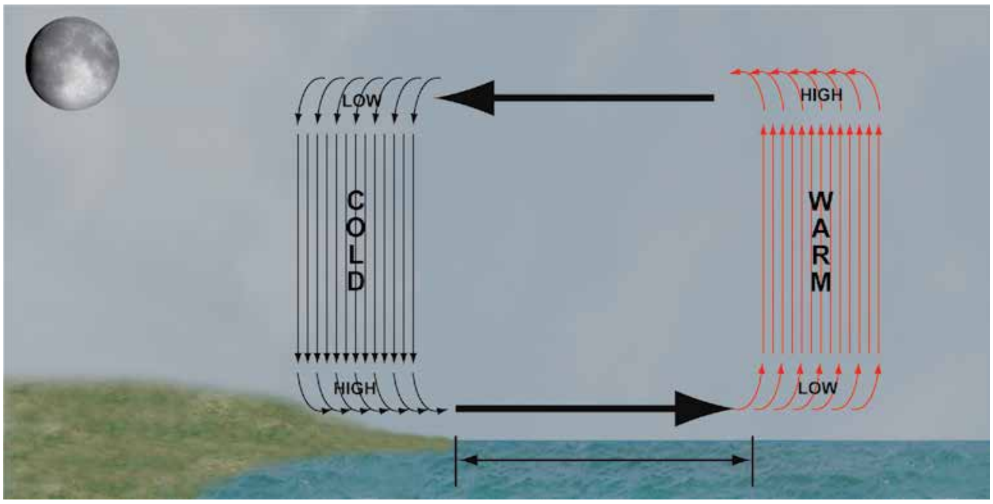

Figure 12.14 The Land Breeze.

The land will cool down faster than the sea. As a result there will be warmer, less dense air above the sea surface than above the land. This air will be heated and start to rise. This situation will cause a localised reduction in pressure and air will start to be drawn in from over the land towards the sea.

Figure 12.15 The sea breeze and the land breeze will produce a cross wind day and night at this coastal airfield.

The airflow from the land to the sea is known as a land breeze, and its strength will be maximum just after sunrise where we have the minimum land surface temperatures. Again this flow of air creates a circulation pattern up to approximately 1 000 ft.

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Land and sea breezes are particularly important to coastal airfields. Shown in *Figure 12.15* is an airfield near the sea with a runway parallel to the coastline. During the night and day, the sea and land breeze effect will always produce a wind across the runway, but remember that sea and land breezes will only develop when there is a weak pressure gradient, but are still subject to Coriolis force, and will, if persistent, end up blowing parallel to the coast.

Anabatic Winds.

There are another two other types of localised winds worth a mention. Again, these only occur when the general wind conditions are slack and there are no major pressure systems dominating the region. They are anabatic and katabatic winds. On the sloping terrain in *Figure 12.16*, during the day, the land will warm and in turn warm the air adjacent to the surface.

This air will be less dense and start to flow up the slope, to be replaced by cold air flowing in from elsewhere. These upward flowing winds are called Anabatic winds. Sometimes clouds on the top of the ridges are signs that anabatic winds are present. Always treat mountain ridges with extra caution regardless of the presence or lack of clouds.

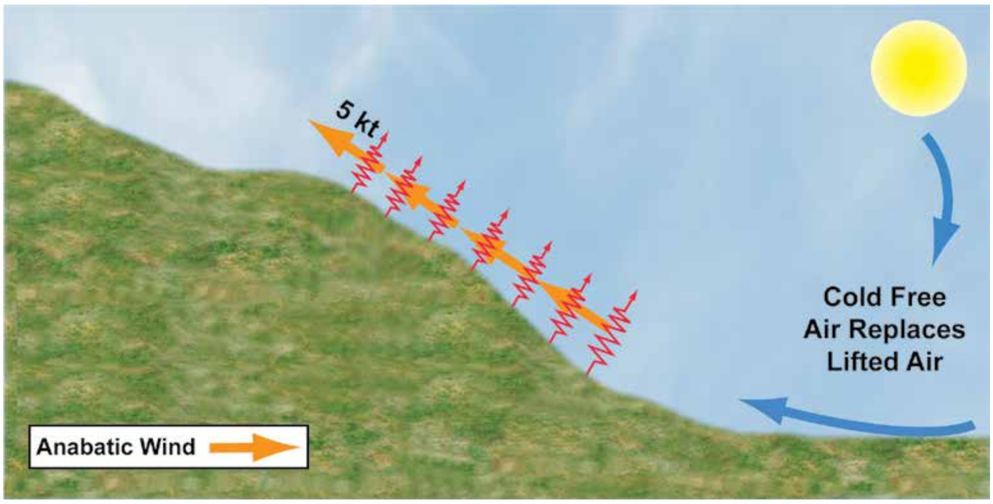

Figure 12.16 Anabatic Wind Formation

Katabatic Winds.

During the night the process is reversed. The surface of the slope will cool faster than the air in the valley and the air overlying it will become heavier and denser. As a result it will sink down the sloping terrain and collect in the valley bottom below. This wind is called a Katabatic wind as illustrated in *Figure 12.17*. Throughout the night, cold air will continue to collect in the valley. If the dew point is reached this can lead to the formation of valley fog.

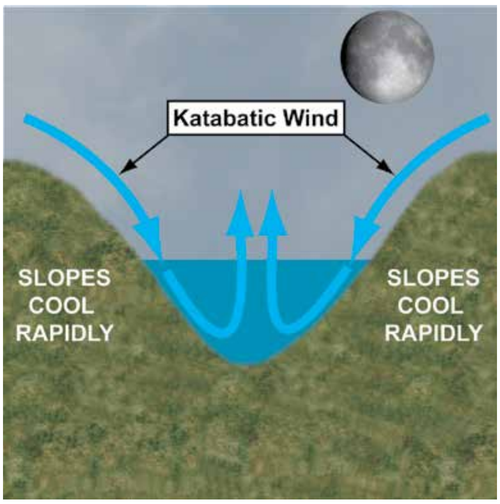

Figure 12.17 Katabatic Wind Formation

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The Föhn Effect.

A Föhn wind is caused when stable air flows over a mountain and descends on the other side. As air is forced over a mountain it will cool at the dry adiabatic lapse rate of 3ºC per 1 000 feet. If the dew point is reached then cloud will form. From then on, if forced ascent continues it cools at the Saturated adiabatic lapse rate of 1.5ºC per 1 000 feet. There may be precipitation produced on the windward slope which reduces the water content of the air mass. However, because the air is stable, it will flow back down the leeward side of the mountain and as it descends it will warm adiabatically. At first it warms at the saturated adiabatic lapse rate until the cloud disperses and then at the dry adiabatic lapse rate as it descends further.

Notice that the air on the leeward side is mostly warming at the DALR rate of 3°C per 1 000 ft. This creates some unique effects. If the air on the windward side cooled mainly at 1.5°C per 1 000 ft but when it descended on the leeward side it warmed at 3°C per 1 000 ft then the air at the base of the leeward side will have become much warmer than when it started on the windward side. *(See Figure 12.18).*

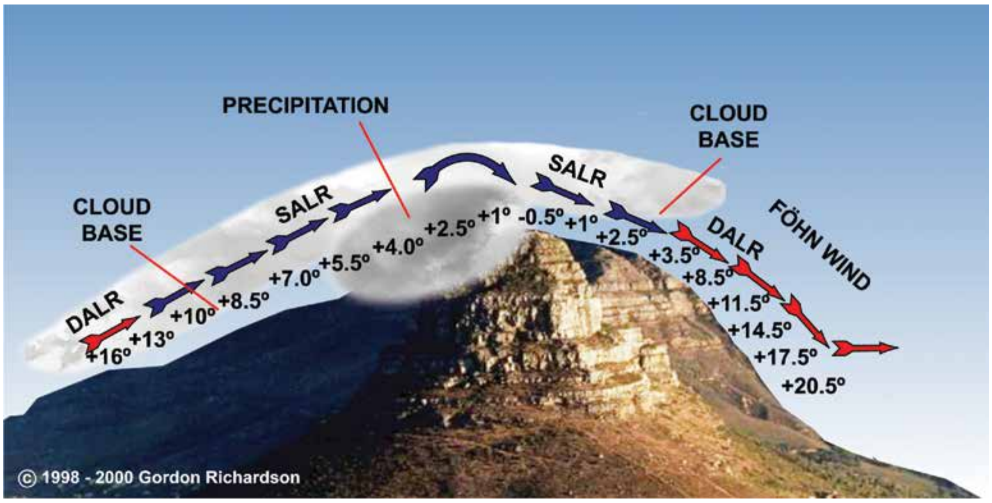

Figure 12.18 The Föhn Wind Effect.

The Föhn wind is a fairly common occurrence in the Southern Alps especially so in winter as the air from mainland Europe gets drawn up and over the mountains into the Mediterranean. These winds can cause major problems in certain areas of the world causing large scale rapidly moving forest fires and this is famously apparent in California around Los Angeles where this wind is called the “Santa Ana”.

This completes the chapter on low level winds. Surface winds are always best understood when comparing them to the geostrophic wind and so a good comprehension of how the geostrophic wind occurs and of the modifications it undergoes in the friction layer are essential. When examining a pressure chart to find the winds to help in flight planning, do not forget also to bear in mind the local effects of hills, valleys and sloping terrain. These may significantly alter the wind from what is suggested by the surface pressure charts.

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Representative PPL - type questions to test your theoretical knowledge of Low Level Winds.

1. At about mid-afternoon the surface wind at an aerodrome was reported as 220/25. using the rule of thumb, what might you expect the 2,000 ft wind to be?

    a. 205/50
    b. 205/15
    c. 245/50
    d. 235/12

2. Low level winds in the northern hemisphere that blow around a depression are drawn on surface weather charts in:

    a. A clockwise direction
    b. An anti-clockwise direction
    c. An anti-cyclonic direction
    d. Either clockwise or anti-clockwise depending on whether the depression is cyclonic or ant-cyclonic

3. How would the wind in the evening be described compared to the surface wind at 1600 local time?

    a. Veered and decreased
    b. Backed and increased
    c. Backed and decreased
    d. Veered and increased

4. Winds that blow round an anti-cyclone (high pressure system) at low levels in the northern hemisphere are represented on a low level chart as blowing in:

    a. A clockwise direction
    b. A clockwise direction if it is warm air and anti-clockwise if it is cold air
    c. An anti-clockwise direction
    d. A cyclonic direction

5. Select the statement that is most representative of land and sea breezes.

    a. The surface wind is likely to blow on-shore during the day
    b. The surface wind is likely to blow on-shore during the night
    c. By day the 1000 ft wind is likely to blow on-shore
    d. They can only be observed in strong pressure gradient forces

6. A pressure gradient causes air to move:

    a. Between the high pressure and the low pressure
    b. From a cyclonic region to an anti-cyclonic region
    c. From low pressure to high pressure
    d. From an anti-cyclonic region to a cyclonic region

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7. The wind over an aerodrome was reported as 330/15. Using the rule of thumb, what might you expect the surface wind to be.

   a. 305/30
   b. 355/30
   c. 315/30
   d. 307/7

8. The latest weather report for an aerodrome on the south coast indicates a sea breeze. If your ETA is mid-afternoon, on what runway might you expect an into wind landing?

   a. 09
   b. 35
   c. 18
   d. 27

9. Coriolis force in the northern hemisphere will cause moving air to be apparently deflected to:

   a. The left and cause the wind to blow parallel to the isobars at about 2 000 ft agl
   b. The right and cause the wind to blow parallel to the isobars at about 2 000 ft agl
   c. The left and cause the wind to blow slightly across the isobars at about 2,000 ft agl
   d. The right and cause the wind to blow slightly across the isobars at about 2 000 ft agl

10. Which of the following types of weather report or forecast give the wind direction with respect to true north.?

   a. TAF, ATIS, AIRMET
   b. METAR, ATIS, SIGMET
   c. TAF, METAR, VOLMET
   d. METAR, TAF, ATIS

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Answer										

The answers to these questions can be found at the end of this book.

CHAPTER 13
VISIBILITY AND FOG

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INTRODUCTION.

Pilots who do not possess an instrument qualification fly solely by visual reference to features outside the cockpit.

Visibility, then, is of the greatest importance to pilots who fly in accordance with the Visual Flight Rules (VFR). Visibility also has significant influence on the legality of landing and take-off.

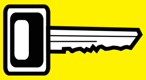
'Meteorological Visibility' is described as: the greatest horizontal distance at which a defined object can be recognised by an observer with normal eyesight, during daylight. At night, visibility is defined by the distance over which lights of a specified candlepower can be distinguished by the naked eye.

Visibility may also be expressed in terms of the degree of clarity or obscurity of the atmosphere.

MEASUREMENT OF VISIBILITY.

Visibility is measured in metres or kilometres. By day, surface visibility is measured by reference to suitable objects at known distances from the observation point. (*See Figure 13.1.*)

Visibility is a measure of atmospheric clarity or obscurity.



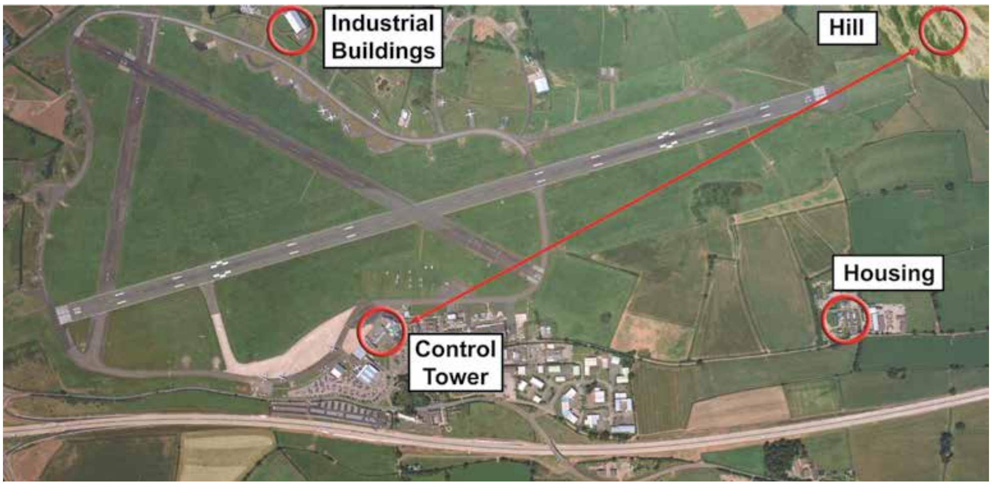


Figure 13.1 The surface visibility at an aerodrome is determined by the observation of features at known distances from an observation point.

At aerodromes, the observation point is normally in, or adjacent to, the Air Traffic Control tower.

In-flight visibility is defined as the forward visibility measured from the cockpit of an aircraft in flight. In-flight visibility is generally greater than surface visibility.

The general VFR minimum visibility below which VFR flight is prohibited, outside controlled airspace, is 3 kilometres. In the United Kingdom, under certain circumstances, VFR flight is allowed, outside controlled airspace, with an in-flight visibility of 1.5 kilometres. (See Volume 1, Air Law.)

In meteorological reports, visibility is not always given as being of the same value measured in all directions. At present, in the United Kingdom, the concept of prevailing visibility has been adopted by the Met Office for aerodrome weather reports. Prevailing visibility is dealt with in Chapter 16.

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Visibility can be measured accurately, using instruments such as the Gold Visibility Meter, the Visiometer and the Transmissometer. (*See Figure 13.2.*)

Figure 13.2 Gold Visibility Meter, Visiometer, Transmissometer.

OBSCURATIONS.

Atmospheric phenomena which degrade visibility are referred to as obscurations. There are two principal types of obscuration in the atmosphere.

The first type of obscuration is caused by the presence of water droplets; these can either be suspended in the form of cloud, mist or fog, or be falling as precipitation, for example, as snow, rain or drizzle.

Smog is a combination of fog and smoke obscuration.

Solid particles such as dust, smoke or sand, constitute the second type of obscuration.

Visibility may also be obscured by a combination of solid matter and water droplets. This type of obscuration is referred to as smog.

Figure 13.3.

Fog: obscuration through water droplets suspended in the atmosphere. *Dust obscuration.*

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STABLE ATMOSPHERIC CONDITIONS AND INVERSIONS.

As you learnt earlier, a stable atmosphere inhibits the vertical movement of air, usually because of the presence of a temperature inversion. In a stable atmosphere, solid particles, generated by industrial and agricultural activities, will be trapped close to the Earth's surface, reducing visibility.

Inversions are a feature of anticyclonic conditions. Inversions may often result in haze which can reduce visibility considerably.

Layers of particle-laden air are frequently seen when flying, and a clear boundary is sometimes visible at the ceiling of such obscuration. Poor visibility of this type is common in the vicinity of cities, especially in anticyclonic conditions.

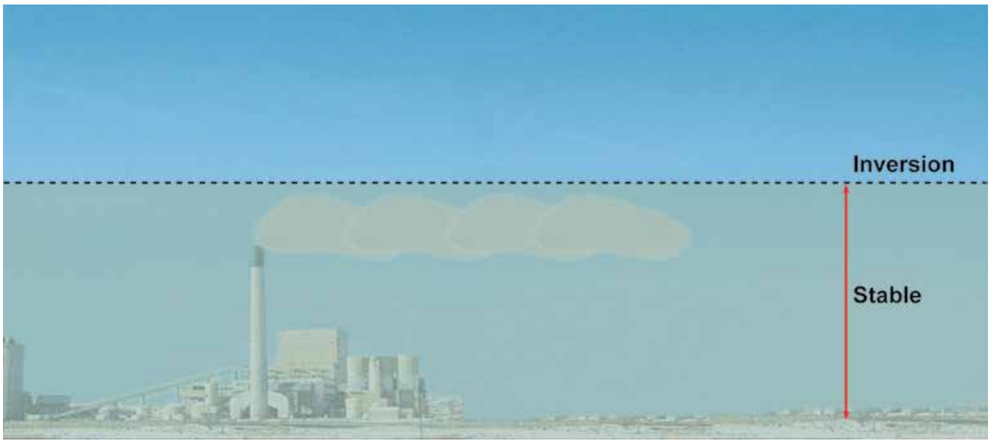

Figure 13.4 Anticyclonic conditions make for a stable atmosphere which restricts the vertical movement of air, trapping solid particles in the lower layers of the atmosphere, thus reducing visibility.

FOG, MIST AND HAZE.

Fog is defined as a visibility of less than 1 000 m, with a relative humidity of 100%. If the visibility is between 1 000 m to 5 000 m (although this upper limit does vary occasionally), and provided that the relative humidity is 95% or more, atmospheric obscuration is referred to as mist.

Fog is present when visibility is less than 1 000 metres, and relative humidity is 100%.

Descriptor	Lower Limit of visibility (metres)	Upper Limit of visibility (metres)	Relative Humidity
HAZE or SMOKE	1000	5000	Less than 95%
MIST	1000	5000	95% or more
FOG	Zero	<1000	100%

Figure 13.5 Table defining the various types of obscuration, by visibility and humidity content of the air.

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Haze or smoke is reported when visibility is below 5 000 m, and when the humidity is not high enough for the obscuration to be classified as mist or fog. Haze or smoke is caused by solid particles. In haze, humidity will be less than 95%, and is frequently in the order of 50-60%.

PRECIPITATION.

All precipitation reduces visibility, but some types of precipitation cause a greater reduction of visibility than others.

Snow showers, can reduce the visibility very swiftly, to as low as 50 m. Drifting snow can reduce visibility to zero.

Figure 13.6 Snow can rapidly reduce the visibility to as low as 50 metres in heavy showers.

In rain, visibility is reduced by varying extents, depending upon the intensity of the rain. Visibility as low as 1 000 m or less can occur in heavy rain.

The table in *Figure 13.7* summarises the effect on visibility of various intensities of rain.

FORM AND INTENSITY OF PRECIPITATION	TYPICAL VISIBILITY
Heavy rain	1000 m or less
Moderate to heavy drizzle	Between 500 m and 3000 m
Moderate rain	Between 3000 m and 10 km

Figure 13.7 The intensity and types of rain, and their effects on visibility.

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FOG.

There are five main types of fog:

- **Radiation fog**.
- **Hill fog**.
- **Advection fog**.
- **Frontal fog**.
- **Arctic Smoke** or **steam fog**.

Radiation Fog.

Radiation fog is caused by loss of heat from the Earth's surface at night. Air in contact with the ground is cooled by conduction. If cooled to below its dew point, the water vapour in the air will condense into water droplets, and fog will form.

There are three conditions which must prevail, in order for the land to cool by the amount required for the dew point to be reached, and radiation fog to form.

- Firstly, the sky must be clear because clouds "trap" heat near the Earth's surface.
- Secondly, there must be sufficient moisture in the air, so that cooling will result in saturation of the air overlying the cold surface. Therefore, the relative humidity of the air needs to be high.
- Thirdly, there must be a light wind of around 2-8 knots. If there is no wind, no condensation nuclei will be suspended in the air, and a dew will form on the ground instead.

Figure 13.8 Radiation Fog.

The above conditions are usually present in the atmosphere in anticyclonic conditions, especially in autumn and winter, around sunrise and sunset. When these conditions exist, radiation fog will form.

If the wind is stronger than 2-8 knots, however, mixing of the cool surface air with warmer air from levels higher up will occur, and radiation fog will not form.

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Radiation fog will clear when the sun warms the Earth's surface by insolation, and the air above the surface is then warmed by conduction which leads to convection, thus mixing the colder surface air with warmer upper air. If the wind speed increases the fog will initially lift into low stratus.

Given the three conditions mentioned on the previous page, radiation fog is most common just after dawn: the time of the day when surface temperatures are at their lowest. As the Sun rises in the sky and solar radiation increases, however, the heating of the Earth's surface will lead to the thinning and eventual dispersal of radiation fog through evaporation.

Furthermore, as the Sun warms the surface, convection becomes established in the lower layers of air, mixing the air near the surface with the warmer upper air, and dispersing the fog.

Radiation fog will be cleared, mainly from below, but also from the fog top and around the edges. Increasing wind will cause mixing and warming of the lower layers, lifting the fog into low stratus cloud.

Hill Fog.

Hill fog forms when moist, stable air is forced to rise over high ground. The moist air will then cool and condense to create low cloud, which shrouds the high ground. This type of cloud is called orographic cloud. (From Greek oros, meaning mountain.) Orographic cloud can be localised, or extensive, and poses a major hazard to low flying aircraft. For hill walkers, orographic cloud is hill fog. Visibility in hill fog will usually be less than 200 m. The mechanism leading to the formation of orographic cloud, illustrated in *Figure 13.9*, has already been described in Chapter 12, in the section on the Föhn Effect.

Hill fog is the same phenomenon as orographic cloud.

Figure 13.9 Hill fog forms when low cloud covers high ground.

Advection Fog.

Advection fog forms when warm moist air flows over a colder surface, which may be sea or land, and can form rapidly by day or night.

Advection fog can form rapidly, by day or night, when warm, moist air moves across a cold surface. The temperature of the surface must be such that the air moving over it is cooled below its dew point. For this to happen, the wind speed must be around 15 knots, and the air must have a high relative humidity. The cold surface can be either land or sea. *(See Figure 13.10.)*

Advection fog is common around coastlines and is sometimes called sea fog. The most common example of advection fog in the United Kingdom is that formed over the Cornish Peninsula, when the land is cold and there is a moist, warm Tropical Maritime air mass blowing over it from the south west.

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Figure 13.10 Advection fog forms when warm moist air moves over a cold surface. Strong winds can lift advection fog to form stratus cloud.

Dispersal of advection fog usually occurs as a result of drier air moving into the area, or by an increase in wind speed, which has the effect of lifting the fog to form low stratus cloud.

Frontal Fog.

Frontal fog forms just ahead of some warm, and occluded frontal systems (see Chapter 15, Air Masses and Fronts). Heavy precipitation from the warm air into the colder air, causes the colder air to reach saturation point and form fog, as shown in *Figure 13.11*. The belt of frontal fog can extend as much as 200 miles ahead of the front itself. The fog will clear once the front has passed.

Figure 13.11 Frontal fog: Fog occasionally forms ahead of fronts when the air ahead of the front becomes saturated. The fog will clear when the front passes.

Arctic Smoke.

Arctic Smoke, or steam fog, is rare in the United Kingdom. Steam fog is created in a situation which is the reverse of that which creates advection fog. For steam fog to form, very stable, cold air moves from the land over a relatively warm, moist surface, (such as the sea, inland stretches of water or bogland). This action may cause a small amount of water vapour above the moist surface to condense, forming a shallow layer of fog.

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In the United Kingdom, steam fog and arctic smoke can occasionally be seen over lakes, rivers and streams during the winter months, generally in Scotland.

Figure 13.12 Steam fog, or Arctic Smoke.

RUNWAY VISUAL RANGE.

Runway Visual Range (RVR) reports are aimed at providing pilots with accurate visibility readings along the length of a runway.

RVR reports can be found in Meteorological Aerodrome Reports (METARs), and SPECIs (special observations to indicate a significant improvement or deterioration in weather conditions), or can be passed by Air Traffic Control to the pilot. RVR measurements are taken from an observation point along the runway itself, and so are representative of what the pilot will see on approach to the runway. RVR reports are, however, reported only when either the horizontal visibility, or the RVR itself, is less than 1 500 metres.

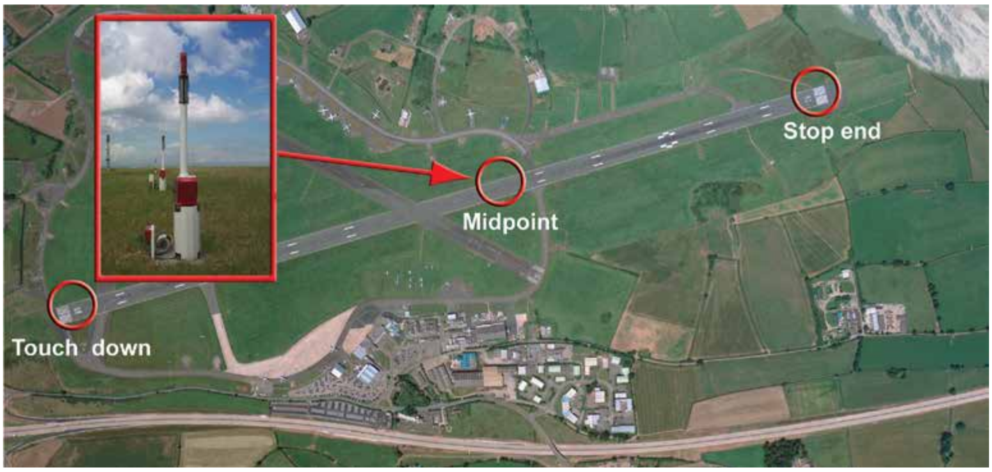

Figure 13.13 RVR (Runway Visual Range) is a reading of visibility along a runway, and is usually measured using a transmissometer.

RVR readings are taken every 15 or 30 minutes, depending on the amount of air traffic at an aerodrome. The instruments used to measure RVR are called transmissometers. *(See Figure 13.13.)* There are usually three transmissometers placed alongside the

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runway: one at each end, and a third at the mid-point. The readings given by the transmissometers are called Instrumented Runway Visual Range readings.

If there are three transmissometer readings available for a runway, readings will generally be reported as touch-down, mid-point or stop-end readings. If there is only one figure available for a runway, it should be assumed to be the touch-down reading.

A typical RVR reading would be given as: R24L / 1100. The prefix "R" is the identifier for RVR information. The next figure is the runway designator; in this example, Runway 24, left. The value "1100" is the touch down zone RVR visibility, in metres. As there is only one RVR value given, the value will apply to the RVR at touch-down.

RVR values of less than 50 metres are reported as M0050. An RVR greater than 1 500 metres is reported as P1500. There may also be a 10 minute trend included in the RVR report. "U" means that the visibility has increased over the last 10 minutes, "D" means that it has decreased, and "N" means that there has been no change in visibility. The letter "V" is included if there are great variations in the measured RVR. In the example: R24L / 450V600, the RVR has varied between 450 metres and 600 metres during the 10 minutes preceding the observation.

OBLIQUE VISIBILITY.

Oblique, or slant, visibility is the distance a pilot can see along the ground when flying at a given height. When flying within a haze layer, visibility will be restricted, especially when heading into sun. The area of restricted visibility is depicted by a so-called visibility hemisphere in front of the aircraft, as depicted in *Figure 13.14*. At the height shown at **Position 1**, it is not possible for the pilot to see the ground, therefore oblique visibility is said to be zero. However, if the aircraft descends to a height depicted by **Position 2**, the pilot would be able to see the ground, but the slant visibility would still not be good. On descending further, to **Position 3**, the pilot would be able to see more of the ground ahead of him.

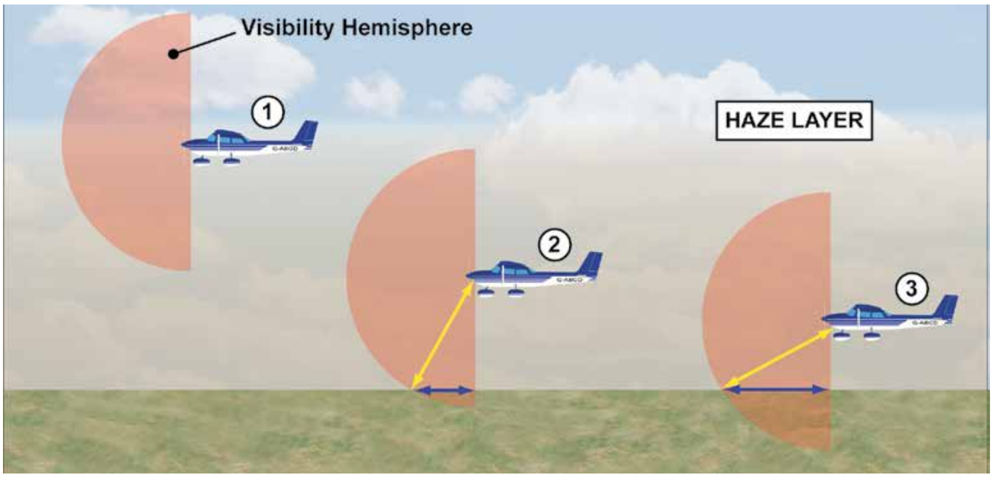

Figure 13.14 Oblique, or slant, visibility, in haze can vary with height.

So, if a pilot is operating within a haze layer, descending should improve oblique visibility.

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Vertical visibility looking down through shallow fog may be good but the slant visibility may not be good enough for a safe approach and landing, if the aircraft descends into the fog.

If there is a shallow fog layer covering an aerodrome, as depicted in *Figure 13.15,* a pilot, looking straight down from an aircraft overhead, may be able to see the surface quite well, and might conclude that the visibility is reasonable. However, lower down, on final approach to land, when the aircraft is within the fog layer, itself, the slant visibility will be much reduced, as the pilot will now be looking through a greater thickness of fog.

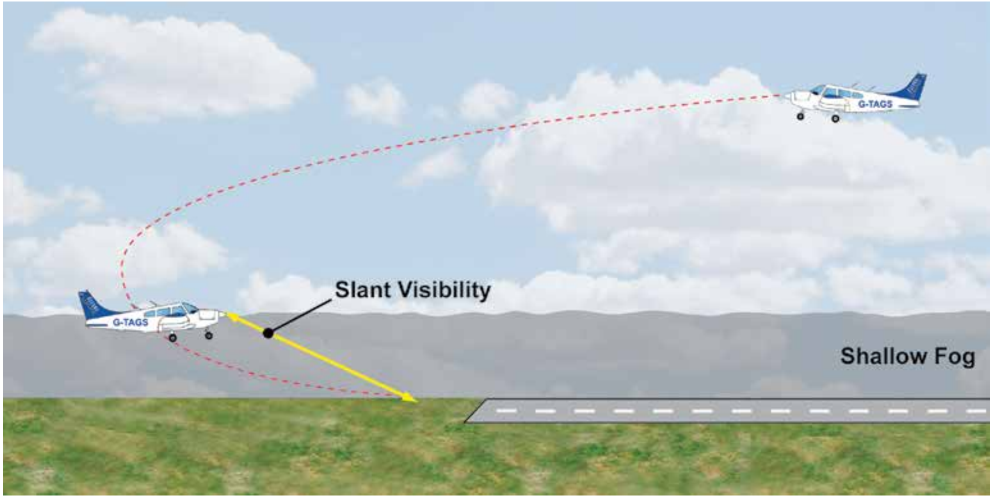

Figure 13.15 When looking straight down, over a layer of fog, the surface may be visible through the fog; but on the final approach, if the aircraft descends into the fog layer, the slant visibility may not be sufficient to carry out a safe landing.

A visual illusion that the aircraft has pitched nose-up may occur on descending into shallow fog, from air where the visibility is good. This is a potentially dangerous situation, which may lead to confusion and disorientation, and is one of the main reasons that the system for determining RVR was devised.

Sixty percent of all weather-related air accidents and fatalities occur in conditions of impaired visibility.

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Representative PPL - type questions to test your theoretical knowledge of Visibility.

1. A type of fog commonly found around coastlines, that develops rapidly both by day or night is typically:

   a. advection fog
   b. radiation fog
   c. frontal fog
   d. dense fog

2. Advection fog is often caused by:

   a. a cold moist air mass under the influence of a moderate wind being warmed to below its dew point by flowing over a much warmer surface
   b. a warm moist air mass under the influence of a moderate wind being cooled to below its dew point by flowing over a much colder surface
   c. High relative humidity, moderate wind and a cloudy sky
   d. a warm moist air mass under the influence of a very strong wind on a clear cloudless night

3. Which of the following conditions is most favourable to the formation of radiation fog?

   a. High relative humidity, moderate wind and a cloudy sky
   b. High relative humidity, light winds and a clear sky, just after sunrise, in autumn
   c. Low relative humidity, light winds and a clear sky, just after sunrise, in summer
   d. High relative humidity, light winds and a cloudy sky

4. Over an inland airfield, radiation fog is reported in the morning. As the wind speed increases to 10 knots, what would you expect?

   a. The fog to thicken
   b. The fog to dissipate
   c. The fog to lift and form low stratus
   d. An increase in mixing, allowing more fog to develop

5. In the vicinity of industrial areas, smoke is most likely to affect surface visibility when:

   a. the surface wind is strong and gusty
   b. cumulus clouds have developed in the afternoon
   c. there is deep low pressure system over the area
   d. there is a low level inversion

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6. In unstable air, surface visibility is most likely to be restricted by:

   a. haze
   b. drizzle
   c. showers of rain or snow
   d. low stratus

7. Frontal fog is most likely to occur:

   a. in summer in the early morning
   b. at the rear of a warm front
   c. in winter in the early morning
   d. in advance of a warm front

Question	1	2	3	4	5	6	7
Answer							

The answers to these questions can be found at the end of the book.

CHAPTER 14
ICING

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INTRODUCTION.

Figure 14.1 Aircraft icing, particularly on the airframe, poses a major hazard to aircraft safety.

This chapter on icing deals with the causes of airframe and engine icing, and the dangers that such icing poses to aircraft operations. You will also learn from this chapter how to recognize icing conditions within the atmosphere, and how to avoid them.

THE CAUSES OF AIRFRAME ICING.

Aircraft icing occurs because of the presence of supercooled water droplets inside clouds. Supercooled water droplets exist either as large or small droplets, or a combination of both. The form that they take is determined by the outside air temperature, and the type of cloud in which they are found. The term supercooled water droplets describes water which is still in a liquid state, even though the temperature of the droplets is below 0°C.

The term super-cooled water droplets describes water which remains in a liquid state below 0ºC.

Supercooled water droplets can exist only when there are no freezing nuclei for the droplets to freeze onto. When freezing nuclei are present, in the form of dust or other impurities, the water droplets will freeze around them, and form ice.

Supercooled water droplets can exist in the atmosphere at temperatures as low as -40°C. But when they encounter a surface onto which they can freeze - such as the skin of an aircraft - supercooled water droplets will turn to ice. The leading edge of an aircraft's wing is particularly prone to collecting ice formed in this way.

TYPES OF AIRFRAME ICING.

The type of airframe icing basically depends on the size of the droplets present within the cloud. As a droplet hits the airframe, 1/40th of it will freeze instantly for every degree below freezing, latent heat being released as it freezes.

Rime Icing.

Small supercooled water droplets exist in cloud at temperatures between -15°C to -40°C. As a droplet hits the airframe, 1/40th of it will freeze instantly for every degree

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below freezing, latent heat being released as it freezes. Since the droplets are so small, the moment they come into contact with the leading edges of an aircraft, they will freeze almost instantly. This type of icing is known as Rime Ice.

Rime ice forms from small super-cooled droplets, in a temperature range of -15ºC to -40ºC. Water droplets freeze almost completely and instantly on impact, trapping air, which gives the ice a granular and opaque appearance.

Rime ice is characterised by its colour and texture, and also by the way it builds up on the leading edge of the wing. Rime ice is opaque or milky in appearance, because of the presence of air trapped inside the ice as a result of the rapid freezing process. Rime ice has a rough, sandpaper-like texture, created by the immediate freezing of the water droplets on contact with the aircraft, and their subsequent accumulation which leads to a granular growth of the ice. Rime ice looks and feels very much like the ice that grows on the inside of domestic freezers. *(See Figure 14.2.)*

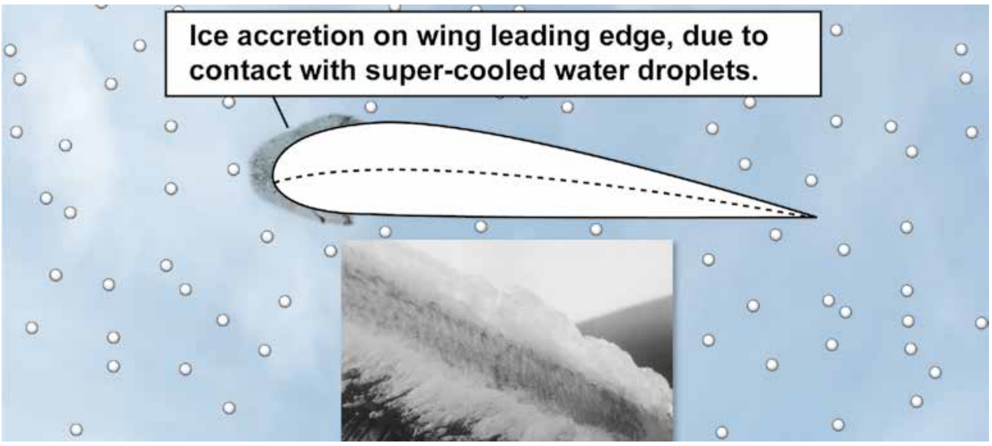

Figure 14.2 Rime Ice is caused by supercooled water droplets freezing instantly.

Clear Icing.

Clear ice is formed from large, super-cooled water droplets, in a temperature range from 0ºC to -15ºC. These droplets do not completely freeze on impact, but flow back over the aerofoil, freezing gradually, and creating a layer of clear, air-free ice which is heavy and adhesive.

Large supercooled water droplets are found in cloud, at temperatures between 0°C and -15°C. These larger droplets freeze in a different way from the small droplets which cause rime ice.

When a large water droplet first strikes the leading edges of an aircraft, only that part of the droplet touching the aircraft will freeze instantly. The remainder of the droplet then flows backwards, in the direction of the airflow, freezing as it comes into contact with the aircraft's skin. This type of build-up produces a type of icing called clear or glazed ice. Clear ice has an appearance similar to glass, and is mostly transparent, making it difficult to detect on initial observation.

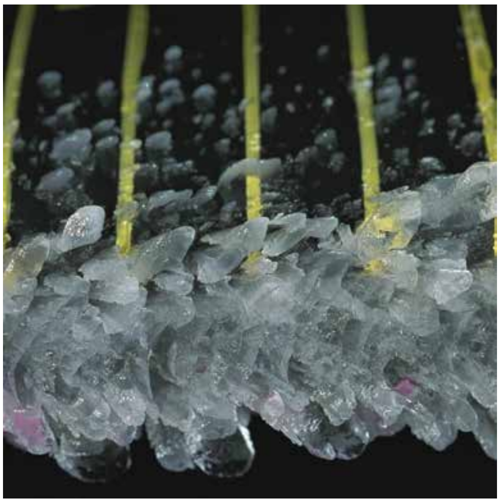

Figure 14.3 Clear Ice.

Clear ice has a transparent glass-like appearance because little air is trapped inside; the freezing process is slow enough to allow any air within the droplet to escape. Clear ice can be very dangerous; it can rapidly accumulate on the wings, and is more difficult to remove than rime ice.

The type of ice that forms on an aircraft will thus depend on the outside air temperature, which largely determines the size of the water droplets.

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Freezing Rain.

Rain ice or freezing rain, is particularly hazardous to aircraft operations. In order for freezing rain to develop, warm air must overlie very cold air, whose temperature is below 0ºC. These conditions are usually possible only on a warm front, such as the one depicted in *Figure 14.4*, or at an occluded front. (See Chapter 15, Air Masses and Fronts.)

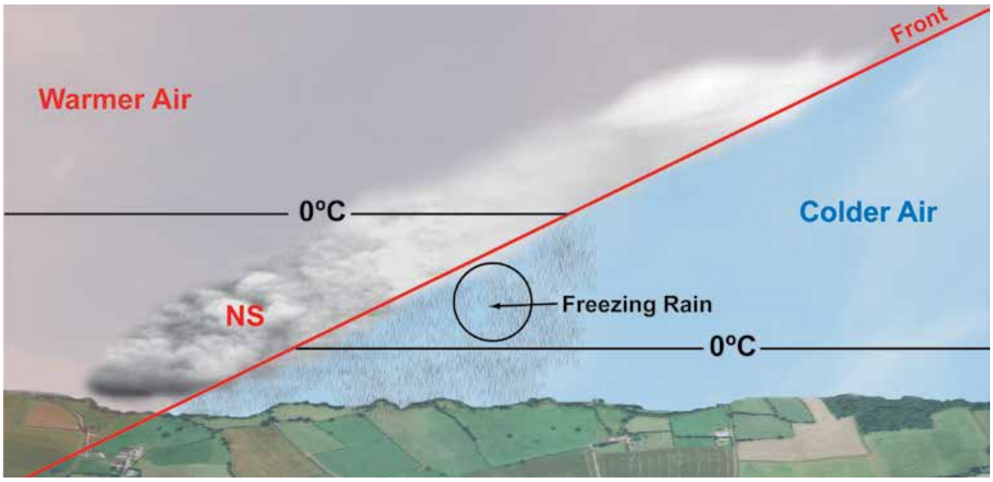

Figure 14.4 Freezing Rain is rain which has become supercooled. Freezing rain is found beneath warm fronts and warm occlusions.

Freezing rain occurs when precipitation falls from warm air into colder air at sub-zero temperatures. Generally, the only conditions that will produce this situation are those associated with a warm or occluded front, where the warm sector air has been lifted over cold air.

Cloud and rain develop inside the warm air, as it rises up and along the warm front. Some of the rain falls into the cold air, which is below 0ºC, causing the raindrops to become supercooled. If an aircraft with a 'cold-soaked' airframe were to be flying in rain consisting of supercooled raindrops, the rate of accumulation of ice would be so severe that, within a very short time, the aircraft would probably be unable to sustain flight.

Pilots must, therefore, be cautious when flying through warm fronts or occlusions, especially if the air ahead of the front is very cold. If freezing rain is encountered, the pilot should fly away from the area of rain immediately.

Hoar Frost.

Hoar Frost is a type of icing that can develop outside cloud. Hoar frost is a crystalline type of frost, identical to that which may form on car windscreens on frosty nights.

Hoar frost can develop on an aircraft in flight or on the ground.

On the ground, during clear nights, when the surface temperature falls below zero, water vapour in contact with the aircraft, can turn directly to ice through sublimation, creating hoar frost in the form of ice crystals *(Figure 14.5)*. Prior to flight, hoar frost *must* be removed, because it will disrupt the airflow over the wings.

Figure 14.5 Hoar frost on an aircraft's wing.

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In flight, hoar frost can form on an aircraft in clear air, if the aircraft climbs rapidly through a temperature inversion. If the air temperature is below 0ºC, the skin of an aircraft, flying low, will also be below 0ºC. Therefore, if the aircraft climbs and enters warmer air, the air coming into contact with its skin will cool rapidly, and sublimation may occur to create the hoar frost , but it is likely to be of short duration if the aircraft stays in the warm air..

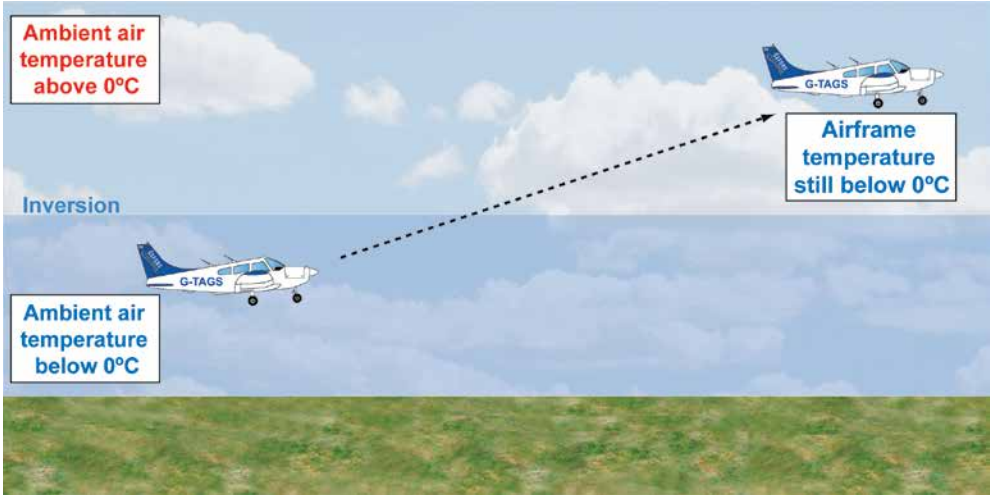

Figure 14.6 Hoar frost may form on an aircraft which climbs from air at 0°C into warmer air.

Hoar frost is formed on aircraft surfaces in clear air, through ***sublimation****, either on the ground, or whilst airborne.*

Hoar frost forming on the canopy, during a rapid descent from very cold air to warmer air, can cause a serious problem for the pilot. The pilot should consider opening the direct vision panel.

Hoar frost can also form during a rapid descent from high altitude, where the air is below freezing, into warmer air, closer to the ground. If hoar frost forms, it is most likely to form under the fuel tanks, as the fuel will not warm up as rapidly as the rest of the airframe; it is not a significant hazard compared with other forms of icing.

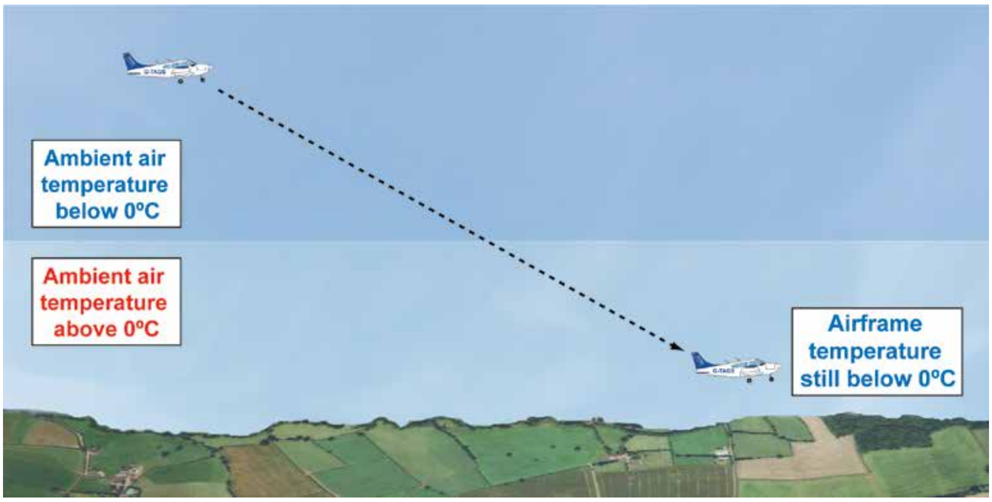

Figure 14.7 A rapid descent from air at sub-zero temperatures into air above 0°C will cause hoar frost to form.

CLOUDS AND ICING.

Air temperature and the type of cloud formation determine the size of super-cooled water droplets.

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Cumuliform Clouds.

Cumuliform-type clouds frequently have strong, vertical updraughts of air moving within them. Cumuliform cloud can, therefore, support significant numbers of large, supercooled water droplets. As a result, a pilot may expect moderate, or even severe clear ice within these clouds, especially if flying just above the freezing level. In cumulonimbus clouds, the updraughts are particular strong, and so the icing risk will be severe. Pilots should avoid all cloud which poses an icing risk.

Stratiform Clouds.

The icing risk from layered cloud is usually much lower than that from cumuliform clouds. Stratiform clouds lack the vertical development of cumiliform clouds, and, therefore, contain within them relatively weak updraughts. Even if the temperatures were low enough for the formation of large supercooled water droplets, stratiform cloud has little capability to support them. As a result, there will usually be only small droplets within stratiform cloud, and, therefore, only light, rime ice is likely to form on an aircraft flying in the cloud. Nimbostratus clouds are, however, the exception to this rule. Nimbostratus clouds may well contain the up-currents able to support large supercooled water droplets, making the icing risk moderate, or even severe, within this type of cloud.

Though stratiform clouds generally pose a lower icing risk than cumuliform clouds, there may still be a moderate to severe icing risk within nimbostratus cloud.

THE EFFECT OF AIRFRAME ICING.

At subsonic speeds air flows around an airframe and it starts ‘getting out of the way’ before the airframe arrives. The inertia in large droplets means that they don’t get out of the way in time. Similary, thin, or sharp protusions don’t give the air much warning and faster aeroplanes similarly so they pick up more ice. That’s why ice on propellers is more likely than ice on a thick 12% wing.

Figure 14.8 Airframe Icing formed on the ground.

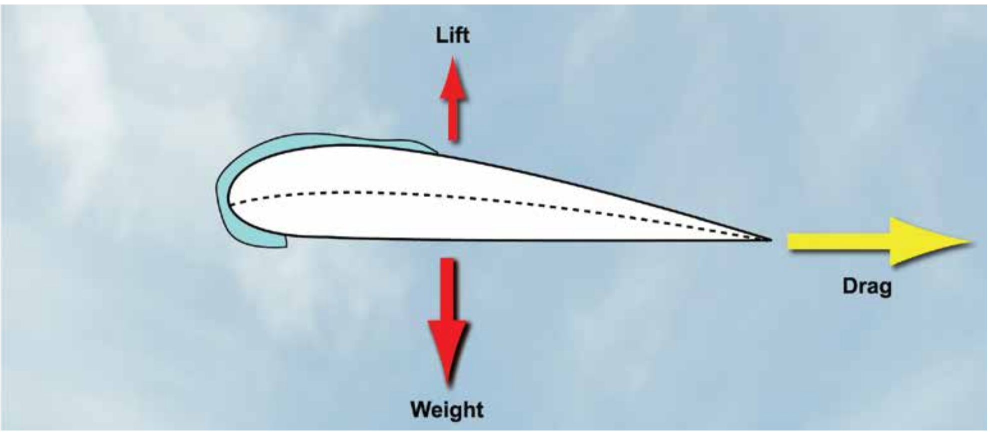

Figure 14.9 Ice on the wing will decrease lift while increasing weight and drag.

An aircraft’s wing is carefully designed to maximise lift and minimise drag. Ice

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Ice on an aircraft's wing will decrease lift while increasing weight and drag. This combination may have a disastrous effect on the aircraft's performance and handling.

accumulation will significantly alter the profile of the aerofoil, and, as a result, lift will be reduced. The greater the ice accumulation, the greater the loss of lift. Ice can also disrupt the flow of air over the airframe creating extra drag, especially in the form of parasite drag.

The accumulation of ice on an aircraft will also increase the aircraft's weight. To counteract the increased weight, lift must increase, but, as just stated, ice on the airframe will reduce lift. The combination of decreased lift and increased weight will increase the stalling speed of an aircraft, and reduces its stability.

Icing may also have an adverse effect on aircraft instruments. Ice can block vents and ports and, so, instruments which function on the basis of the pitot-static system may be particularly vulnerable to icing-induced error.

INDUCTION SYSTEM ICING.

Carburettor icing, may occur in conditions of high humidity, within the temperature range from -17ºC (0ºF) to +37ºC (98ºF). In temperate lands, such as United Kingdom, therefore, engine icing may be experienced at any time of the year.

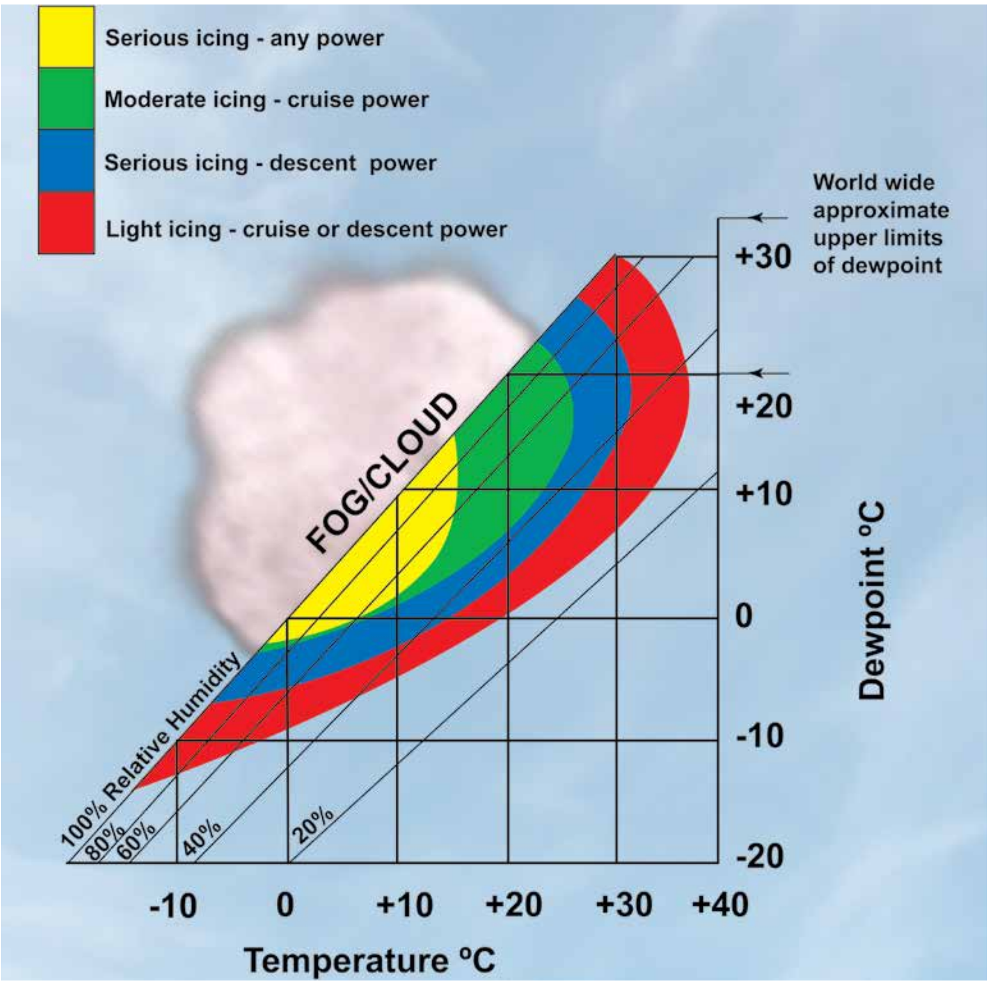

Figure 14.10 Graph for assessing the risk of carburettor icing by comparing temperature, relative humidity and dew point.

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Figure 14.10 illustrates graphically the conditions of temperature and humidity which can lead to engine icing. For instance, as can be read from the graph at *Figure 14.10*, when the Outside Air Temperature is +10°C, and the Relative Humidity is 50% or more, a pilot may expect serious carburettor icing at any power setting.

Pilots should be constantly aware of the possibility of induction-system icing, be able to recognise its symptoms, and be prepared to take action to prevent it. Unless action is taken immediately to remedy induction-system icing, it may can cause the engine to fail.

The three forms induction-system icing affecting piston engines fitted with carburettors are: Impact Icing, Refrigeration Icing (also known as Carburettor Icing), and Fuel Icing. Below, we examine how these types of icing may affect an aircraft.

Impact Ice.

Impact ice occurs when snow or supercooled water droplets either stick to, or freeze instantaneously as they come into contact with, the walls of the air intake, intake duct and air filter.

The ingress of snow or supercooled water droplets may eventually block the air intake and air filter completely, causing the engine to stop. *(See Figures 14.11 and 14.12.)* Any type of piston engine can suffer from this type of ice build-up.

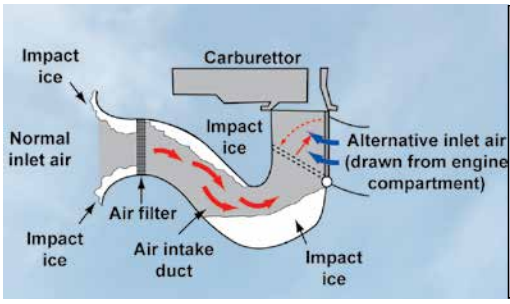

Figure 14.11 Impact ice in the intake duct.

Figure 14.12 Impact ice on engine air intake.

Refrigeration Icing or Carburettor Icing.

When the relative humidity is higher than 50%, and the temperature lies between -10ºC and +30ºC, another type of ice, called Refrigeration or Carburettor Ice, can build up within the induction system. Carburettor Ice forms in float-type carburettors as a result of the low temperatures caused by the fuel vaporising, and the low air pressure within the carburettor combined with the moisture in the air-fuel mixture. *(See Figure 14.13.)*

Carburettor icing is most likely to occur at lower power settings in warm, moist air.

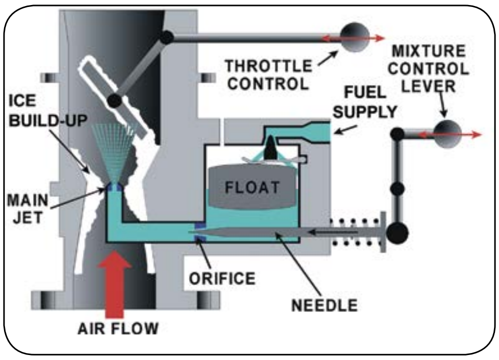

Figure 14.13 Refrigeration, or carburettor icing.

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Fuel Icing.

Fuel icing is caused by moisture in the fuel coming out of suspension, and being frozen by the low temperatures in the carburettor. This ice tends to accumulate on the inside bends of the inlet manifold, as shown in *Figure 14.14*. Ice accumulation of this nature reduces the flow of the air-fuel mixture into the engine.

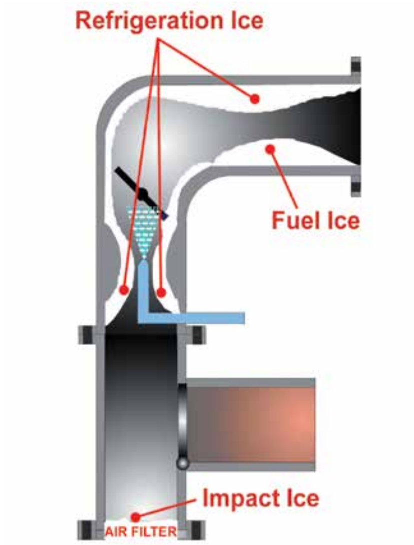

Figure 14.14 Types of engine icing in a simplified carburettor.

Recognition of Symptoms.

Once an engine has stopped because of induction or carburettor icing, it is most unlikely that a pilot will be able to restart it in time to prevent an emergency landing. Therefore, early recognition and correction of the onset of icing is vital.

The Indications of Induction-System Icing.

Early recognition of carburettor icing, and use of carburettor heat, is vital.

The indications of induction system icing to the pilot of an aircraft fitted with a carburettor, and a fixed pitch propeller, would be a gradual drop in RPM which may be accompanied by engine rough-running and vibration.

Figure 14.15. Carburettor Heat Control.

If the aircraft is fitted with a constant speed propeller, induction system icing would be indicated by a drop in manifold pressure or reduction in airspeed in level flight.

If the engine is fitted with a carburettor, the carburettor heat control should be selected to fully hot, whenever carburettor icing is suspected, and left in the hot position for a sufficient length of time to clear the ice. This could take up to 1 minute, or even longer, depending on the severity of the icing. If icing conditions persist, leave the carburettor heat on.

Use of the Carburettor Heat Control.

Full carburettor heat must always be used to clear icing, unless the aircraft is equipped with a carburettor air temperature gauge, in which case the manufacturer's instructions should be adhered to. Always follow the guidelines in the Pilot Operating Handbook with regard to using carb heat.

The carburettor heat control directs heated air from around the exhaust pipe into the induction system. The hot air melts the ice, which then passes through the engine as water. This water, combined with the hot air, may cause the engine to run even more roughly for a short time. Pilots should note that this is a sign that the carburettor heat system is functioning correctly, and that the ice is clearing.

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Icing is most likely to occur during prolonged periods of flight at reduced power, such as during a glide descent, or let-down for approach and landing. Heat is derived from the engine, so during long descents at low or idle power, the engine temperature will gradually lower, thus reducing the effectiveness of the hot air system.

Whenever there is a risk of icing, the pilot should, therefore, select full hot air before reducing power, so that benefit is gained from the hot engine before its temperature starts to reduce. To help maintain engine temperatures and provide a sufficient heat supply during a prolonged descent, to prevent any ice forming in the carburettor, a pilot should increase power periodically, at intervals of between 500 and 1 000 ft. This action also prevents fouling of the spark plugs.

Carburettor icing can occur during taxying, at small throttle settings, or when the engine is at idle RPM. If carburettor icing is suspected, the pilot should ensure that hot air is used during taxying, but must also remember to select cold air before opening the throttle to full power on take-off.

When selecting carburettor heat to hot there are a number of factors that a pilot should understand.

- The application of hot air reduces engine power output by approximately 15%, and also creates a richer mixture, which may cause rough running.

- Carburettor heat should not be selected “hot” at power settings greater than 80%, as there is a danger of detonation and engine damage. Intake icing should not occur at high power settings.

- The continuous use of carburettor heat should be avoided, because carburettor heat modifies mixture strength, and increases engine temperatures.

Be aware of conditions likely to cause carburettor icing. Carburettor icing is most likely to occur in conditions of high humidity; for example, on damp, cloudy, foggy or hazy days, or when flying close to cloud, or in rain, or drizzle, even at temperatures well above 0º.

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Representative PPL - type questions to test your theoretical knowledge of Icing.

1. Ice accretion in a piston engine induction system is produced by:

   a. high power settings, moderate humidity and cold air
   b. low power settings, low humidity and warm air
   c. low power settings, high humidity, at an outside air temperature of between -10°C and +30°C
   d. high power settings, 30% Relative Humidity, at an outside air temperature of between -10°C and +30°C

2. If a cloudy, granular type of ice is seen to collect and protrude from the leading edge of the aerofoil, what type of ice is it most likely be?

   a. Rime ice
   b. Clear ice
   c. Rain ice
   d. Hoar frost

3. If flying just below a cloud base from which rain is falling, with an outside air temperature is between 4ºC and 6ºC, there would be a risk of:

   a. rime ice
   b. clear ice
   c. rain ice
   d. carburettor icing

4. Hoar frost forms on an aircraft when:

   a. the aircraft suddenly enters a cloud at below freezing temperature
   b. the aircraft in sub-zero clear air suddenly enters a colder region
   c. the aircraft in sub-zero clear air suddenly enters a warmer, more humid region
   d. the aircraft in warm air suddenly enters a cloud containing super-cooled raindrops

5. Clear ice forms as a result of:

   a. water vapour freezing to the aircraft
   b. ice pellets splattering on the aircraft
   c. small supercooled water droplets splashing over the aircraft
   d. large supercooled water droplets spreading as they freeze

6. What is the main reason water can exist in a liquid state even though the temperature is sub-zero?

   a. No freezing nuclei
   b. No condensation nuclei
   c. Water takes a long time to cool to below zero degrees
   d. Water is hygroscopic

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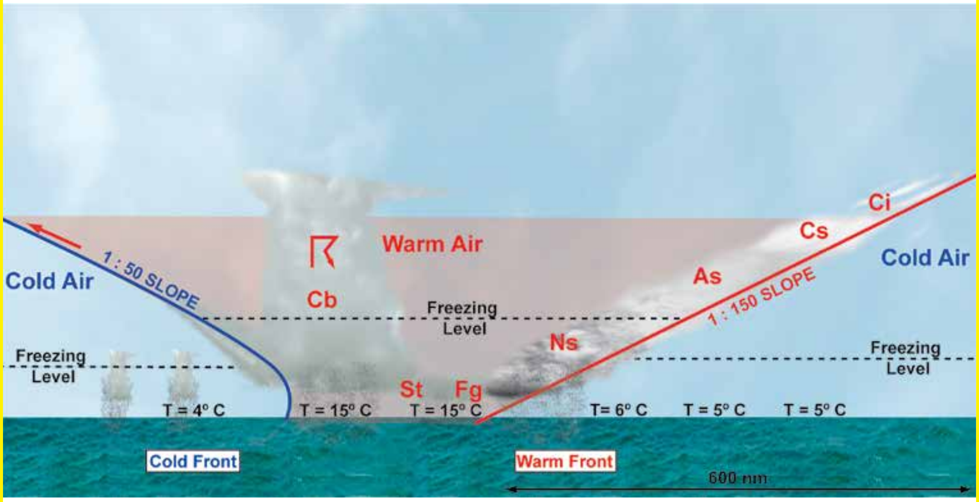
7. You are flying above the freezing level in the cold air just ahead of the warm front. If rain were to fall in this area, what kind of icing might you expect?

a. Carburettor ice
b. Rain ice
c. Rime ice
d. Hoar frost

Question	1	2	3	4	5	6	7
Answer							

The answers to these questions can be found at the end of the book.

CHAPTER 15
AIR MASSES AND FRONTS



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INTRODUCTION.

An air mass which is capable of influencing the weather in a region of the Earth may be defined as an extensive, homogenous body of air in which, horizontally, the temperature, pressure and humidity are approximately constant. Typically an air mass will cover an area of many thousands of square miles.

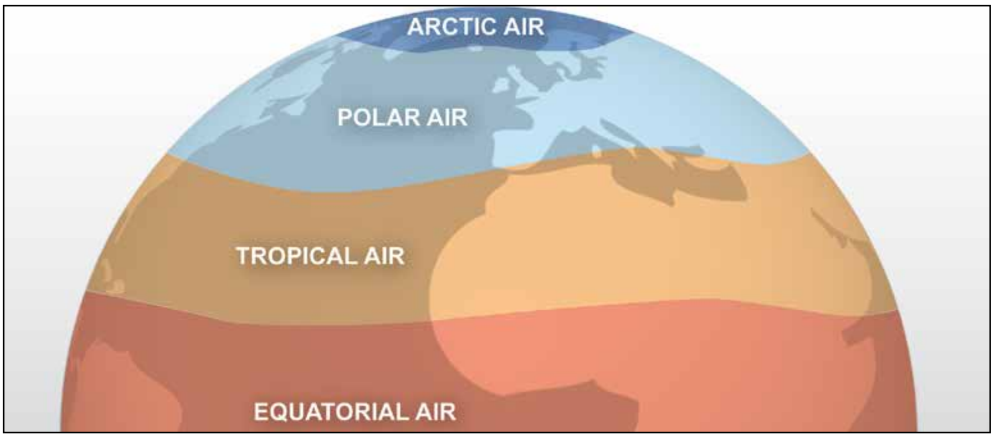

Figure 15.1 Air masses acquire their distinctive characteristics from source regions.

Air masses, with distinctive characteristics, originate from different source regions around the globe. These air masses acquire the characteristics of the Earth's surface underlying the areas over which they lie.

The air masses which affect the world's weather originate from different source regions, and acquire the characteristics of the surface over which they lie.

For example, if the surface of the Earth from which an air mass originates is cold and wet, then the overlying air, given enough time, will also become cold and wet. Conversely, if the source region is warm and dry, the corresponding air mass, with which the source region is related, will also be warm and dry.

In order for an air mass to take on the characteristics of the underlying surface, the air mass must remain over the source region for a considerable time. This is exactly what occurs in extensive areas of high pressure. In these high pressure areas, the winds are light, and the air mass itself remains stationary for a relatively long period of time.

The air masses that affect the British Isles gain their initial characteristics in areas of high pressure, where an air mass may remain stationary for long periods.

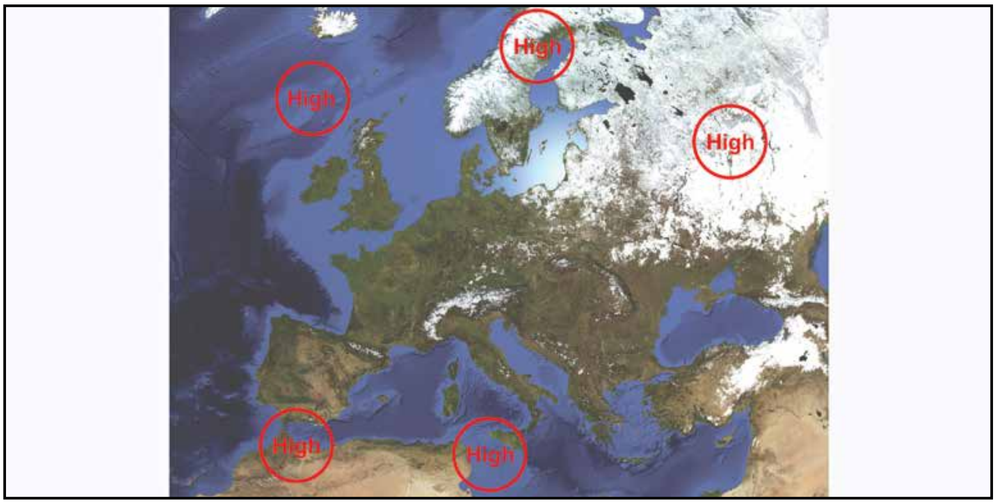

Figure 15.2 Air masses - Source regions are areas of high pressure over which air masses remain stationary for long periods.

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In this chapter, we consider air masses which influence weather in the Northern Hemisphere. *Figure 15.2*, on the previous page, shows typical areas where air masses which may eventually affect the British Isles gain their characteristics.

CLASSIFICATION OF AIR MASSES BY TEMPERATURE AND HUMIDITY.

We have learnt, then, that the characteristics of an air mass are acquired while the air mass remains over the surface of the source region in which the air mass originates.

Air masses are classified by temperature, and by humidity.

Air masses classified by temperature are divided into two main types. Polar air masses, which are cold air masses from source regions towards the Earth's North and South poles, and Tropical air masses consisting of comparatively warm air from the Tropics *(See Figure 15.1)*.

There is a third type of air mass, classified as Arctic, which is a specific type of polar air. The term Arctic does not necessarily imply that the air mass described is colder than a polar air mass, but, rather, describes its source region, which is nearer to the North Pole than the anticyclonic source areas where more general polar air originates.

The two classifications for the humidity of air masses are: Maritime, which refers to a moist air mass, whose source region is over the sea, and Continental, which describes a dry air mass, whose source is a continental land mass.

AIR MASSES AFFECTING THE BRITISH ISLES.

A combination of temperature and humidity characteristics is used to name the various air mass types which affect our weather. In the temperate latitudes, to which the British Isles belong, the air masses which affect our weather systems are:

- **Polar Maritime (PM).**
- **Polar Continental (PC).**
- **Tropical Maritime (TM).**
- **Tropical Continental (TC).**
- **Arctic (A).**
- **Returning Polar Maritime (rPM).**

The source regions of the above air masses, and arrows indicating their movement to affect the weather of the British Isles and the continent of Europe, are shown in *Figure 15.3.*

Under certain meteorological conditions, and, at specific times of year, all of the air masses depicted in *Figure 15.3* will affect the British Isles. Of course, in order to affect the weather in Britain, an air mass must move from its source region. Once an air mass moves, it becomes modified by the surface over which it moves.

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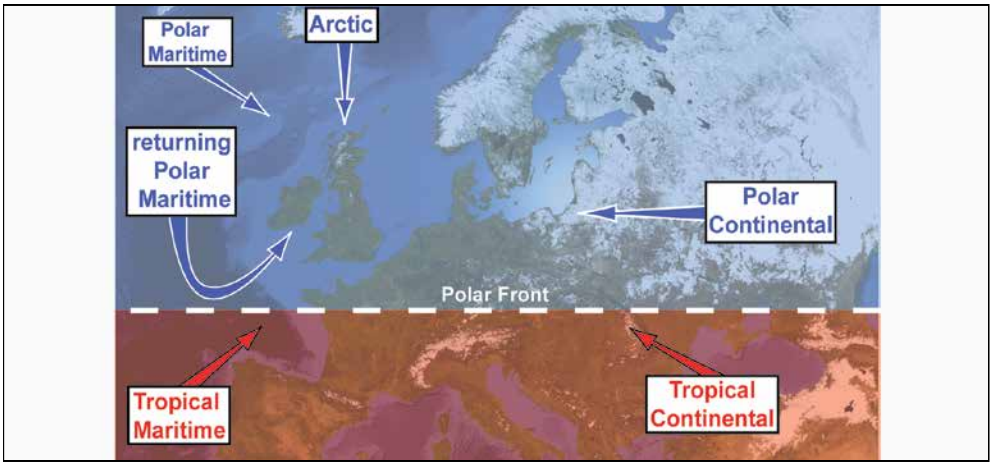

Figure 15.3 Air masses which affect Europe and the British Isles: Polar Maritime, Tropical Maritime, Tropical Continental. Also Arctic air, Returning Polar Maritime.

An air mass will normally be either warmed or cooled as it is displaced, and this will dramatically change the nature of the air mass.

If an air mass moves towards a warmer area, for instance towards the Equator, it will be warmed from beneath. Its Environmental Lapse Rate (ELR) will then increase, and the air will become unstable favouring the formation of cumuliform clouds.

Conversely, if an air mass moves from its source region to a colder part of the globe, towards the poles, for instance, it will be cooled from below. In this case, its ELR will decrease, and the air will become stable. If cloud develops in this stable air, it will be low level stratiform cloud, perhaps forming from cumulous clouds which, unable to develop vertically, spread out horizontally, to become stratocumulus.

Below, we consider, in more detail, each of the air masses that we have identified so far, and give a description of how each air mass affects the weather over the British Isles.

Polar Maritime.

Polar Maritime air approaches the British Isles from the Northwest *(see Figure 15.3)*, and is the air mass which affects Britain most frequently throughout the year. The source region for Polar Maritime air is the cold North Atlantic, but, when moving southwards, Polar Maritime air will pass over warmer areas of the Atlantic Ocean. This will cause the air mass to absorb moisture from the sea and become increasingly humid and unstable as it approaches the British land mass. As a result of the instability of this relatively moist airflow, cumulus and, occasionally, cumulonimbus clouds may develop. As the Polar Maritime air arrives over the British Isles, showers can be expected, accompanied by hail and thunder, under some circumstances.

Polar maritime air is cold, moist and unstable.

Daytime flying conditions in Polar Maritime air are quite bumpy, due to turbulence caused by the air mass's inherent instability. Visibility, however, is generally excellent outside areas of precipitation. Showers accompanying the Polar Maritime air usually die out overnight as the land cools, often leading to clear skies, temperature inversions, and sometimes, radiation fog, during the night and in the hours immediately after sunrise.

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Polar Continental air is dry and cold, originating from Siberia in the Winter and Spring months.

Polar Continental.

The Polar Continental air mass affects Europe and the British Isles during the winter. Originating from Siberia or Northern Russia *(see Figure 15.3)*, it is a stable, very dry and cold air mass which reaches Britain when easterly, or north-easterly winds become established. Polar continental air has little moisture, since it originates over an extensive land mass, and usually brings cloudless, but bitterly cold, weather to the British Isles.

If the Polar Continental air mass follows a sufficiently long track across a sea area such as the North Sea, there may have been enough warming of the air mass from beneath to cause convection to take place. Sufficient moisture may also have been picked up to cause some instability leading to snow showers in eastern coastal areas of Britain.

The visibility conditions accompanying the Polar Continental air mass are variable and dependent on the areas over which the air mass has travelled. If the Polar Continental air has originated in Scandinavia, the visibility is generally good; however, if the air mass has originated over the industrialised areas of Eastern Europe, visibility may be poor, due to atmospheric pollution.

Arctic air is a specific type of Polar Maritime air mass which originates close to the North Pole and follows a long sea track before it reaches Northern Britain.

Arctic.

Arctic air arrives in Britain as a strong, northerly airflow direct from the North Pole *(see Figure 15.3)*. Arctic air quickly becomes moist and unstable as it moves southwards across the relatively warmer sea, bringing snow showers to Northern Scotland.

Tropical Maritime air is warm and moist. As it moves toward the British Isles, it is cooled from below and becomes stable, bringing advection fog and low cloud.

Tropical Maritime.

Tropical Maritime air originates in the mid-Atlantic from around the Azores, and approaches the British Isles from the South West. This air mass cools from below on its northward track which increases its stability. Since it is the lower layers which cool, only low cloud is produced, with accompanying poor visibility. Advection fog can also form, especially on windward coastlines. Inland conditions are often slightly better, but still relatively poor, with extensive low cloud. Inland in summer, however, there is usually enough heat from the Sun to lift, and occasionally break, the cloud into shallow cumulus cloud.

Tropical Continental air is warm and dry and mainly a summer phenomenon. Conditions will be dry, hot and cloudless, with poor visibility.

Tropical Continental.

Tropical Continental air approaches the British Isles from the South East. This air mass mainly affects Britain in the summer, and is responsible for the highest temperatures. Tropical Continental air is dry, usually with cloudless skies, although hazy conditions often predominate, with moderate to poor visibility.

Returning Polar Maritime air is an unstable moist airflow, modified in its lower layers to become stable, because it initially tracks South and then turns back towards the British Isles on a north-easterly track.

Returning Polar Maritime.

If Polar Maritime air undergoes a long southerly journey, and then swings towards the British Isles on a north-easterly track, it is called Returning Polar Maritime air. *(See Figure 15.3.)* As its initial track was southwards, Returning Polar Maritime air becomes warmer and more unstable than the classic Polar Maritime air mass, and so contains a significant amount of moisture gathered on its passage over the Atlantic Ocean.

However, as Returning Polar Maritime air swings North East towards the British Isles, it becomes stable in its lower layers as it moves to a relatively cooler region, and so cools from below. Meanwhile the middle and upper layers remain unstable. Cloud

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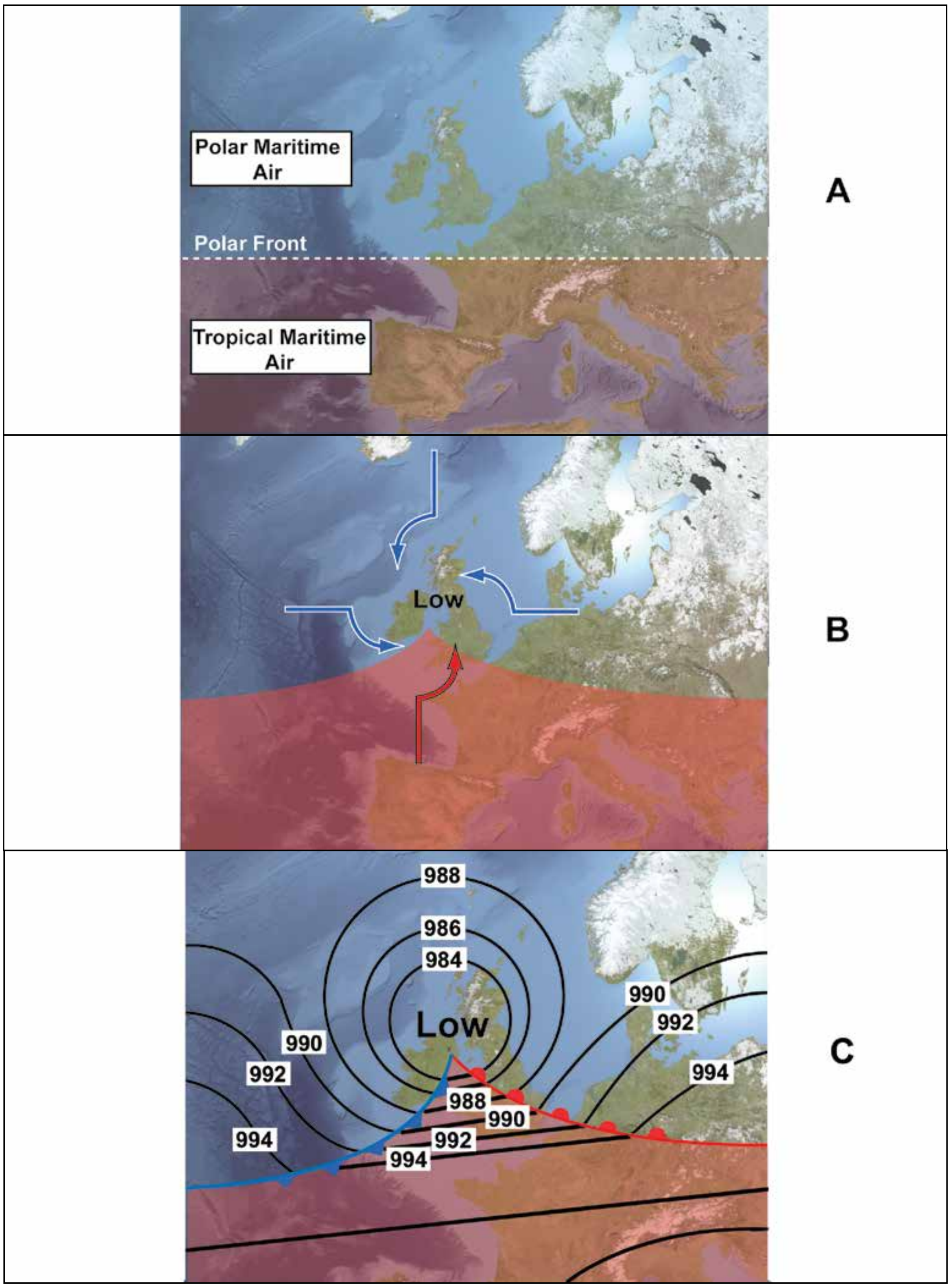
formations associated with Returning Polar Maritime air are, in general, stratiform in the lowest layers, with convective cloud developing in the unstable middle layers.

POLAR FRONTS.

Fronts are transition zones between air masses of different temperature, namely polar and tropical air masses. In Chapter 5, Pressure Systems, the frontal boundary, which exists between Polar Maritime air and Tropical Maritime air, was described. Known as the Polar Front, this boundary between Polar Maritime and Tropical Maritime air is fluid in nature. When warm air moves northwards to replace heavy cold air, a kink

Fronts are transition zones between different air masses.



A classic Polar Front depression is caused by warm Tropical Maritime air intruding into Polar Maritime air causing surface pressure to decrease.

Figure 15.4 A kink in the Polar Front leads to a reduction in surface pressure and the formation of a Warm Sector Depression.

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is formed in the Polar Front and surface pressure is reduced, creating a polar front depression, otherwise known as a warm sector depression.

As air moves towards the low pressure area in the Northern Hemisphere, it is deflected to the right by the Coriolis Force. This flow of air creates two unique frontal features; a cold front and a warm front.

CLOUD TYPES

Cu = Cumulus
St = Stratus
Ci = Cirrus
Cs = Cirro - Stratus
As = Alto - Stratus
Ns = Nimbo - Stratus

The Polar Front.

Along the part of the Polar Front identified by blue triangles in *Figure 15.4c*, cold Polar Maritime air is being forced against warm Tropical Maritime air, and under-cutting the warmer air. By this mechanism, a cold front is formed as depicted in *Figure 15.5*.

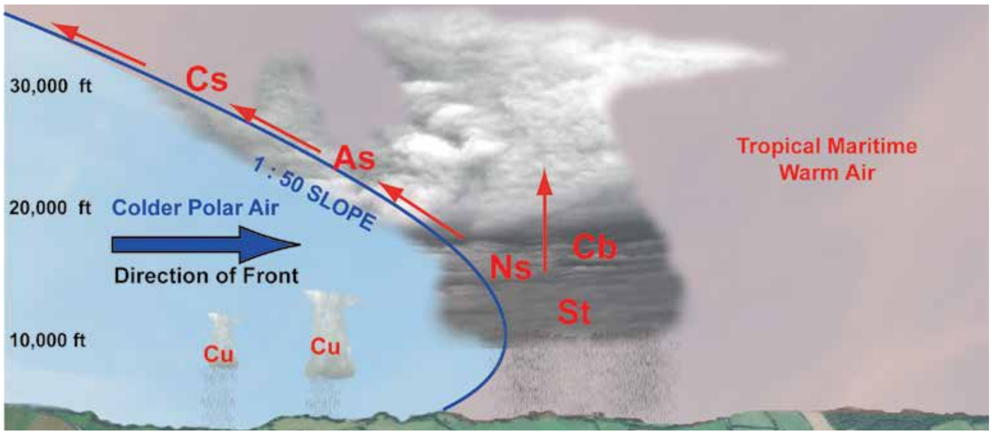

Figure 15.5 A cross section of a Cold Front. Cold air is replacing warm air and undercutting it.

Along the part of the polar front identified by red semi-circles in Diagram C of *Figure 15.4*, warm Tropical Maritime air is being forced up and over the colder air, on the other side of the front. By this mechanism, a warm front is created as depicted in *Figure 15.6*.

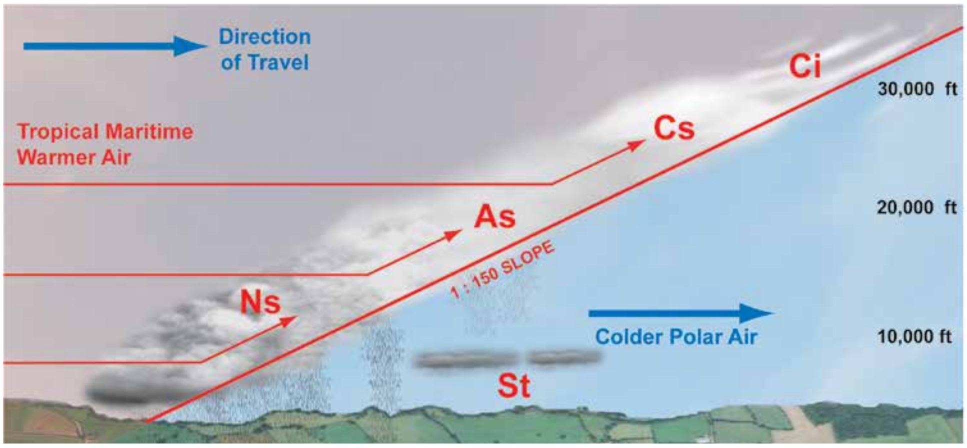

Figure 15.6 A cross section of a Warm Front. Warm air is replacing cold air and overriding it.

Polar Frontal systems, of the type described above are found between latitudes 35° N and 65° N. They move from West to East across the Atlantic and Pacific. The Atlantic fronts will normally arrive over the British Isles in sequence: the warm front first, followed by the cold front.

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The Warm Front.

Figure 15.7 shows a cross section across a polar front depression, depicting both the warm and the cold fronts. The warm front, on the right hand side of the illustration, will be the first of the fronts to influence the weather over the British Isles as the depression moves from West to East.

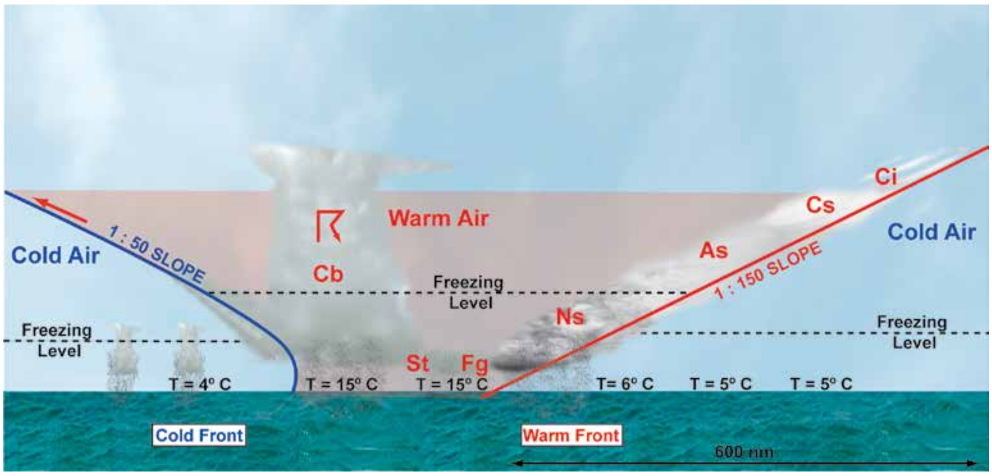

Figure 15.7 The slope of the warm front is 1:150. The cloud sequence seen as the warm front approaches is Ci - Cs - As - Ns. Precipitation starts 200 - 300 nm ahead of the front.

CLOUD TYPES

Ci = Cirrus
Cs = Cirrostratus
As = Altostratus
Ns = Nimbostratus
St = Stratus
Cb = Cumulonimbus
Cu = Cumulus

The slope of a typical warm front is a very shallow gradient of about 1 in 150, and the clouds that develop along the front are mainly of stratiform type. The first clouds noticed by an observer on the ground in Britain, as a warm front approaches, will be very high altitude cirrus, then cirrostratus. As the front gets closer, thicker, lower altostratus will be observed. The clouds will continue to thicken and lower as the surface front gets nearer, until, eventually, where the warm front meets the Earth's surface, nimbostratus cloud will prevail.

The slope of a warm front will typically be 1:150.

The whole extent of the warm front may take up to 12 hours to pass over a location, with the cloud ahead of the warm front extending for about 600 nautical miles (nm) ahead of the surface position of the front. The main area of precipitation starts some 200 to 300 nm ahead of the surface front, as the base of the cloud gradually lowers. Precipitation may persist for several hours as the front gets closer. As the precipitation increases in intensity, closer to the ground position of the front, visibility will reduce, and eventually, frontal fog may occur.

Precipitation associated with a warm front may begin 200 to 300 miles ahead of the surface front.

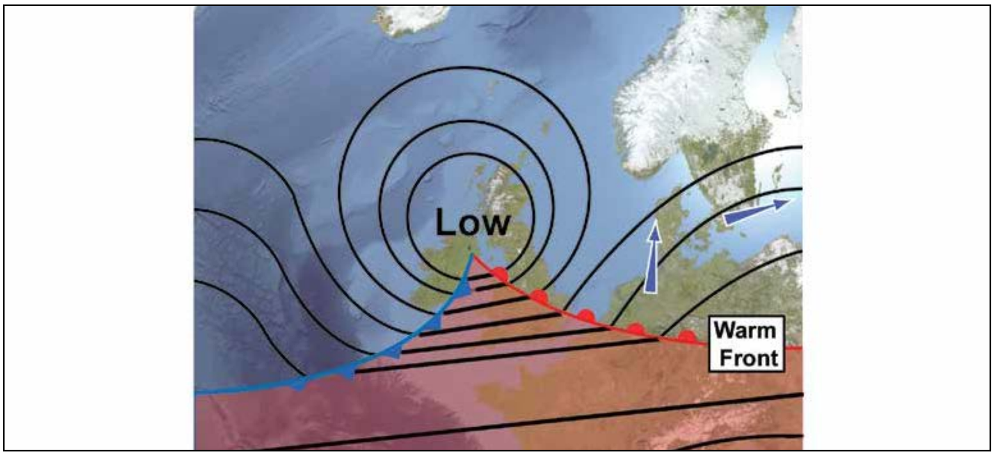

Figure 15.8 As the warm front approaches, the wind will back and strengthen. The blue arrows in the diagram depict the initial backing of the wind.

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Veer - *wind direction changes in a clockwise direction.*

Back - *wind direction changes in an anticlockwise direction.*

As the warm front approaches, the wind will back and increase but at the passage of the front it will veer sharply.

Conditions as the Warm Front Approaches.

The wind ahead of a warm front is fairly light, coming from about 250°, but, as the front approaches, the character of the wind begins to change. The wind slowly increases in speed and blows from about 200°; so, with the approach of the warm front, the wind backs slightly and strengthens. Ahead of the front, the visibility will deteriorate, and atmospheric pressure will fall steadily. The temperature, however, will remain at a fairly steady, low value. The dew point temperature will usually be steady, and fairly low, too.

Conditions at the Warm Front.

At the warm front, itself, the cloud will be low-level, extensive and stratiform, while precipitation will be continuous and moderate, perhaps even heavy. From *Figure 15.9,* it can be seen that the wind changes direction quite markedly, from approximately 200º, just before the front, to approximately 260º just after the front has passed. The wind, therefore veers sharply.

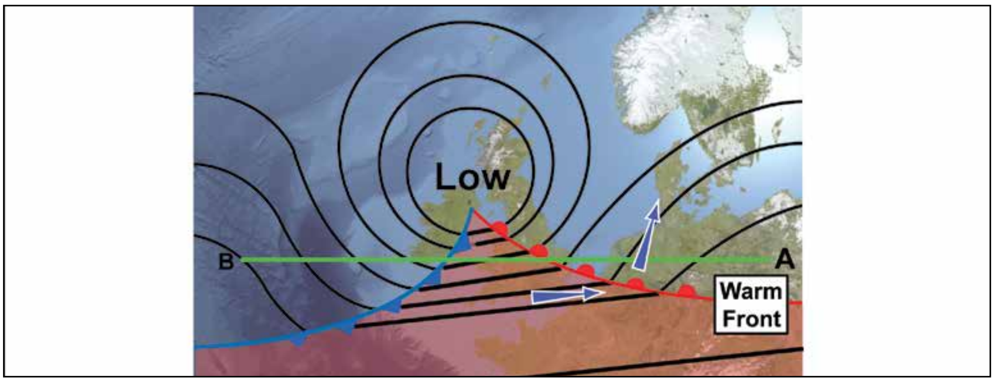

Figure 15.9. Conditions at the warm front are characterised by thick, low level cloud, continuous heavy precipitation, with a sharp veer in the wind.

When planning a flight, pilots should always bear in mind the effect on wind strength and direction of a passing front. Visibility will be poor, with widespread hill fog developing, over high ground.

As the warm front passes, pressure will continue to decrease slightly; however, the temperature and dew point will suddenly rise in the warm air behind the front itself. The warm air between the cold and warm fronts is called the warm sector.

The cloud in the warm sector will be extensive, low level stratus or strato-cumulus; there may also be precipitation in the form of drizzle.

Conditions in the Warm Sector.

The warm sector lies between the warm and cold fronts; it is a stable, warm, air mass, with fairly consistent weather throughout. The weather conditions associated with the warm sector are characterised by a fairly low, uniform base of extensive stratus or stratocumulus cloud *(see Figure 15.7)*, with the possibility of light drizzle. The wind will be steady, and often strong. The visibility can be poor, with extensive fog over high ground.

By examining the plan view in *Figure 15.9*, you may be able to deduce that, in the warm sector, as the cold front approaches, along the line **AB**, the pressure continues to fall slowly. However, the temperature and dew point will remain fairly high and steady, throughout this warm moist air mass, as depicted in *Figure 15.7*.

The Cold Front.

The cold front, a cross section through which is depicted in *Figure 15.10,* follows behind the warm sector as the system moves from West to East. Note that the average slope of a cold front is steeper than that of a warm front, usually about 1 in 50.

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In the cold front, cold air advances, and undercuts the warm air, forcing it to rise. This uplift causes the air to cool adiabatically to its dew point temperature, at which stage the water vapour within the warm air mass starts to condense and form cloud. Over the whole extent of the cold front, the main cloud type will be stratiform, since, though steeper than the warm front, the slope of the cold front remains fairly shallow. However, the wedge of cold air, caused by friction holding back the air mass in direct contact with the surface, creates very unstable conditions. The wedge forces air ahead of the cold front to rise rapidly, creating active cumuliform clouds, which sometimes develop into cumulonimbus, ahead of the surface position of the front. This makes the passage of the cold front appear to be quite sudden, with little warning that it is approaching.

The slope of a cold front will typically be about 1:50.

*The strong convection at the cold front caused by the **wedge** of advancing cold air is the most common cause of frontal thunderstorms.*

Cumuliform clouds on a cold front can create dangerous squall-line thunderstorms, developing rapidly into cumulonimbus cloud which may be hidden inside stratiform cloud layers. Pilots should give cold fronts a wide berth, and keep a watchful eye on the weather immediately ahead of any cold front in their vicinity.

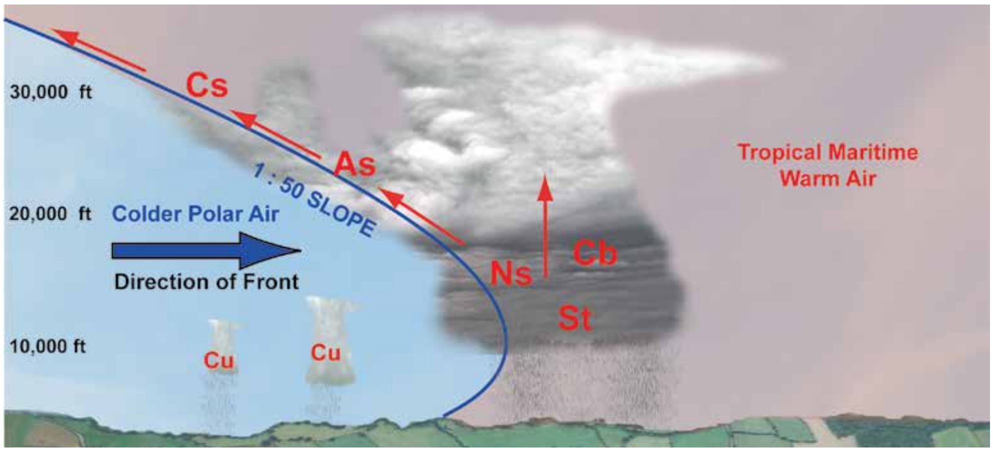

Figure 15.10 The Cold Front. Embedded cumulonimbus (CB) cloud inside stratiform cloud layers.

Conditions at the Cold Front.

An observer on the ground in the British Isles, seeing an approaching cold front, would expect to observe cumuliform cloud or cumulonimbus cloud which may, however, be embedded within the stratiform cloud to give both steady and showery precipitation. The wind will veer sharply, with gusts, and possibly squalls.

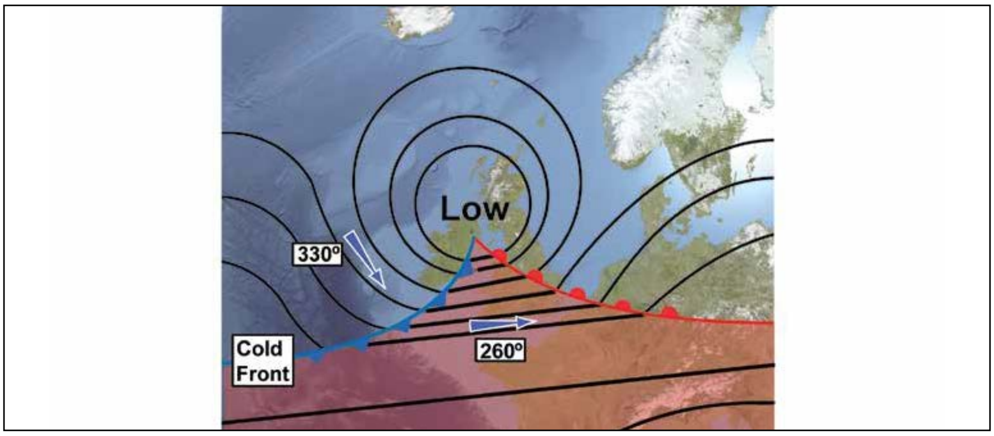

Figure 15.11 As the cold front passes, the wind will veer sharply from about 260° to 330°.

*At the passage of a cold front, the **wind** will **veer** sharply. In **precipitation,** the **visibility** will be poor, <u>but</u> will improve quite rapidly. The pressure will begin to rise, while the temperature and dew point will fall.*

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Before the cold front arrives, the surface pressure will fall, but will rise once the front has passed. In precipitation, visibility will be poor, but will quickly improve. The temperature and dew point will usually fall sharply as the cold air behind the front moves in. *Figure 15.11* shows the change in wind direction associated with the passing of a cold front. The wind will veer sharply.

Conditions behind the Cold Front.

Once the cold front has passed, weather will be dominated by the sector of cold Polar Maritime air. Because the Polar Maritime air will have been moving South, and, therefore, travelling over warmer surfaces, it will be unstable. Consequently, isolated cumuliform clouds will develop behind the cold front.

The cumulous clouds in the cold sector will produce moderate to heavy showers of rain, or hail. Pressure will continue rising with the passing of the front, and visibility will be good, though it will deteriorate temporarily in showers. The atmosphere will be unstable behind the cold front.

The Speed of Warm and Cold Fronts.

The cold front moves faster than the warm front.

The speed of movement of a warm front may be estimated if you have access to a weather chart incorporating a geostrophic wind scale, as shown in *Figure 15.12*.

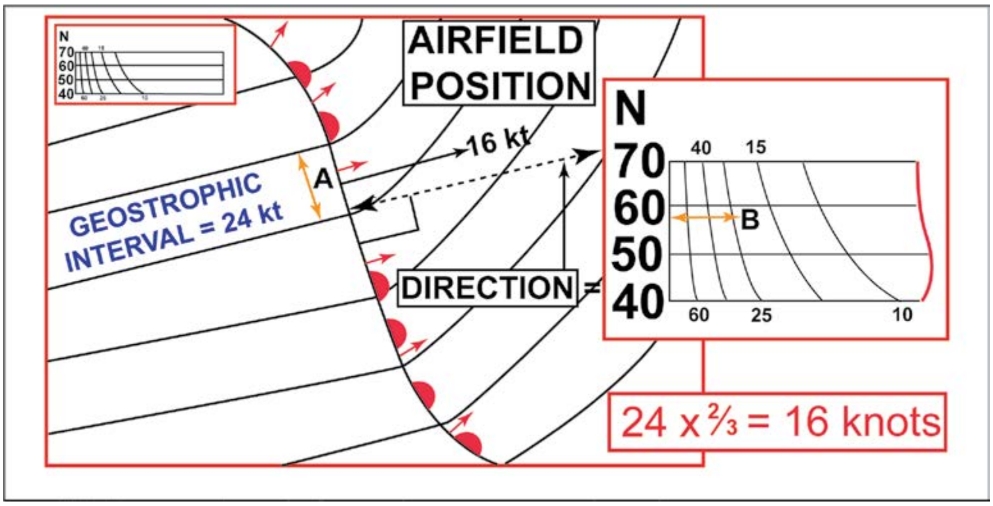

Figure 15.12. Calculating the speed and direction of movement of fronts.

From *Figure 15.12,* measure the isobaric spacing on the warm front as shown by the orange arrow marked **'A'**. Apply that measurement to the geostrophic wind scale, measuring from the vertical axis, at the appropriate latitude (see orange arrow marked **'B'**), in this case, **60º N**; then multiply the answer by **2/3**. This gives the approximate speed of the warm front. The front will move in the direction of the symbols, parallel to the isobars behind the front.

The speed of movement of a cold front can be estimated in a similar manner. Again, measure the isobaric spacing on the front, and use the geostrophic wind scale, but do not multiply the answer by 2/3.

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Because a warm front moves more slowly than a cold front, the warm front will eventually be overtaken by the cold front, leading to the creation of an occluded front.

The cold front moves faster than the warm front. The speed of the warm front is, approximately, two thirds that of the cold front.

The Occluded Front.

Where the cold front overtakes the warm front, an occluded front is formed, as depicted in *Figure 15.13*. When the two fronts meet they merge, and, so, to identify this new front, both the warm and cold front symbols appear together on the frontal line of an occluded front.

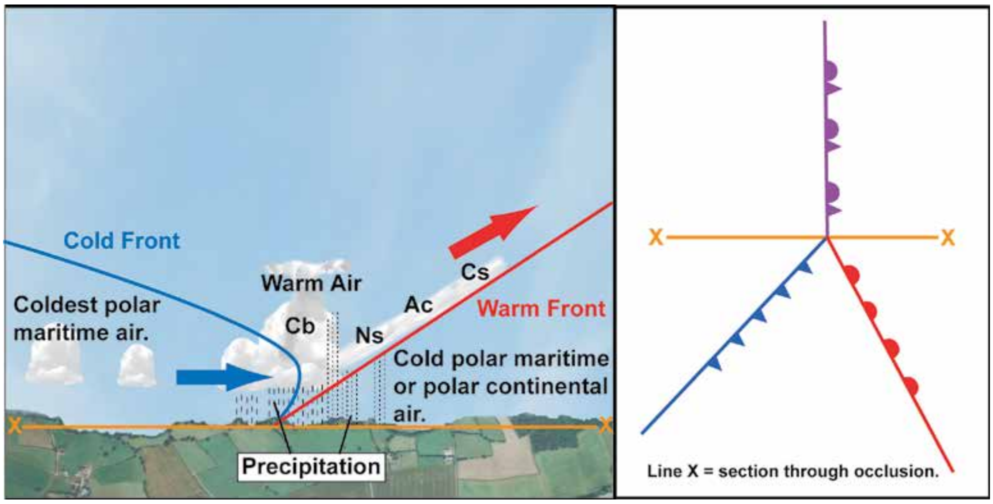

Figure 15.13 An occluded front is created when the cold front starts to overtake the warm front.

The cold front eventually overtakes the warm front to form an occluded front.

The warm and cold fronts can merge to form an occluded front in two ways.

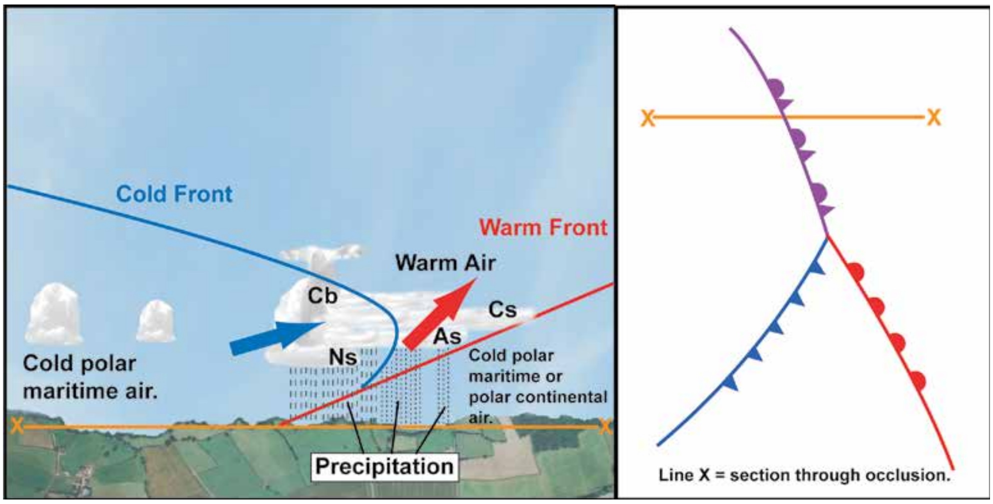

Figure 15.14 A Warm Occlusion: the cold front over-rides the warm front.

There are two types of ***occluded front:*** *a* ***warm occlusion*** *and a* ***cold occlusion.***

If the cold front rides up and over the warm front, as shown in *Figure 15.14*, the front so formed is called a warm occlusion. If, however, the cold front undercuts the warm front, as shown in *Figure 15.15*, overleaf, a cold occlusion is created.

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In a flight across an occlusion, a pilot would encounter severe weather and a significant change in wind speed and direction.

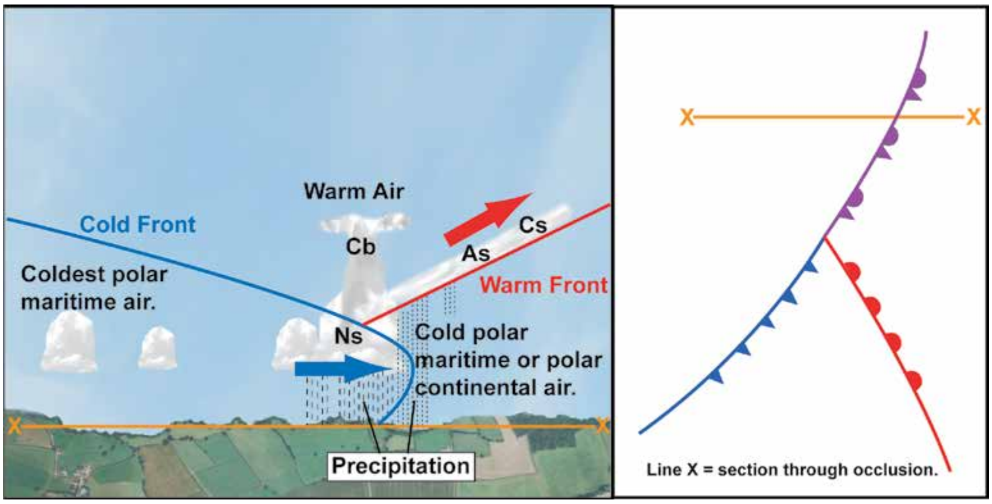

Figure 15.15 A Cold Occlusion: the cold front undercuts the warm front.

***Occlusion weather** is characterised by long periods of continuous rain, interspersed with long showers.*

The weather associated with an occlusion is a combination of warm and cold front weather. Typically, occlusion weather is characterised by long periods of continuous rain, interspersed with heavy showers. Occlusions in the British Isles have been responsible for most of the major flooding over recent years.

The Quasi-stationary Front.

Figure 15.16 returns to the illustration of the polar front, from which we began the description of frontal systems.

If there is little interaction between the warm Tropical Maritime and Polar Maritime air, no kinks or disturbances will occur at the front boundary. In such circumstances, a quasi-stationary front is formed. *Figure 15.16* depicts how the cold and warm front symbols are used to signify the quasi-stationary front. Note that the winds will blow parallel to the frontal position line, as depicted by the blue and white arrows.

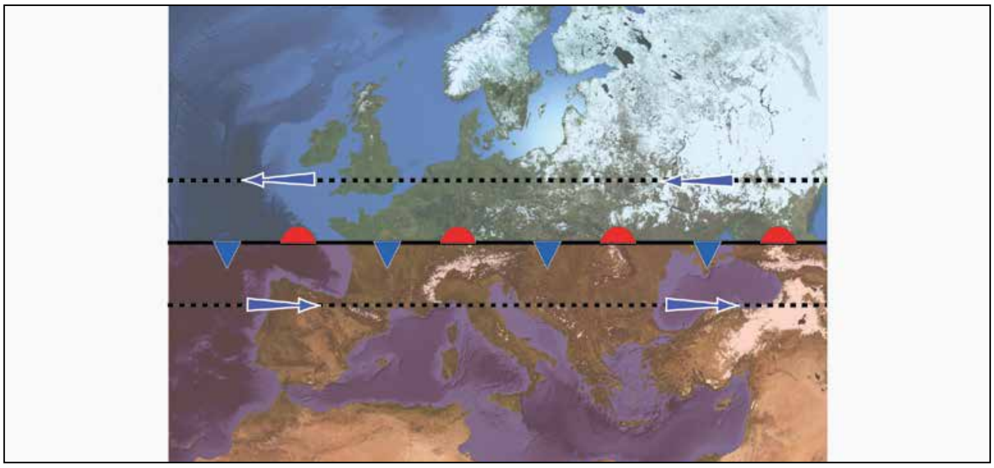

Figure 15.16 The Quasi-Stationary Front. This is a polar front which has no observed kink or disturbance along its axis. Winds are parallel to the front axis.

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Representative PPL - type questions to test your theoretical knowledge of Air Masses and Fronts.

1. The extent of rainfall ahead of a typical warm front may stretch up to distance of:

   a. 50 miles ahead of the surface position of the warm front
   b. 200 miles ahead of the surface position of the warm front
   c. 500 miles ahead of the surface position of the warm front
   d. 2 miles ahead of the surface position of the warm front

2. Seen from the surface, the passage of a warm front is characterised by which of the following cloud types, seen in sequence:

   a. Embedded cumulonimbus within dense nimbostratus
   b. Cirrostratus, cirrocumulus, nimbostratus and finally cumulus
   c. Cirrus, cirrostratus, altostratus, nimbostratus and finally stratus
   d. Nimbostratus, altostratus, cirrostratus and finally cirrus

3. What will normally happen to the surface wind direction following the passage of a warm front?

   a. Stay constant
   b. Back
   c. Veer
   d. Veer then back

4. What is the general speed of a warm front?

   a. Approximately 1/3 of the speed of the cold front
   b. Approximately 2/3 of the speed of the cold front
   c. Approximately 1/2 the speed of the cold front
   d. The same speed as the cold front

5. Which air mass arriving over the United Kingdom would be characterised by cold, moist, unstable air?

   a. Polar maritime
   b. Tropical maritime
   c. Polar continental
   d. Tropical continental

6. Your planned flight lies within the warm sector of a polar front depression. What would you expect the cloud to be?

   a. A fairly low, uniform base of stratus or stratocumulus cloud
   b. Low, medium and high level cloud
   c. Only high level cloud
   d. Clear skies

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7. You observe the passage of a frontal system and notice this sequence of clouds: cirrus, cirrostratus, altostratus, nimbostratus and stratus. What kind of a front are you observing?

   a. A cold front
   b. An occluded front
   c. A stationary front
   d. A warm front

8. When two air masses converge in a depression, and warmer air replaces the colder air at the surface, the front is known as:

   a. A cold front with a typical slope of 1:150
   b. A warm front with a typical slope of 1:150
   c. A warm front with a typical slope of 1:50
   d. A cold front with a typical slope of 1:50

9. The conditions most likely to be encountered when following an East/West track that crosses an occluded front lying North/South, would be:

   a. Thick stratus and drizzle ahead of the occlusion, with a light wind generally backing across the occlusion
   b. Calm conditions before the occlusion, with considerable backing of the wind across the occlusion
   c. Extensive rain, interspersed with heavy showers
   d. Calm, settled weather with poor visibility

10. When dry air flows over a warm water surface, the air in contact with the surface will absorb water vapour and become:

    a. More dense and stable
    b. Less dense, colder and remain at the surface
    c. Less dense and unstable
    d. More dense and cool

11. What are the characteristics of the passage of a cold front?

    a. A dew point rise, a temperature fall and wind backing
    b. A dew point rise, a temperature fall and wind veering
    c. Steady dew point and temperature but a sharp backing in the wind
    d. A dew point fall, a temperature fall and the wind veering

12. Tropical maritime air that affects European weather originates from:

    a. The Azores
    b. The Indian Ocean
    c. The Mediterranean
    d. The North Sea in summer

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13. Which of the following frontal systems is most likely to produce thunderstorms?

    a. A quasi-stationary front
    b. A warm front
    c. A ridge of high pressure
    d. A cold front

14. What would be the change in weather of a typical warm front?

    a. Pressure falls, 8 oktas of cloud with a lowering base, and poor visibility
    b. Pressure increases steadily, no more then 4 oktas of cloud and good visibility
    c. Pressure stops falling, 4 oktas of cloud with a very low base and rapidly improving visibility
    d. Pressure falls, 8 oktas of cloud with a lowering base and improving visibility

15. Tropical maritime air coming from the Azores gives what kind of weather?

    a. Moist unstable conditions leading to well developed cumulonimbus
    b. Moist but stable conditions due to the general subsidence caused by cooling from below, giving low stratus and poor visibility
    c. Dry stable conditions leading to good visibility at low level
    d. Moist but stable conditions due to the ascent of air caused by being warmed from below, giving low stratus and poor visibility

16. What features characterise an air mass?

    a. A mass of air of constant temperature, pressure and humidity, overlying a localised hotspot on the Earth's surface
    b. A mass of air displaced from an anticyclone to a depression, as a frontal wind
    c. A mass of air, of large horizontal extent, possessing fairly uniform horizontal values of temperature, pressure and humidity drawn from the cyclonic weather of which it is part
    d. A mass of air, of large horizontal extent, displays fairly uniform horizontal values of temperature, pressure and humidity, drawn from the anticyclonic region over which it lies

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Answer												

Question	**13**	**14**	**15**	**16**
Answer				

The answers to these questions can be found at the end of the book.

CHAPTER 16
THE METAR

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INTRODUCTION.

The letters METAR stand for METeorological Aerodrome Report. METARs contain coded messages pertaining to the actual weather conditions at a given aerodrome, at a stated time. *Figure 16.1* illustrates typical METARs for United Kingdom aerodromes, extracted from the United Kingdom Met Office website.

ALDERNEY	EGJA 291350Z 26007KT 230V370 9999 FEW030 12/06 Q1013
BIGGIN HILL	EGKB 291350Z 26009KT 9999 SCT020 12/03 Q1009
BOSCOMBE DOWN	EGDM 291350Z 27012KT CAVOK 15/01 Q1010 BLU NOSIG
BOURNEMOUTH/HURN	EGHH 291350Z 27012KT 9999 SCT040 14/02 Q1011
BRISTOL	EGGD 291350Z 27016KT 9999 SCT045 13/04 Q1011
BRIZE NORTON	EGVN 291250Z 30007KT 9999 FEW025CB SCT038 13/04 Q1010 TEMPO 7000 -SHRA SCT024CB
CARDIFF	EGFF 291350Z 25014KT 9999 FEW040 13/06 Q1011
CRANFIELD	EGTC 291350Z 26011KT 9999 FEW035 12/04 Q1009
CULDROSE	EGDR 291320Z 22010KT 9999 FEW035 13/07 Q1013 BLU NOSIG
EXETER	EGTE 291350Z 29007KT 250V340 9999 SCT035 14/02 Q1011

Figure 16.1 Typical METARs for United Kingdom aerodromes as displayed on the UK Met Office website.

A METAR is a Meteorological Aerodrome Report for a given aerodrome at a stated time.

METARs are issued every half hour, during aerodrome operating hours.

METARs are usually issued every half hour during aerodrome operating hours. The aim of this chapter is to explain the METAR coding, group by group.

DECODING THE METAR.

Report Type, Aerodrome and Date-Time Groups.

Figure 16.2 reproduces the first eight code-groups normally found in a METAR. The first code, **(a)**, is the identification of the type of report; in this case a METAR. The four-letter ICAO designator of the issuing aerodrome is shown next, **(b)**; this example is for Oxford/Kidlington, EGTK.

METAR EGTK 231020Z 260 12 G 25KT 220 V 300

(a) (b) (c) (d) (e) (f) (g) (h)

Figure 16.2 The initial codes of a METAR. Report type (a), ICAO designator (b), Date and time group (c): Observed on 23rd at 1020Z. Wind information (d): 260º True, 12 knots (e) gusting (f) 25 knots (g). Wind direction variable between 220º and 300º True (h).

The third group, **(c)**, is the date/time group, which simply gives the time of the actual weather observation. The first two digits represent the day of the month, followed by the time in hours and minutes. Time is always given as Coordinated Universal Time (UTC)*****, which is, for all practical purposes, the same as Greenwich Mean Time (GMT): the local time at Greenwich, London. In the METAR itself, UTC is indicated by the code **Z**, pronounced "Zulu".

Wind Information.

The next item in the METAR (**d**, **e** ,**f** and **g**) is the observed wind information. Firstly, the direction of the wind given in degrees true, rounded up or down to the nearest 10 degrees, **(d)**, and then the wind speed in knots, **(e),** which is a mean speed taken over a 10 minute period. However, if a gust is observed which is at least 10 knots more than the mean wind speed, then a gust figure, **(g)**, comes after the mean wind; this gust figure is preceded by the letter G, **(f)**.

* *Do not be confused by the abbreviation used for **Coordinated Universal Time**. Different languages have different words to describe any given concept. **UTC** are the letters that have been internationally agreed to stand for what, in English, is called **Coordinated Universal Time.***

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The next code-group, **(h)**, may or may not appear depending on the directional variability of the wind. Variability is shown after the main wind group and signifies the extremes in the direction of the wind during the previous 10 minutes. The letter V will appear between these two extremes. If there is no wind, the coding, 00000KT, will be used.

Visibility.

Visibility in the METAR is represented by the next group, depicted in **red** in *Figure 16.3*. In the METAR, the reported visibility is the prevailing visibility and, may, under certain conditions, include the minimum visibility. Here, the prevailing visibility is reported as 1 400 metres.

Prevailing visibility is the visibility value which is either reached, or exceeded, around at least half the horizon circle, or within at least half of the surface of the aerodrome. If the visibility in one direction, which is not the prevailing visibility, is less than 1 500 m, or less than 50% of the prevailing visibility, the lowest visibility observed, and its general direction, should also be reported.

Up to 10 km, the visibility is measured in metres. For example, 6000 means that the prevailing visibility is 6 000 metres. Once the visibility reaches 10 km or more, the code figure used is 9999.

Visibility of less than 50 metres is indicated by the code 0000. In *Figure 16.3*, the prevailing visibility is 1 400 metres.

METAR EGTK 231020Z 26012G25KT 220V300 1400

Figure 16.3 Prevailing visibility is 1 400 m.

In some instances, runway visibility information is given in a METAR; this is known as Runway Visual Range (RVR.) RVR is given only when either the horizontal visibility or the RVR itself is less than 1 500 metres. The RVR group starts with the letter **R**, and then goes on to give the runway in use, followed by the threshold visibility in metres.

In our example for **Oxford Kidlington** *(See Figure 16.4.)*, we have a prevailing visibility of 1 400 metres, with an RVR, on Runway 30, of 1 100 metres.

METAR EGTK 211020Z 26012G25KT 1400 R30/1100

Figure 16.4 The RVR on Runway 30 is 1 100 m.

If the RVR is more than the maximum reportable value of 1 500 metres, the code P is used in front of the visibility value, R30/P1500.

A letter can sometimes come after the RVR to indicate any trends that the RVR has shown. A U means that the visibility has increased by 100 m or more in the last 10 minutes, e.g. R30/1100U. A D shows that visibility has decreased in that same time period, e.g. R30/1100D. An N added to the visibility group shows that there is no distinct trend observed, e.g. R30/1100N.

The Weather Group.

The next section of the METAR is the weather group. The weather group gives information on the present weather at, or near, the aerodrome at the time of the observation. *Figure 16.5, below,* adds the weather group, highlighted in **red**, to our example METAR: **+SHRA**, meaning “heavy showers of rain”.

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METAR EGTK 211020Z 26012G25KT 1400 R30/1100 +SHRA

Figure 16.5 The highlighted weather group means "heavy showers of rain".

The table at *Figure 16.6* lists the various codes which may be used in the METAR weather group to describe different weather phenomena. The first column represents the intensity or proximity of a weather phenomenon.

The symbols in the first column have the following meaning:

- – meaning light.
- **+** meaning heavy.
- **VC** meaning in the vicinity of, but not at, the observation point.
- If there is no qualifier (i.e. no **+** or **-**) in front of precipitation, the precipitation is moderate.

Significant Present and Forecast Weather Codes				
Qualifier		Weather Phenomena		
Intensity or Proximity	**Descriptor**	**Precipitation**	**Obscuration**	**Other**
- Light	MI - Shallow	DZ - Drizzle	BR - Mist	PO - Dust/Sand Whirls (Dust Devils)
Moderate (no Qualifier)	BC - Patches	RA - Rain	FG - Fog	SQ - Squall
+ Heavy (well developed in the case of FC and PO)	BL - Blowing	SN - Snow	FU - Smoke	FC - Funnel Cloud(s) (tornado or water spout)
VC - In the vicinity	SH - Shower(s)	IC - Ice Crystals (Diamond Dust)	VA - Volcanic Ash	SS - Sandstorm/ Duststorm
	TS - Thunderstorms	PL - Ice Pellets	DU - Widespread Dust	
	FZ - Freezing (Super - Cooled)	GR - Hail	SA - Sand	
	PR - Partial (covering part of aerodrome)	GS - Small hail - (<5 mm in diameter and/ or snow pellets)	HZ - Haze	
		UP - Unknown Precipitation		
		PY - Spray		

Figure 16.6 Weather codes used in METARs.

The second column in the table, bearing the title Descriptor, contains letters which add detail to each weather phenomenon; for example, BC means patches, and is frequently used to describe fog, SH means showers, and TS means thunderstorm.

The last three columns in the table contain codes which describe the weather phenomena themselves.

The column headed Precipitation contains codes for drizzle, rain, snow, hail etc. The next column covers those weather phenomena which are classified as Obscurations; these include mist, fog, smoke, ash etc.

The last column in the table contains those weather phenomena which have not already been mentioned in the table. This group mainly consists of the more unusual weather events that are rarely reported in the United Kingdom.

Referring to the weather group of the partially complete METAR at *Figure 16.5* which indicated heavy showers of rain, +SHRA, we see that + means heavy, SH indicates showers and RA stands for rain.

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Thunderstorms.

A Thunderstorm report will appear in a METAR if thunder has been heard within the last 10 minutes.

A thunderstorm is represented by the letters TS. If there is no precipitation, the letters TS will appear on their own. However, if there is precipitation, a further two letters, which signify the type of precipitation, are inserted after the TS. For example, if there is rain observed from the thunderstorm, TSRA will appear in the METAR. If hail were to be observed, the code would read TSGR, or TSGS, with GS meaning small hail.

Cloud Coverage.

The next code-group to appear in the METAR gives detail of **cloud coverage**, as highlighted in red, in *Figure 16.7*, below.

METAR EGTK 211020Z 26012G25KT 1400 R30/1100 +SHRA OVC020CB

Figure 16.7 This highlighted code means "overcast sky, base 2000 feet, with cumulonimbus".

There are several prefixes which are used to describe cloud amount, at any given level. Cloud coverage is reported in the METAR using the following three-letter codes:

- **FEW (FEW)** meaning **one to two eighths** of cloud coverage.
- **SCATTERED (SCT)** meaning **three to four eighths** of cloud coverage.
- **BROKEN (BKN)** meaning **five to seven eighths** of cloud coverage.
- **OVERCAST (OVC)** meaning **complete cloud coverage**, or **eight eighths.**

Figure 16.7 illustrates the different classifications of cloud coverage.

CLOUD COVERAGE.

$^1/_8$ - $^2/_8$ sky obscuration = FEW

$^3/_8$ - $^4/_8$ sky obscuration = SCT

$^5/_8$ - $^7/_8$ sky obscuration = BKN

complete sky coverage = OVC

Figure 16.7 In the METAR, cloud is reported as FEW, SCT, BKN and OVC.

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Cloud base is given as a three-digit figure showing hundreds of feet. Cloud base in a METAR is always measured as height above aerodrome level, using the current aerodrome QFE.

For example, 6 eighths of cloud (6 oktas) at 1 900 feet above aerodrome level would appear in the METAR as BKN019. 8 oktas at five hundred feet would be abbreviated to **OVC005**.

The only cloud types that are specified in the METAR are the **s**ignificant convective clouds. These are cumulonimbus **(CB)** and towering cumulus **(TCU)**.

Looking back to the cloud group, highlighted in *Figure 16.7*, we see the code **OVC020CB**. This refers to an overcast sky covered by cumulonimbus cloud whose base is 2 000 ft above aerodrome level. The previous weather group**, +SHRA,** indicates that the cloud detailed in the cloud group is producing a heavy shower of rain. If there is no cloud observed at the airfield, the code **SKC**, meaning sky clear, is used.

Obscuration.

If the sky at an aerodrome is obscured for reasons other than cloud cover, and cloud coverage cannot easily be determined, the code **VV** is used in place of the cloud information. **VV** is followed by the **vertical visibility** in hundreds of feet.

METAR EGTK 231020Z 26005KT 300FG OVC VV002
(a) (b) (c)

Figure 16.8 The highlighted codes in this METAR indicate that visibility is 300m in fog (a), the sky is overcast (b), and the vertical visibility is 200ft (c).

The METAR shown in *Figure 16.8,* decodes as follows:

METAR for Oxford/Kidlington, observed at 1020 UTC on 23rd of the month; the surface wind is 260º True, at 5 knots; the visibility is 300 m in fog **(a)**; the sky is overcast **(b)**, and a vertical visibility of 200 ft has been reported **(c)**.

If the vertical visibility cannot be assessed, three forward slashes will replace the cloud height figures, e.g. **VV///**.

The code **CAVOK** is frequently used in the METAR code, being the abbreviation for "cloud, (or ceiling) and visibility are OK." If **CAVOK** is used, it will replace the visibility, RVR, weather and cloud groups. There are four criteria which must be met in order for **CAVOK** to appear in the METAR. These are:

- the visibility must be 10 kilometres or more.
- the height of the lowest cloud must be no less than 5 000 feet, or the level of highest minimum sector altitude, whichever is the greater.
- there must be no cumulonimbus present.
- there must be no significant weather.

METAR EGTK 231020Z 26012G25KT 220V300 CAVOK

Figure 16.9 CAVOK - visibility is greater than 10km, there is no cloud below 5 000ft. No cumulonimbus are present, and there is no significant weather.

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Temperature and Dew Point.

The temperature and dew point constitute the next group in the METAR code. The temperature and dew point code is simply a two-digit number giving the air temperature, with a forward slash, followed by another two-digit number which indicates the dew point. Both temperatures are measured in degrees Celsius. For example, the code **10/02** indicates that the air temperature is plus 10º C, and the dew point is plus 2º C. If either figure is **negative**, the prefix **M** will be used, as in **10/M02**. The dew point in the example just given is minus 2º C.

METAR EGTK 231020Z 26012G25KT 220V300 CAVOK 10/M02

Figure 16.10 Temperature +10ºC, dew point -2ºC.

The METAR in *Figure 16.10, above*, decodes as follows:

METAR for Oxford/Kidlington, observed at 1020 UTC on 23rd of the month; the surface wind is 260º (True) at 12 knots, gusting to 25 knots and varying in direction from 220º (T) to 300º (T); the visibility is 10 km or more, with no cloud below 5 000 ft; there are no cumulonimbus and there is no significant weather at, or in the vicinity of, the aerodrome; the air temperature is +10º C and the dew point is -2º C.

QNH.

The next METAR code is the QNH. The QNH will be represented by the letter **Q**, followed by a four digit number representing the actual pressure value. If the QNH is less than 1 000 millibars, the value will be preceded by a zero. For example, a QNH of 991 millibars would appear as **Q0991**. *(See Figure 16.11).*

METAR EGTK 231020Z 26012G25KT 220V300 9999 -RA FEW060 SCT120 10/M02 Q0991

Figure 16.11 QNH 991 millibars.

It is important to note that the only pressure value given in a METAR is the QNH. The QNH is always rounded down for safety reasons, if there are digits after the decimal point; for instance, if the QNH were 991.7 millibars, the QNH would be reported as **Q0991**.

The METAR in *Figure 16.11* decodes as follows:

METAR for Oxford/Kidlington observed at 1020 UTC on 23rd of the month; the surface wind is 260º (T) at 12 knots, gusting to 25 knots, and variable in direction from 220º (T) to 300º (T); the prevailing visibility is 10 km or more with light rain; there are 1 to 2 oktas of cloud at 6 000 ft and 3 to 4 oktas at 12 000 ft; the air temperature is +10º C and the dew point is -2º C; the QNH is 991 millibars.

Recent Weather.

If there has been recent significant weather, either in the past hour, or since the last METAR was issued, and if the significant weather has ceased, or reduced in intensity, a METAR code group beginning with **RE** will appear. **RE** stands for recent. If there has been a thunderstorm during the hour, but which has now abated, giving only light rain, the present weather is reported as light rain, **–RA**; the fact that there have been thunderstorms in the past hour is reported by the four-letter code **RETS**:

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METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS

Figure 16.12 The Code RETS indicates recent thunderstorm activity.

Windshear.

Although not currently issued at United Kingdom airfields, windshear information may be reported in the METAR. This will simply be denoted by the letters **WS**, followed by the necessary details, such as **WS ALL RWY**, meaning windshear on all runways, or **WS 30**, meaning windshear present on Runway 30.

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY

Figure 16.13 WS ALL RWY indicates that windshear is present, on all runways.

TREND, BECMG, TEMPO.

A **TREND** forecast is valid for 2 hours after the time of the observation of the METAR, and constitutes the final section of the METAR. The change in weather conditions indicated by the code, **TREND**, can be further qualified by the codes, **BECMG,** meaning **becoming**, or **TEMPO** meaning temporarily.

The TREND forecast in a METAR message is valid for 2 hours after the time of the observation.

BECMG indicates that the change in the present weather will be long-lasting. **TEMPO**, on the other hand, means that the change is temporary, and that the different conditions will prevail for periods of less than one hour, only, and no more than half the time period, in aggregate. The codes may be followed by a time period in hours and minutes. The time periods given may be preceded by **FM** meaning from, **TL** meaning until, or **AT** meaning at.

BECMG indicates a permanent change in weather conditions from the time indicated; TEMPO indicates a temporary change of one hour or less.

For example, **TEMPO FM1020 TL 1220 1000 +SHRA** translates as: temporarily, from 1020Z to 1220Z, the visibility will reduce to 1 000 metres, in heavy showers of rain.

If there is no expected change in the meteorological conditions being forecast by the **METAR**, the code **NOSIG** is used to indicate that no significant change is expected in the next two hours.

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY NOSIG

Figure 16.14 NOSIG shows No Significant Change.

SNOWTAM.

An additional eight-figure runway-state code will be added after any **TREND** information, when there is **snow** or other runway contamination. This code is sometimes referred to as a **SNOWTAM**.

The **SNOWTAM** takes the form;

- runway designator.
- runway deposits.
- extent of runway contamination.
- depth of deposit.
- the braking action.

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In order to decode a **SNOWTAM**, a pilot should consult the UK AIP, GEN 3.5.10, Meteorological Codes.

SPECIAL REPORTS.

A variation on the METAR is the Special Report. A Special Report, which is denoted by the abbreviation, **SPECI**, has the same format as a METAR except that the code **SPECI** will replace METAR at the beginning of the report. A **SPECI** will be issued when the weather conditions significantly change in the period between routine observations. A **SPECI** can be issued to indicate either an improvement or a deterioration in the weather.

SPECI EGTK 231025Z 26012G25KT 220V300 2000 +RA OVC010 5/M02 Q0991 RETS WS ALL RWY NOSIG

Figure 16.15 SPECI denotes a Special Report.

END OF MESSAGE.

An equals sign (=) appears at the end of the METAR to denote that the message is complete.

METAR EGTK 231020Z 26012G25KT 220V300 9999 –RA FEW060 SCT120 10/M02 Q0991 RETS WS ALL RWY NOSIG =

Figure 16.16 = denotes the end of the message.

SUMMARY.

Although METARs may appear confusing to the uninitiated, with practice, it is quite a simple task to decode a METAR accurately and speedily. Pilots should consult METARs for departure and destination aerodromes and also for other aerodromes along the planned route, and, in particular, for aerodromes upwind of a destination aerodrome, in order to get a picture of the weather which is approaching the destination.

If the aerodrome of destination does not issue a METAR, consult a METAR from an aerodrome in the vicinity of your destination.

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Representative PPL - type questions to test your theoretical knowledge of The METAR.

1. When a TREND is included at the end of a METAR, the TREND is a forecast valid for:

   a. 1 hour after the time of observation
   b. 2 hours after the time of observation
   c. 2 hours after it was issued
   d. 1 hour after it was issued

2. A METAR is:

   a. A routine weather report for a large area
   b. An aerodrome forecast containing a TREND for the next 2 hours
   c. A routine weather report concerning a specific aerodrome
   d. A weather forecast concerning a specific aerodrome

3. In the METAR shown below, the cloud base has been omitted. At what height might you expect the cloud-base to be if cumulus cloud was present? 28005KT 9999 SCT??? 12/05 Q1020 NOSIG

   a. SCT042
   b. SCT020
   c. SCT280
   d. SCT024

4. Which of the following correctly decodes the METAR shown below?

   METAR EGKL 130350Z 32005KT 0400N DZ BCFG VV002

   a. Observed on the 13th day of the month at 0350Z, surface wind 320º (T), 05 knots, minimum visibility 400 metres to the north, moderate drizzle, with fog patches and a vertical visibility of 200 ft
   b. Reported on the 13th day of the month at 0350Z, surface wind 320º (M), 05 knots, minimum visibility 400 metres to the north, moderate drizzle, with fog patches and a vertical visibility of 200 ft
   c. Valid on the 13th day of the month between 0300 and 1500Z, surface wind 320º (T)/05 knots, minimum visibility 400 metres, drizzle, with fog patches and a vertical visibility of 200 ft
   d. Valid between 1300 and 1350Z, surface wind 320º (T)/05 knots, minimum visibility 400 metres to the north, moderate drizzle, with fog patches and a vertical visibility of 200 ft

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5. A temperature group of 12/06 in a METAR means that:

   a. the temperature is 12ºC at the time of reporting, but it is expected to become 6ºC by the end of the TREND report
   b. the dry bulb is 12ºC and the wet bulb temperature is 6ºC
   c. the dew point is 12ºC and the temperature is 6ºC
   d. the temperature is 12ºC and the dew point is 6ºC

6. Providing the minimum sector altitude is not a factor, CAVOK in a TAF or METAR:

   a. means visibility 10 km or more, and no cloud below 5 000 ft
   b. means visibility 10 km or more, and few cloud below 5 000 ft
   c. means visibility 10 nm or more, and no cloud below 5 000 ft
   d. means visibility 10 nm or more, and no scattered cloud below 5 000 ft.

7. The visibility group R20/0050 in a METAR means:

   a. as measured by runway measuring equipment for Runway 20, a current visibility of 50 metres
   b. for Runway 20, a current visibility of 500 metres measured by runway visual range equipment
   c. the runway visibility reported is 50 metres as measured by runway visual range equipment in the last 20 minutes
   d. on Runway 20 the current viability is less than 5 000 metres

8. The code “BECMG FM 1100 –RASH” in a METAR means:

   a. from 1100UTC, the cessation of rain showers
   b. becoming from 1100UTC slight rain showers
   c. becoming from 1100UTC rain showers
   d. becoming from 1100UTC till 0000UTC slight rain showers

Question	1	2	3	4	5	6	7	8
Answer								

The answers to these questions can be found at the end of the book.

CHAPTER 17
TERMINAL AERODROME FORECASTS

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INTRODUCTION.

Terminal Aerodrome Forecasts (TAFs) are forecasts of meteorological conditions at an aerodrome, as opposed to the report of actual, present conditions as given in a METAR. The format of the TAF is similar, however, to that of a METAR, with many of the coding groups identical in both the METAR and TAF. TAFs usually cover a period of between 9 and 24 hours, however some major airports issue TAFs covering a period of 30 hours, to meet the operational requirements of international carriers. 9-hour TAFs are issued every 3 hours, and 12 to 30-hour TAFS every 6 hours. *Figure 17.1* shows examples of typical 9-hour TAFs.

A TAF is a forecast of the weather for a specified aerodrome, over a defined period of time.

```
Kirkwall      TAF EGPA 160602Z 1607/1616 15010KT 9999
             SCT012 BKN030 PROB30 TEMPO 0713 7000 -RADZ
             SCT008 BKN012=
Aberdeen      TAF EGPD 160656Z 1607/1616 13008KT 4000HZ
             0912 5000 HZ BKN007=

Inverness     TAF EGPE 160723Z 1607/1616 VRB03KT 9999
             FEW035=

Santiago      TAF LEST 160800Z 1610/1619 24007KT 9999
             SCT040=

Valencia      TAF LEVC 160800Z 1610/1619 12008KT CAVOK
             TEMPO 1419 05006KT=
```

Figure 17.1 Examples of 9-hour TAFs.

DECODING TAFS.

The first code which appears in the TAF is the identifier, TAF. The next code is the ICAO location indicator of the aerodrome for which the report is issued. The example given below is for EGTK, Oxford, Kidlington, airport.

The Date-Time Information.

As we have established, the TAF gives a forecast for a period of time. Consequently, the date-time information in TAFs is slightly different from that given in a METAR. In the TAF, there are two items of date-time information.

The first date-time group, highlighted in red below, indicates the date and time at which the TAF was issued.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

The digits **13** identify the day of the month; this information is followed by the time in hours and minutes UTC. The above TAF, then, originates on 13th of the month, at 0600 hours, UTC. In the TAF, Coordinated Universal Time, UTC, is indicated by the letter **Z**.

The next code-group identifies the period of validity of the TAF. The day of the month is repeated, **13**, and is followed by the start of the forecast time in hours, **07**, and, then, seperated by a slash the end of the forecast time, with the day of the month repeated, **13**, and the end of the validity period in hours, **16.** If a 30 hour TAF had been issued, at 0600 hours on the 13th, the second number group would be 1413, with 14 being the date, and 13-(1300 hrs, the end of the period).

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So, in the example given below, the date and time of the origin of the report is 0600 UTC on 13th of the month, and the validity period, highlighted in red, is from 0700 UTC to 1600 UTC on the same day. This example, then, is a nine hour TAF.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Wind.

The wind codes in the TAF are the same as in the METAR. Our example TAF shows a mean wind direction of 310° (True), at a wind speed of 15 knots.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Weather.

The weather coding in the TAF is also the same as in the METAR. In our example, the visibility is 8 000m with light showers of rain.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Cloud.

Cloud coding in the TAF can be slightly different from the METAR.

If there is no cloud below 5 000 ft, or cloud cover below the minimum sector altitude, whichever is the lower, and if the codes **CAVOK** or **SKC** are not appropriate, the code **NSC** is used, which stands for no significant cloud.

You should note, too, that while cloud-coverage is reported in the TAF, in the same way as in a METAR, only cumulonimbus clouds are reported in TAFs.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018=

Our example TAF, above, is forecasting scattered cloud at 1 000 feet, with broken cloud at 1 800 feet (above the airfield).

The main TAF information ends with the cloud group. TAFs do not contain information on temperature and dew point, QNH, recent weather, wind-shear or runway state information.

Only significant changes of weather follow the cloud group. These significant changes are introduced by codes classified as forecast change indicators.

FORECAST CHANGE INDICATORS.

There are distinctive TAF codes which indicate that a change is expected in some or all of the forecast meteorological conditions. The nature of the change can vary: it may, for instance, be a rapid, gradual or temporary change. These codes are **FM** (meaning FROM), **BECMG** (meaning BECOMING), **TEMPO** (meaning TEMPORARILY), and **PROB** (meaning PROBABILITY).

The From (FM) Group.

The FROM group in a TAF is introduced by the code **FM** and marks the fact that a rapid change in the forecast conditions is expected, which will lead to the appearance of a new set of prevailing conditions becoming established at the aerodrome.

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TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 FM 1220 27017KT 4000 BKN010=

The change indicator **FM** is followed by a four-digit time group in hours, and minutes, to indicate the time at which the change is expected to begin. In our example **FM 1220** means that certain weather changes will occur from 1220 UTC. This weather **forecast** following the code **FM** supersedes the TAF forecast, prior to 1220 UTC.

*The **FM** indicator introduces what is effectively a new forecast.*

The **FM** indicator, therefore, introduces what is effectively a new forecast, associated with a new weather situation, and which supersedes the previous forecast. The **FM** group contains all the elements of a complete **T**AF forecast: wind, visibility, weather and cloud.

In the example below, highlighted in red, we read that from 1220Z until the end of the TAF period, the wind will change to be 270° (T) at 17 knots, with a prevailing visibility of 4 000 metres, and broken cloud at 1 000 feet.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 FM 1220 27017KT 4000 BKN010=

The forecast following the **FM indicator** continues either to the end of the current TAF, or until another change indicator occurs in the TAF.

The Becoming (BECMG) Group.

The change group **BECMG,** meaning becoming, is followed by a four-figure time group which indicates the period during which there will be a permanent change in the forecast conditions. However, **BECMG** marks a more gradual change in conditions than **FM**.

*The code **BECMG** marks a permanent change in the forecast weather, but which will establish itself more gradually than weather conditions introduced by the code **FM**.*

The forecast gradual change, introduced by **BECMG,** will occur at an unspecified time within the time period stated.

The following example TAF indicates that, at some time between the 0900 UTC and 1100 UTC, but definitely by 1100 UTC, the prevailing conditions will give 5 000 metres visibility, in light rain. There is no new wind information after **BECMG**, so the implication is that the wind will be as previously forecast: 310° (T) at 15 knots.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 BECMG 0911 5000 –RA=

The Temporary (TEMPO) Group.

"**TEMPO"**, meaning **t**emporarily, indicates that a change in meteorological conditions will occur at any time within the specified time period, but is expected to last less than one hour each time, and, in aggregate, will last no longer than half the time period of the complete forecast. The **TEMPO** indicator is followed by a 4-digit time group indicating the hours between which the temporary conditions are expected to begin and end.

*The code **TEMPO** introduces a temporary change in weather conditions, expected to last for less than one hour.*

The example TAF, which follows, tells us that sometime between 1200 UTC and 1400 UTC, the visibility will fall to 4 000 metres, with the weather being thunderstorms and moderate rain. There will be 5 - 7 oktas of cumulonimbus cloud at 1 000 ft. However, after 1400 UTC, the weather will return to the conditions specified in the first part of the message.

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TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 TEMPO 1214 4000 TSRA BKN010CB=

PROB30 indicates a low probability of a change occurring.

PROB40 indicates a high probability of a change occurring.

The Probability (PROB) Indicator.

The code **PROB** (meaning probability) in a TAF indicates the probability of the occurrence of specified weather phenomena.

The probability indication is a percentage probability of the occurrence of significant weather events such as thunderstorms and associated precipitation. A probability of 30% is considered a low probability where as a probability of 40% is considered a high probability that the weather being forecast will actually occur. The code **PROB** can be followed by a time group of its own, and/or by an indicator, such as **BECMG** or **TEMPO**.

The example TAF below tells us that there is a high probability that, between 1000 UTC and 1400 UTC, there will be thunderstorms with heavy rain and hail, and from 3 to 4 oktas of cumulonimbus clouds at 500 ft.

The storms will not last longer than one hour at a time and no more than two hours in total, which is one half of the period to which the TAF applies.

TAF EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 PROB40 TEMPO 1014 +TSRAGR SCT005CB=

Amendment.

When a **TAF** requires an **amendment**, the amended forecast may be indicated by the code **AMD**, highlighted in red, after the **TAF identifier**, as shown below:

TAF AMD EGTK 130600Z 1307/1316 31015KT 8000 –SHRA SCT010 BKN018 PROB40 TEMPO 1014 +TSRAGR SCT005CB=

Figure 17.2 PROB40 TEMPO1014 +TSRAGR SCT005CB.

Used correctly, **TAFs** will enable a pilot to make accurate and informed decisions about a planned flight, including the expected conditions en-route, and at destination and alternate aerodromes.

End of Message.

An equals sign **(=)** appears at the end of the **TAF** to denote that the message is complete.

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Representative PPL - type questions to test your theoretical knowledge of Terminal Aerodrome Forecasts.

1. The weather group **RERA** in a TAF means:

   a. rain in retreat
   b. recent rain
   c. returning rain
   d. retreating rain

2. **TEMPO** in a TAF means:

   a. a temporary variation to the main forecast that will last for less than one hour or, if recurring, for less than half the period indicated
   b. a temporary variation to the main forecast lasting less than an hour
   c. the development of unpredictable conditions that may be a hazard to aviation
   d. a variation to the base line conditions laid down in the main forecast that will continue to prevail until the end of the main forecast

3. The weather group **SHSNRA** in a TAF means:

   a. slight showers of snow and rain
   b. moderate showers of snow and rain
   c. heavy showers of snow and rain
   d. recent snow showers

4. A TAF time group 0220 means that the TAF:

   a. is a short range forecast only, at 0220 UTC
   b. was observed at 0220 UTC
   c. was issued at 0220 UTC
   d. is a long range forecast for the 18 hour period from 0200 UTC to 2000 UTC

5. **BECMG 1820 BKN030** in a TAF means:

   a. becoming between 1800 UTC and 2000 UTC 3-4 oktas of cloud at 300 ft AGL
   b. becoming from 1820 UTC 5-7 oktas of cloud at 3000 ft AGL
   c. becoming from 1820 UTC 3-4 oktas of cloud at 3000 ft AGL
   d. becoming between 1800 UTC and 2000 UTC 5-7 oktas of cloud at 3000 ft AGL

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6. Which of the following correctly decodes a TAF that reads:

EGLL 0615 VRB08KT 9999 SCT025=

a. Valid from 0600 UTC to 1500 UTC; surface wind variable at 8 knots; visibility 10 nm or more; with a cloud base of 2 500 ft above mean sea level
b. Observed at 0615 UTC; the surface wind was variable in direction and speed; averaging 8 knots; with a visibility of 10 km or more, and a cloud base of 2 500 ft above aerodrome level
c. Valid from 0600 UTC to 1500 UTC; surface wind will be variable at 8 knots, with a visibility 10 km or more; 3-4 oktas of cloud with a base of 2 500 ft above aerodrome level
d. Observed at 0600 UTC; the surface wind was variable in direction and speed; with a visibility of 10 km and a cloud base of 2 500 ft above ground level

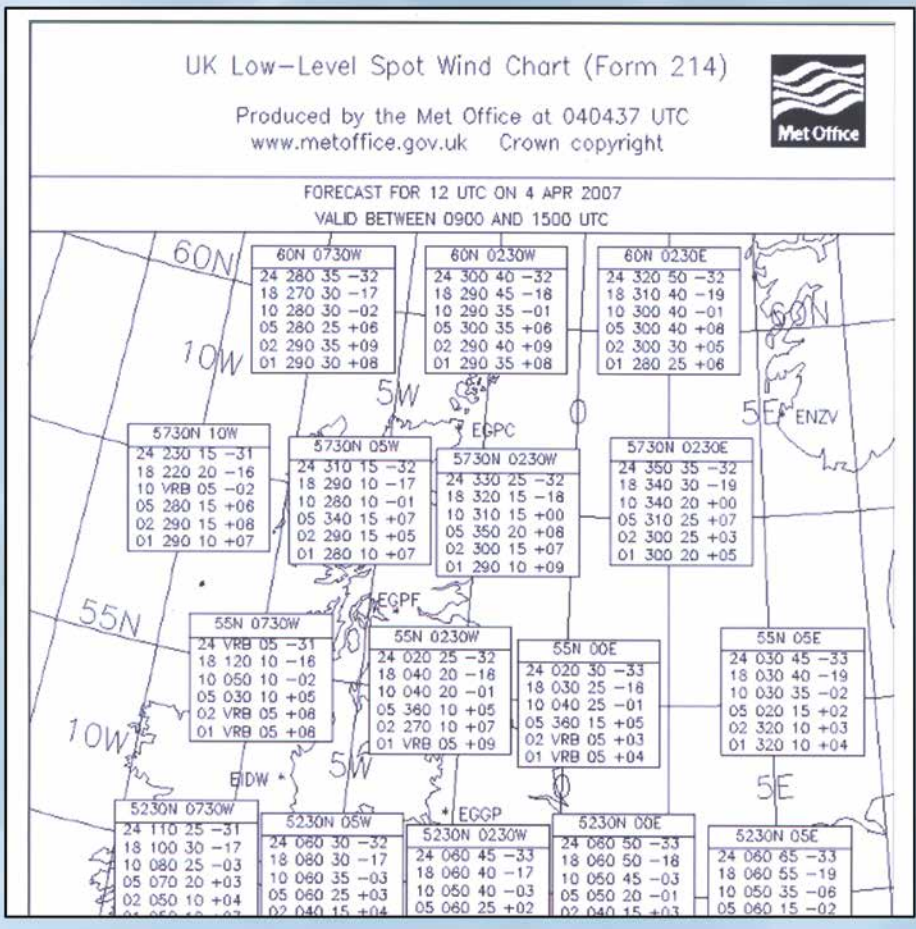
7. The correct decode for a **TAF 0615 14025G40KT 1200 BR** would be:

a. The forecast is for a nine hour period from 0615 UTC with a surface wind of 140º M at 25 knots gusting 40 knots, visibility 1 200 metres in mist
b. The forecast is for a nine hour period from 0615 UTC with a surface wind of 140º T at 25 knots, visibility 1 200 metres in fog
c. The forecast is for a nine hour period from 0600 to 1500 UTC with a surface wind of 140º M at 25 knots gusting 40 kts, visibility 1 200 metres in broken patches
d. The forecast is for a nine hour period from 0600 to 1500 UTC with a surface wind of 140º T at 25 knots gusting 40 kts, visibility 1 200 metres in mist

Question	1	2	3	4	5	6	7
Answer							

The answers to these questions can be found at the end of the book.

CHAPTER 18
THE SPOT WIND CHART



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INTRODUCTION.

The Spot Wind Chart is an excellent briefing tool, informing pilots of the forecast wind velocity and air temperature for altitudes up to 24 000 ft, at different locations above the Earth's surface. In the United Kingdom, the Spot Wind Chart is referred to as Form 214.

In the UK, Spot Wind Charts are issued 4 times a day.

At the top of every Spot Wind Chart, there is information on validity times. Since there are 4 issues of this chart every day, it is important to ensure that the one consulted covers the time period of the planned flight.

The Spot Wind Chart gives wind velocities and air temperatures, for altitudes from 1 000 ft to 24 000 ft.

FORECAST AND VALIDITY PERIODS.

The Spot Wind Chart is a forecast of wind conditions expected on a given date for a specified time. In the example chart in *Figure 18.1,* the forecast is for 4th April 2007 at 1200 UTC, but valid during the period extending from three hours prior to this time, i.e. from 0900 UTC, until three hours after the forecast time, that is, until 1500 UTC.

The Spot Wind Chart (Form 214) is a forecast for a specified time, but the information is valid from 3 hours before that time until 3 hours beyond the forecast time.

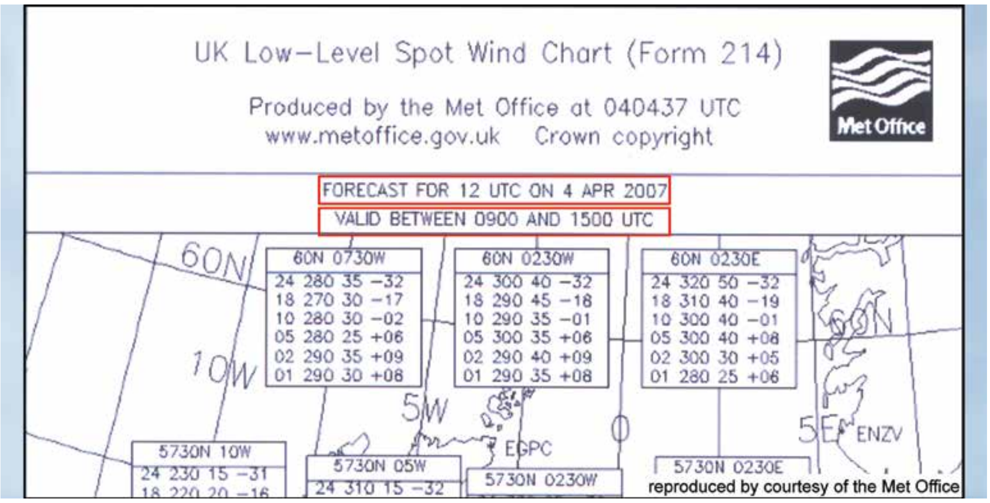

Figure 18.1 An example of the Spot Wind Chart (Form 214).

Currently, in the United Kingdom, Spot Wind Charts (Form 214) can be accessed free of charge on the UK Met Office website (www.metoffice.gov.uk) under the page-title Services for General Aviation.

INFORMATION ON THE SPOT WIND CHART.

The Spot Wind Chart shows a map of the Earth's surface overlaid with boxes containing wind information for a defined spot or location identified by that location's latitude and longitude. The co-ordinates of the locations appear at the top of each box. *Figure 18.2, overleaf,* shows a Spot Wind Chart for the British Isles. The wind information box for 60º N 2º 30' W is highlighted. Notice that the box overlies the intersection point of the latitude and longitude co-ordinates to which the wind information pertains.

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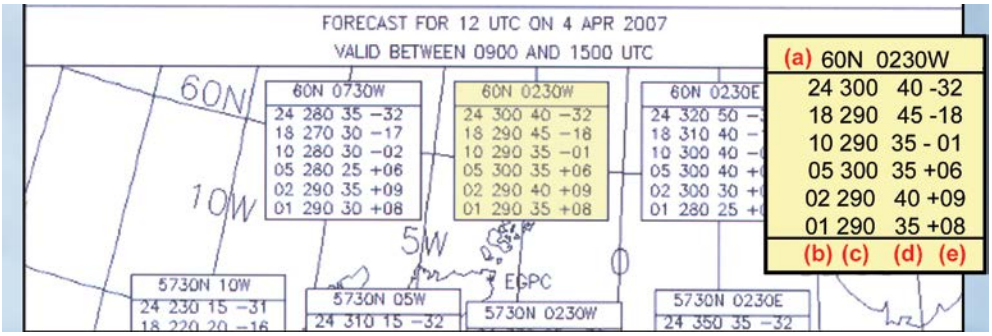

Figure 18.2 Information boxes at the intersection of certain lines of latitude and longitude contain wind information for that defined "spot" on the Earth's surface.

In the Spot Wind Chart, wind direction is in degrees True.

Underneath the co-ordinates, for each box, there are four columns containing data concerning the wind. (*See Figure 18.3*.)

The column on the extreme left gives the altitude, in thousands of feet above sea-level, for which the wind forecast is made.

In the Spot Wind Chart, level information is ***altitude*** *above mean sea-level.*

The next column along shows the forecast wind direction which is given in ten degree intervals and referenced to True North.

Next follows the wind speed, in knots, in 5 knot increments. Occasionally, the abbreviation VRB will be used to denote a variable wind direction, when the wind speed is less than 5 knots.

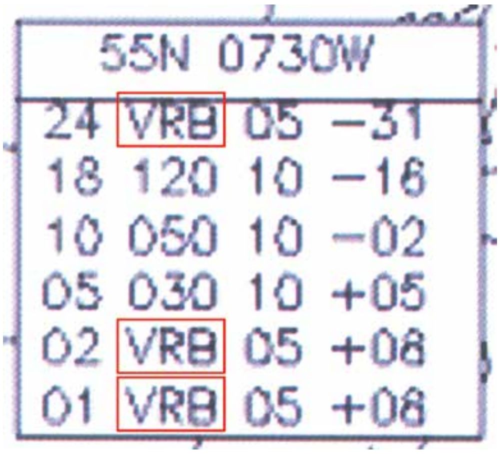

Figure 18.3 A Wind Information Box.

The final column gives the air temperature to the nearest whole degree Celsius, with either a positive or negative prefix.

THE SPOT WIND CHART AND FLIGHT PLANNING.

When using a ***Spot Wind Chart*** *in order to obtain the forecast wind for the altitude and region of your planned flight, you may need to* ***interpolate****.*

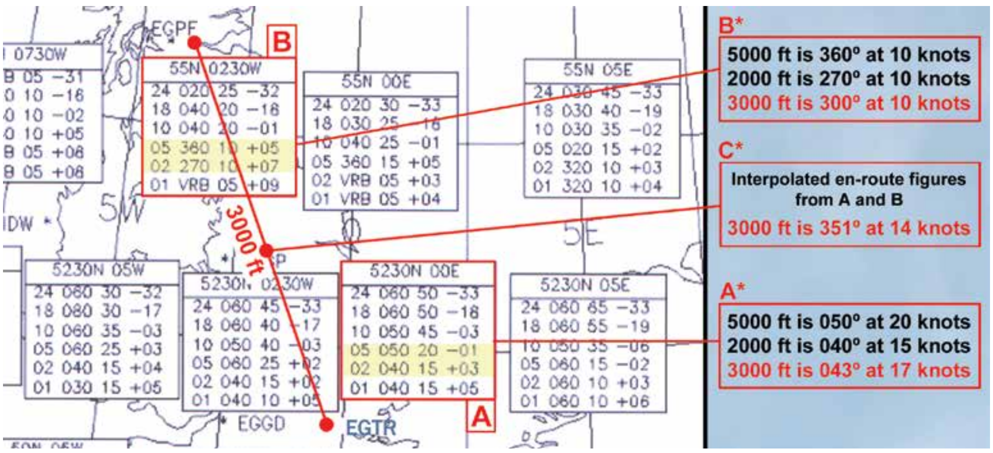

Figure 18.4 Interpolation of wind velocity for different altitudes and locations on a route from Elstree to Edinburgh.

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When using the **Spot Wind Chart** for flight planning and flight briefing, **interpolation** of the **spot wind** figures may be necessary, if the **wind** figures that the pilot requires for his **planned flight** are between the **co-ordinates** and **altitudes** given in the boxes.

The verb interpolate means to estimate unknown values from the known values in a series of data.

Figure 18.4 shows the planned track of a flight from Elstree (EGTR) to Edinburgh (EGPF) superimposed on a Spot Wind Chart. As the weather and visibility for the flight are forecast to be good along the route, the pilot plans to fly most of the route at 3 000 feet above mean sea-level, and has declared a safety altitude of 4 500 feet.

The pilot's initial flight planning concern, therefore, is to determine the wind speed and direction at 3 000 feet, along the route. The pilot decides, therefore, to record in his flight log, the wind velocities at 3 000 feet, that he will extract from the current Spot Wind Chart for the departure and destination regions and for the route mid-point.

But, as the winds on the Spot Wind Chart are not given for 3 000 feet, in order to extract the wind information he needs, the pilot will have to interpolate for altitude along the whole route. For the route mid-point, he will also need to interpolate laterally for location.

Interpolation of Spot Wind Chart Data.

On the right hand side of *Figure 18.4,* in the column shaded in blue, you will see the interpolations of the spot wind figures, shown in red, that the pilot has made to obtain the winds at 3 000 feet, along the route.

Box A contains the wind direction and wind speed figures forecast for 2 000 feet and 5 000 feet, at 52º 30' N 0º E. **Box A** is the nearest to the departure aerodrome of Elstree. The pilot decides, therefore, that **Box A** will give him the wind for the first part of his flight, but, as we have pointed out, he sees that he will have to interpolate to find the forecast wind speed and direction at 3 000 feet. The interpolated figures for 3 000 feet are shown in red i**n** *Figure 18.4*.

Interpolation of Wind Direction in Box A.

To arrive at the wind direction for 3 000 feet in Box A, the pilot must first find the difference between the wind direction figures at 5 000 feet and 2 000 feet. This is done as follows:

At **5 000 feet**, the **wind direction** is from **050º**.
At **2 000 feet**, the **wind direction** is from **040º**.

We see, then, that the wind changes direction by 10º between 2 000 feet and 5 000 feet. As there are 3 000 feet between the altitudes 2 000 feet and 5 000 feet, the pilot divides 10º by 3 in order to obtain the average change in wind direction per 1 000 feet.

10° ÷ 3 = 3.3333°, which approximates to **3° per 1 000 feet**. We note, then, that the wind is **changing by 3° per 1 000 feet** between **2 000 feet** and **5 000 feet**.

As there is 1 000 feet between 2 000 feet and the pilot's planned cruising altitude of 3 000 feet, the pilot can now easily calculate that the forecast wind direction at **3 000 feet** will be: **40° + 3° = 043°.**

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Interpolation of Wind Speed in Box A.

To interpolate values for the wind speed, the same method is used as for the interpolation of wind direction. Taking the figures from **Box A**:

At **5 000 feet,** the **wind speed** is **20 knots**.
At **2 000 feet,** the **wind speed** is **15 knots**.

So, between 2 000 feet and 5 000 feet, the wind increases in strength by 5 knots.

Dividing 5 knots by 3, to obtain the mean difference in wind speed per 1 000 feet, we obtain 1.666 knots per 1 000 feet, which is 2 kts per 1 000 feet, to the nearest knot.

Therefore, the approximate wind speed at **3 000 feet** is:

15 knots + 2 knots = 17 knots.

So, for the first part of the route, the pilot has calculated that the wind direction is 043° (True), and its speed is 17 knots.

Wind Velocity for the Final Part of the Route.

The interpolation for wind at any altitude can be made using the method just demonstrated.

The pilot is easily able to interpolate, therefore, that the wind at 3 000 feet for the final part of the route, as he approaches Edinburgh, is forecast to be 10 knots from 300° (True).

Interpolation of the Mid-Route Wind Velocity.

The pilot must now interpolate wind direction and speed for the region approximating to the mid-point of the route. This calculation may be made using the same interpolation method as for the previous examples.

We have already calculated that the 3 000 feet wind at the beginning of the route will be 043°/17 knots, and that the 3 000 feet wind approaching Edinburgh should be 300°/10 knots.

In order to arrive at the wind at the mid-route point, then, the pilot must interpolate laterally between 043°/17 knots and 300°/10 knots. This means that he must take the mean value of these two wind directions and wind speeds. Consequently, the pilot calculates that the wind at 3 000 feet, at the route mid-point, should be about 351°/14 knots.

Interpolation of Air Temperature.

Air temperature at different altitudes may also be found using interpolation. For instance, let us assume that the pilot wishes to know the 0°C altitude on the approach to Edinburgh. He sees from the Box for 55° N 2° 30' W that the temperature at 10 000 feet is -01°C, and that the temperature at 5 000 feet is +05°C. He estimates, therefore, that the 0°C altitude must be at about 9 000 feet.

Other Sources of Wind Information for Flight Planning.

Although the Spot Wind Chart contains much useful information pertinent to flight planning, the pilot will almost certainly need to supplement this information with data from other forecast documentation such as Low Level Forecast Charts and relevant TAFs and METARs.

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Representative PPL - type questions to test your theoretical knowledge of Spot Wind Charts.

1. Referring to the diagram below, estimate the wind velocity and temperature at 10 000 ft over position 50° N, 0° E.

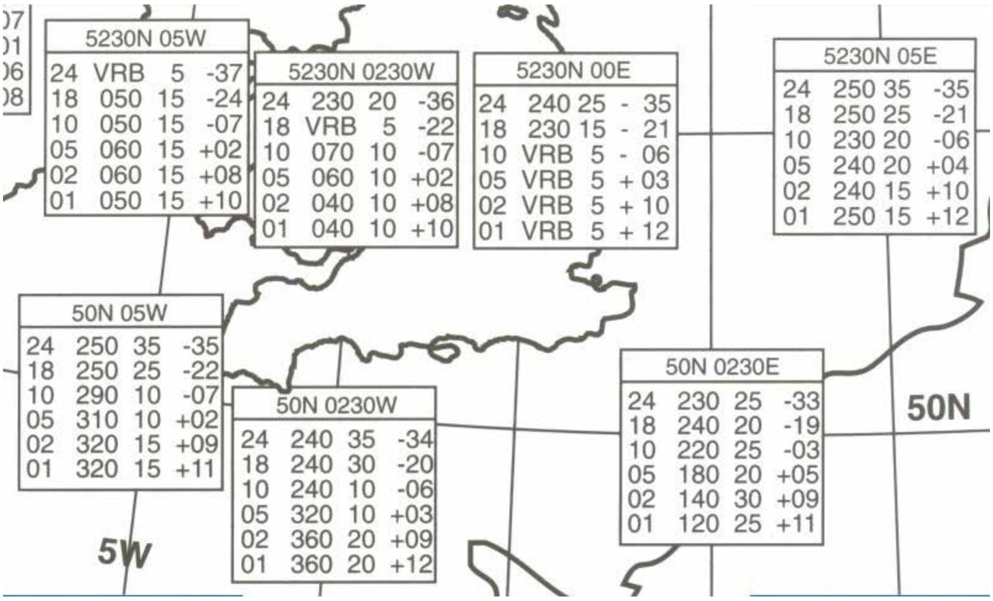

Diagram 1.

a. 240/10 -6°C
b. 230/17 -4°C
c. 220/25 -3°C
d. 120/25 +11°C

2. In the United Kingdom, how many times is the Spot Wind Chart (F214) issued in a 24 hour period?

a. 2
b. 4
c. 6
d. 8

3. Up to what altitude does the Spot Wind Chart give wind and temperature forecasts?

a. 10 000 ft
b. 15 000 ft
c. 24 000 ft
d. 18 000 ft

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4. Referring to the diagram below, find the wind velocity and temperature at 2 000 ft at position 52º 30'N, 0ºE.

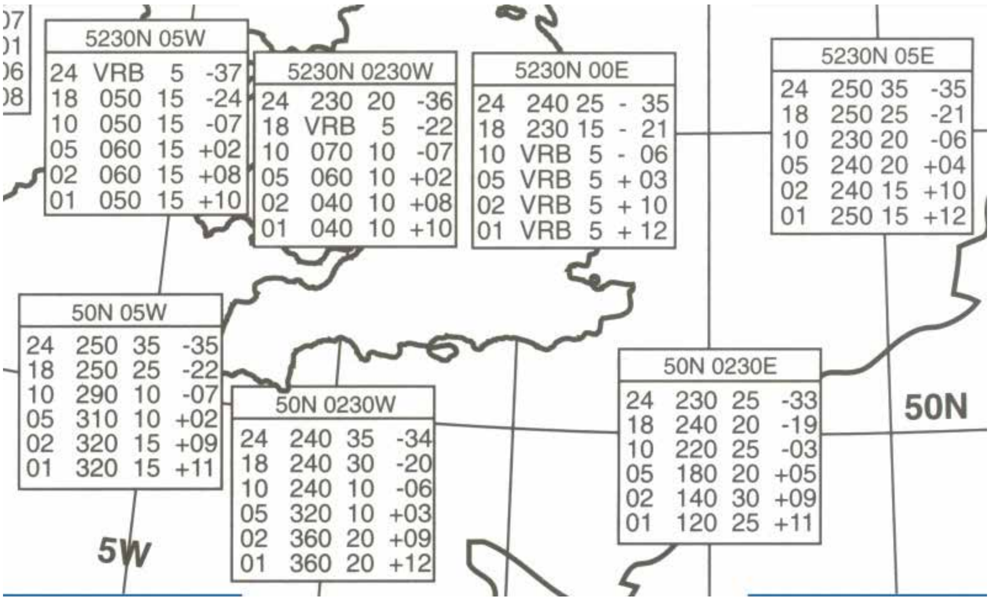


Diagram 2.

a. 240/15 kts +10º C
b. 360/20 kts +9º C
c. 140/30 kts +9º C
d. VRB/5 kts +10º C

5. Referring to *Diagram 2*, estimate the forecast wind velocity at 5 000 ft at position 50ºN, 0ºE.

a. 180/20 kts
b. 250/15 kts
c. 070/15 kts
d. 230/10 kts

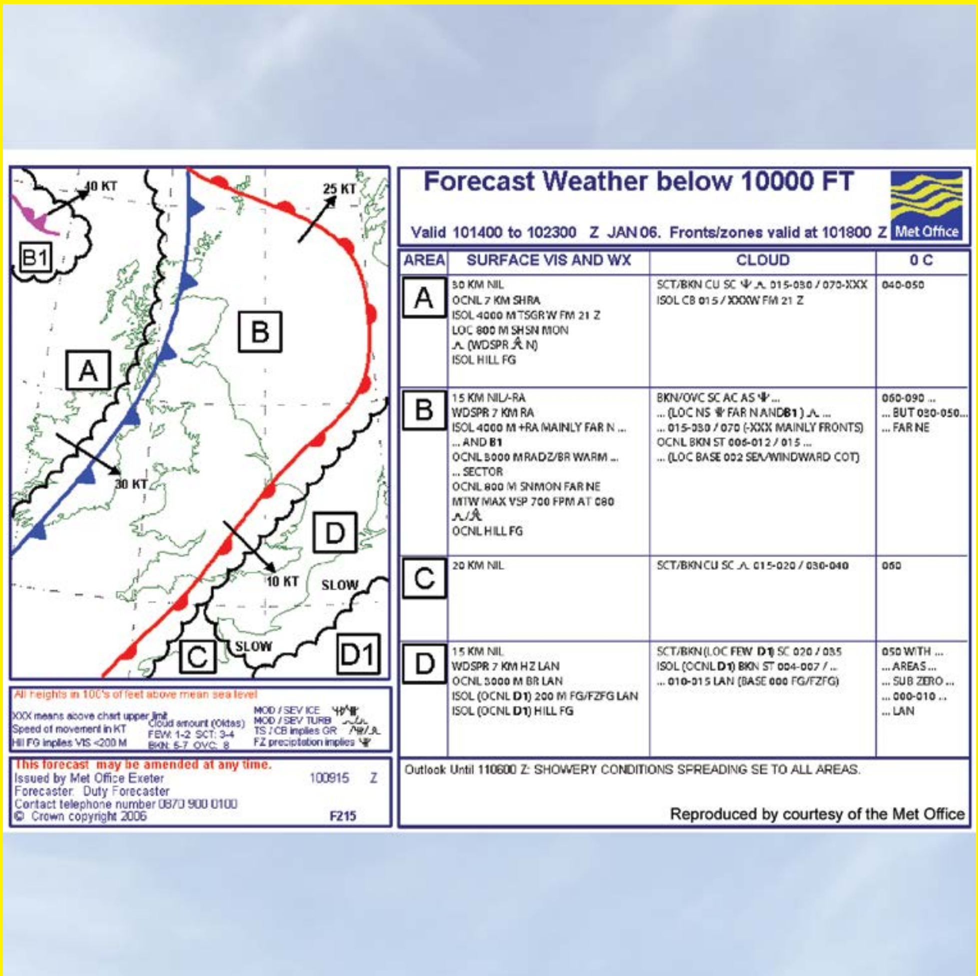
6. Referring to *Diagram 2*, estimate the 0º C altitude at 52º 30' N, 2º 30' W.

a. 6 000 ft
b. 9 000 ft
c. 8 000 ft
d. 8 500 ft

Question	1	2	3	4	5	6
Answer						

The answers to these questions can be found at the end of the book.

CHAPTER 19 LOW-LEVEL FORECAST CHARTS



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INTRODUCTION.

Low level significant weather charts are a valuable aid to successful flight planning for flights which take place below 10 000 feet. These charts indicate, in a precise and very structured format, the meteorological phenomena which are anticipated during a specified time period. In the United Kingdom, this type of chart is commonly referred to as the Form 215. It is produced every 6 hours, 365 days a year for aircraft flying below 10 000 feet over the British Isles.

Form 215 is issued every 6 hours, forecasting the weather up to 10 000 ft. Each issue is valid for 9 hours.

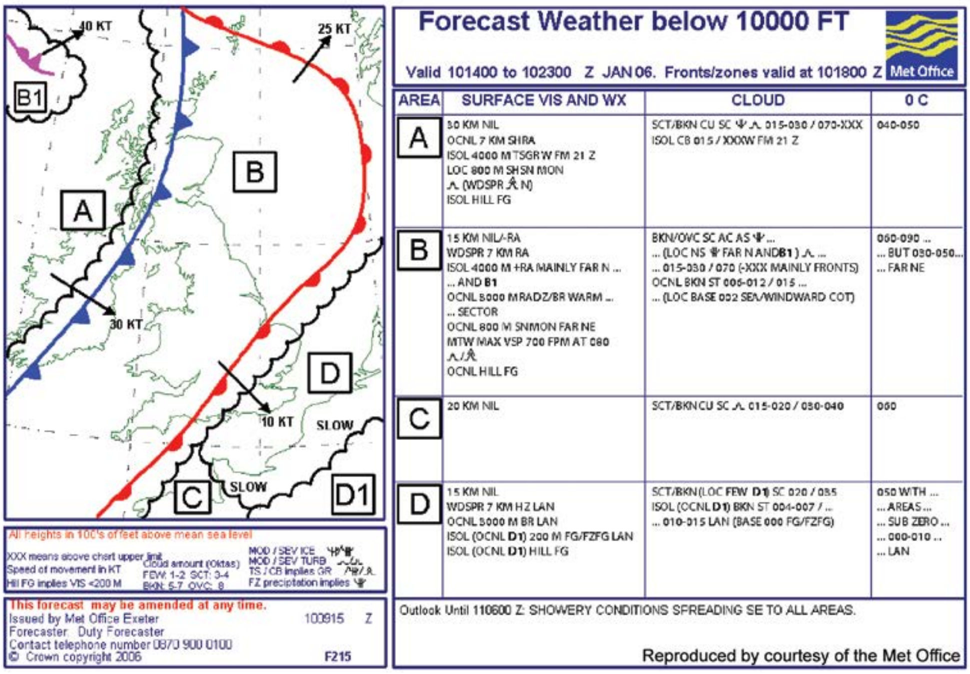

Figure 19.1 Low Level Significant Weather Chart (Form 215).

The example low level forecast chart shown at *Figure 19.1* was issued by the United Kingdom Met Office at 0915 on the 10th day of the month. This fact is indicated in the box at the bottom left of the chart, by the date-time group 100915. In the main title box at the head of the chart, the month is identified as January 2006. As you can see from *Figure 19.1*, the chart is issued approximately five hours before the start of the validity period, and is valid for a period of nine hours. The precise period of validity of the forecast is clearly identified at the top of each chart. In the example chart, the validity period is between 1400 UTC (indicated by the code letter Z) on the 10th of January, and 2300 UTC, on the same day.

Also marked in the title box is the fact that the frontal systems shown are predicted to be positioned on the chart as at 1800Z.

Currently, in the United Kingdom, Low Level Forecast Charts (Form 215) can be accessed, free of charge, from the UK Met Office website (**www.metoffice.gov.uk**) under Services for General Aviation.

THE MAP.

The left hand side of the low-level forecast chart features a schematic map showing the positions of any fronts for the specified forecast time, with the different significant weather phenomena divided into areas delineated by black scalloped lines, and identified by letters of the alphabet. Sub areas may have numbers attached to the letters. *(See Figure 19.1.)*

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In the Meteorology Examination there may be questions requiring the identification of one or more of the labelled features on the Form 215.

The chart uses standard weather symbols, with which you should be familiar.

Any **high pressure centres** are identified on the map by a small circle and the letter **H**. Any **low pressure centres** are identified by a small cross and the letter **L**.

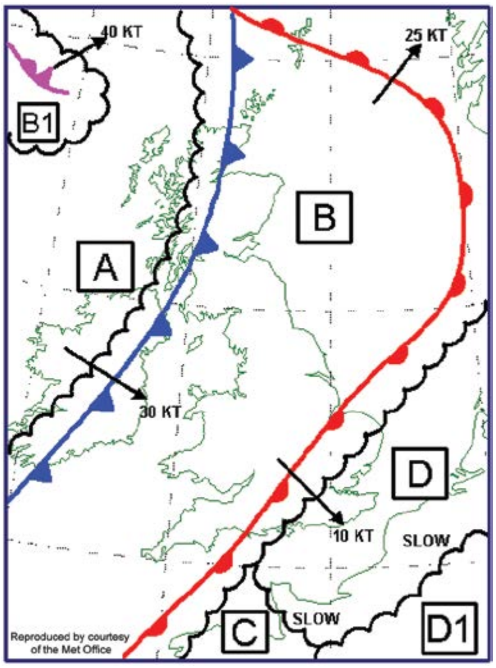

Figure 19.2 Forecast Map at a single forecast time.

Frontal boundaries and areas of weather are clearly displayed using standard symbology. In our example, you can see a warm front running North East - South West, over South East England, and a cold front behind it, of the same orientation, over Northern Scotland and Ireland.

The Form 215 map in *Figure 19.2* is divided up into 6 different areas. Each area is linked to the text contained in the main body of the chart by the area letter. The movement of fronts and area boundaries is identified by arrows which indicate the direction of movement.

The numbers which appear beside the arrows indicate the speed in knots at which the feature is moving. If a front or area boundary is stagnant, or moving at less than 5 knots, the word SLOW appears alongside the feature. *(See Figure 19.2.)*

WEATHER AREA INTERPRETATION.

Let us now look at the textual information which appears in the boxes on the right of the low level significant weather chart. *(See Figure 19.1.)* As we have mentioned, this forecast information is linked to the different areas of the map by area letters. For each area there are 3 different columns of textual information. *Figure 19.3* shows the textual information describing the meteorological conditions in Area **A**, and we will refer to Area **A** to begin our examination of the meaning of the text. The textual information is designed to follow the codes used in Terminal Area Forecasts (TAFs), with information appearing in the same order: visibility, weather, cloud.

AREA	SURFACE VIS AND WX	CLOUD	0 C
A	30 KM NIL OCNL 7 KM SHRA ISOL 4000 M TSGR W FM 21 Z LOC 800 M SHSN MON ᴧ (WDSPR ᴧ N) ISOL HILL FG	SCT/BKN CU SC ѱ ᴧ 015-030 / 070-XXX ISOL CB 015 / XXXW FM 21 Z	040-050

Figure 19.3 Area A Surface Visibility and Weather.

Surface Visibility and Weather (SURFACE VIS AND WX).

The first text column, (SURFACE VIS AND WX) of the Low Level Forecast Chart, describes the surface visibility and weather phenomena as well as the frequency and distribution of that weather. The codes VIS and WX stand for visibility and weather

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respectively. The second column contains the forecast cloud and any associated hazard. The third column details the forecast freezing levels.

The first line of text details the general conditions that are forecast to occur in a weather area. In this case, the general conditions will feature a surface visibility of 30 kilometres with nil weather.

However, some variation in conditions are forecast, within Area **A**, which may differ from the general conditions in the area. More detail on these variations is provided underneath the general information using the abbreviations **OCNL (occasional)**, **ISOL (isolated)**, **LOC (localised)**, **WDSPR (widespread)**, and **FRQ (frequent)**.

The variations in the weather include the visibility, the weather phenomena themselves, and further precise detail on when, or where, the weather phenomena will occur, such as on or near coasts, or over land, hills and mountains. These locations are abbreviated to **COT (coast)**, **LAN (land)**, **HILL** and **MON (mountain)** respectively. As we have mentioned, the coding used is similar to that used in the TAFs and METARS.

From *Figure 19.3*, then, we can see the general conditions in Area **A** are: 30 kilometres visibility with nil weather. However, occasionally the visibility will be 7 kilometres with moderate showers of rain. In isolated areas in the West, expect 4 000 metres visibility with thunderstorms (TS) and moderate hail (GR) from 2100 Zulu. Locally, around the mountains, visibility will be down to 800 metres with moderate snow showers (SHSN). There will, generally, be moderate turbulence ( ), but widespread severe turbulence (WDSPR) to the North. Lastly, in isolated areas, there will be hill fog. Hill fog implies a visibility of less than 200 metres, as shown by the information in the chart legend. *(See Figure 19.4.)*

Figure 19.4 Chart Legend.

Cloud.

The second column of information in the low-level forecast chart relates to the forecast cloud and associated weather hazards. The first line gives the general cloud conditions for the area, with variations detailed in the following lines of text.

The first element in the forecast is always the cloud amount expressed as **FEW, SCT (scattered)**, **BKN (broken)** or **OVC (overcast)**. Next follows the type of cloud, using the standard cloud abbreviations. Following the cloud type any icing and/or turbulence hazard is given.

Cloud heights come next, indicated as 100s of feet, in the format 030/060 (meaning a base of 3 000 feet with tops at 6 000 feet). If cloud tops exceed 10 000 feet, the code XXX is used.

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Severe turbulence, severe icing and hail are automatically assumed to be associated with cumulonimbus cloud.

Below, we decode the cloud information for weather Are**a A**, in *Figure 19.3*.

Generally, throughout the area, there will be scattered to **broken cumulus (CU)** and **stratocumulus (SC)** clouds. There will be a risk of moderate icing and moderate turbulence within the cloud. Cloud bases range from **1 500 feet to 3 000 feet** above mean sea-level **(AMSL)**, and cloud tops range from **7 000 feet** to above **10 000 feet AMSL**.

In isolated areas, there may be cumulonimbus clouds with bases of 1 500 feet, and tops extending to above the 10 000 feet chart level, anytime from 2100 UTC.

You should note, especially, that when cumulonimbus clouds are indicated, it is implicit that there will be associated severe icing, severe turbulence and hail.

Freezing Level.

The last column of information in the low-level forecast chart relates to the freezing level, which is given in hundreds of feet above sea level.

AREA	SURFACE VIS AND WX	CLOUD	0 C
A	30 KM NIL OCNL 7 KM SHRA ISOL 4000 M TSGR W FM 21 Z LOC 800 M SHSN MON Λ (WDSPR Λ N) ISOL HILL FG	SCT/BKN CU SC Ψ Λ 015-030 / 070-XXX ISOL CB 015 / XXXW FM 21 Z	040-050 **(a)**
B	15 KM NIL/-RA WDSPR 7 KM RA ISOL 4000 M +RA MAINLY FAR N ... ... AND **B1** OCNL 3000 M RADZ/BR WARM ... ... SECTOR OCNL 800 M SNMON FAR NE MTW MAX VSP 700 FPM AT 080 Λ/Λ OCNL HILL FG	BKN/OVC SC AC AS Ψ ... ... (LOC NS Ψ FAR N AND **B1**) Λ ... ... 015-030 / 070 (-XXX MAINLY FRONTS) OCNL BKN ST 006-012 / 015 ... ... (LOC BASE 002 SEA/WINDWARD COT)	060-090 ... ... BUT 030-050... ... FAR NE **(b)**

Figure 19.5 Freezing Levels for Area A and B.

In Area **A**, the freezing level is forecast to be between 4 000 and 5 000 feet.

Moving on to Area **B**, we see that the freezing level will be between 6 000 and 9 000 feet, but as low as 3 000 to 5 000 feet to the far North-East of the area. *(See Figure 19.5.)*

D	15 KM NIL WDSPR 7 KM HZ LAN OCNL 3000 M BR LAN ISOL (OCNL **D1**) 200 M FG/FZFG LAN ISOL (OCNL **D1**) HILL FG	SCT/BKN (LOC FEW **D1**) SC 020 / 035 ISOL (OCNL **D1**) BKN ST 004-007 / ... ... 010-015 LAN (BASE 000 FG/FZFG)	050 WITH ... ... AREAS ... ... SUB ZERO ... ... 000-010 ... ... LAN **(c)**

Figure 19.6 Freezing Levels for Area D.

In Area **D**, the main freezing level is at 5 000 feet, but, over land (LAN), there are sub zero layers of air from the ground to 1 000 feet. *(See Figure 19.6.)*

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THE OUTLOOK.

At the bottom of the chart *(Figure 19.7)* is the outlook for the 12 hours following the expiry of the main chart, at 1800 Zulu. The outlook does not go into precise detail about cloud heights and weather phenomena, but gives an indication of how the synoptic situation is expected to change.

Outlook Until 110600 Z: SHOWERY CONDITIONS SPREADING SE TO ALL AREAS.

Figure 19.7 The weather outlook for the 12 hours following the expiry of the main chart.

THE PROGNOSIS.

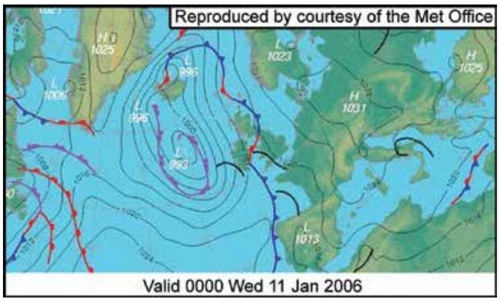
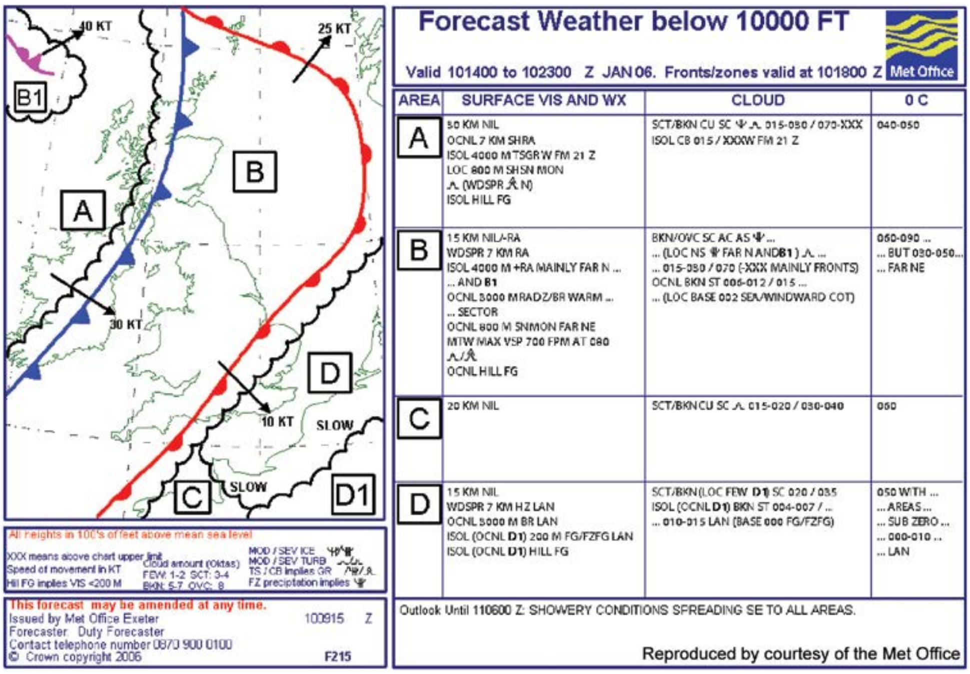


Figure 19.8 A Prognosis Chart.

An additional element of the low-level forecast chart which is not shown on Form 215, itself, but can be found beneath the chart on the Met Office website: **www.metoffice.gov.uk**, is the prognosis chart. *(See Figure 19.8.)* The prognosis is a surface pressure chart, showing conditions six hours on from the time given in the main chart for the surface position of the fronts and zones. In the case of our example map, six hours on from 1800 Zulu, on Tue 10 Jan 06, is midnight. Therefore the chart time for the prognosis would be 0000 UTC on Wed 11 Jan 2006.

SUB AREAS.

Occasionally, when conditions suit, an area will be divided into sub areas.



AREA	SURFACE VIS AND WX	CLOUD	0 C
A	30 KM NIL OCNL 7 KM SHRA ISOL 4000 M TSGR W FM 21 Z LOC 800 M SHSN MON (WDSPR N) ISOL HILL FG	SCT/BKN CU SC 015-050 / 070-XXX ISOL CB 015 / XXX W FM 21 Z	040-050
B	15 KM NIL/-RA WDSPR 7 KM RA ISOL 4000 M +RA MAINLY FAR N ... ... AND B1 OCNL 3000 M RADZ/BR WARM ... ... SECTOR OCNL 800 M SNMON FAR NE MTW MAX VSP 700 FPM AT 080 OCNL HILL FG	BKN/OVC SC AC AS ... ... (LOC NS FAR N AND B1) ... ... 015-050 / 070 (-XXX MAINLY FRONTS) OCNL BKN ST 006-012 / 015 ... ... (LOC BASE 002 SEA/WINDWARD COT)	060-090 ... ... BUT 030-050... ... FAR NE
C	20 KM NIL	SCT/BKN CU SC 015-020 / 030-040	050
D	15 KM NIL WDSPR 7 KM HZ LAN OCNL 3000 M BR LAN ISOL (OCNL D1) 200 M FG/FZFG LAN ISOL (OCNL D1) HILL FG	SCT/BKN (LOC FEW D1) SC 020 / 035 ISOL (OCNL D1) BKN ST 004-007 / ... ... 010-015 LAN (BASE 000 FG/FZFG)	050 WITH ... ... AREAS ... ... SUB ZERO ... ... 000-010 ... ... LAN

Outlook Until 110600 Z: SHOWERY CONDITIONS SPREADING SE TO ALL AREAS.

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Figure 19.9 The low-level forecast chart.

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On our example map, in *Figure 19.9*, you can see Area **B** and Sub-Area **B1**, in the top left hand corner of the chart. A sub area is shown when an area shares many weather characteristics of the main area, but may display one or two important differences.

For example, the first column for Area **B** on the chart at *Figure 19.9* tells us that the general conditions for Area **B** and, therefore, **B1**, are 15 km visibility, with possibly nil weather, or light rain. However, with this rain being widespread throughout the area, the visibility will reduce to 7 km with moderate rain.

In isolated areas, in Area **B**, the visibility will be as low as 4 000 metres in heavy rain, but this visibility will mainly be to the far North of Area **B**, while it will exist throughout Area **B1**.

The next few forecast lines do not apply to Area **B1** since Area **B1**, is not in the warm sector, nor does it have mountains or hills.

Looking at the cloud section for Area **B**, notice that there are local areas of nimbostratus giving a severe icing risk to the North of Area **B**, and throughout Area **B1**.

USING LOW-LEVEL FORECAST CHARTS.

Low level forecast charts represent one of the best self-briefing tools for the general aviation pilot and should always form part of pre-flight weather briefing.

As we have mentioned, low level forecast charts can be accessed on the UK Met Office website, free of charge. General aviation pilots who plan to fly to Europe may also obtain from the UK Met Office website a chart which encompasses a larger area of the near-continent, called Form 415. An example of a Form 415 is shown at *Figure 19.10*. Always ensure that you select the appropriate chart to cover the time period for your planned flight. There are four charts produced each day, all of which have different validity periods.

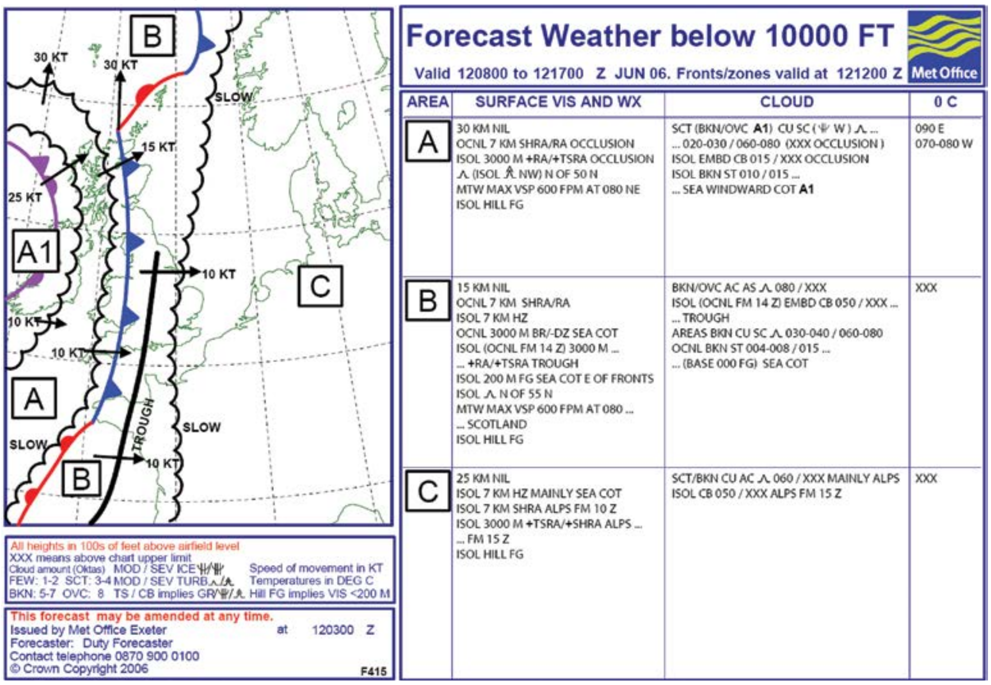

Figure 19.10 Low Level Forecast Chart for the UK and near Continent (Form 415).

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Representative PPL - type questions to test your theoretical knowledge of Low-Level Forecast Charts.

1. Referring to the Form 215 at Chart 1 on Page 257, what is the height of the freezing level over South West England?

   a. 3 000 feet
   b. 5 000 feet
   c. Between 6 000 feet and 9 000 feet
   d. Between 4 000 feet and 5 000 feet

2. Referring to Chart 1 on Page 257, what is the lowest forecast cloud base in weather Area A?

   a. 3 000 feet
   b. 7 000 feet
   c. >10 000 feet
   d. 1 500 feet

3. Referring to Chart 1 on Page 257, what is the worst turbulence and icing hazard associated with clouds that is forecast to occur in Area A?

   a. Severe icing and severe turbulence
   b. Widespread severe turbulence and moderate icing
   c. Moderate icing and moderate turbulence
   d. Moderate icing

4. Referring to Chart 1 on Page 257 in Area A, to what height above mean sea level are the cumulonimbus cloud tops forecast?

   a. 10 000 feet
   b. 15 000 feet
   c. >10 000 feet
   d. 8 000 feet

5. Referring to Chart 1 on Page 257, what will be the general weather situation in Area B?

   a. Broken or overcast stratocumulus
   b. Nil weather with 30 kilometres visibility
   c. Nil weather but occasional hill fog
   d. Generally either nil weather or light rain with widespread outbursts of rain with isolated heavy showers in the far North

6. Referring to Chart 2 on Page 258, what is the lowest forecast surface visibility over central France?

   a. 7 km
   b. 2 000 m
   c. 300 m
   d. <200 m on the hills

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7. Referring to Chart 1 on Page 257, in Area D what would be the surface visibility and weather for a flight over the English Channel?

   a. 15 km visibility with nil weather
   b. Widespread 7 km visibility in haze
   c. Occasional 3 000 m visibility in fog
   d. Isolated 200 m visibility in fog

8. Referring to Chart 2 on Page 258, what are the general weather and visibility conditions expected in the Southern part of the North Sea, just off the German and Danish coast?

   a. Showers
   b. Nil weather, 20 kilometres visibility
   c. Widespread rain and drizzle
   d. Isolated hill fog

Question	1	2	3	4	5	6	7	8
Answer								

The answers to these questions can be found at the end of the book.

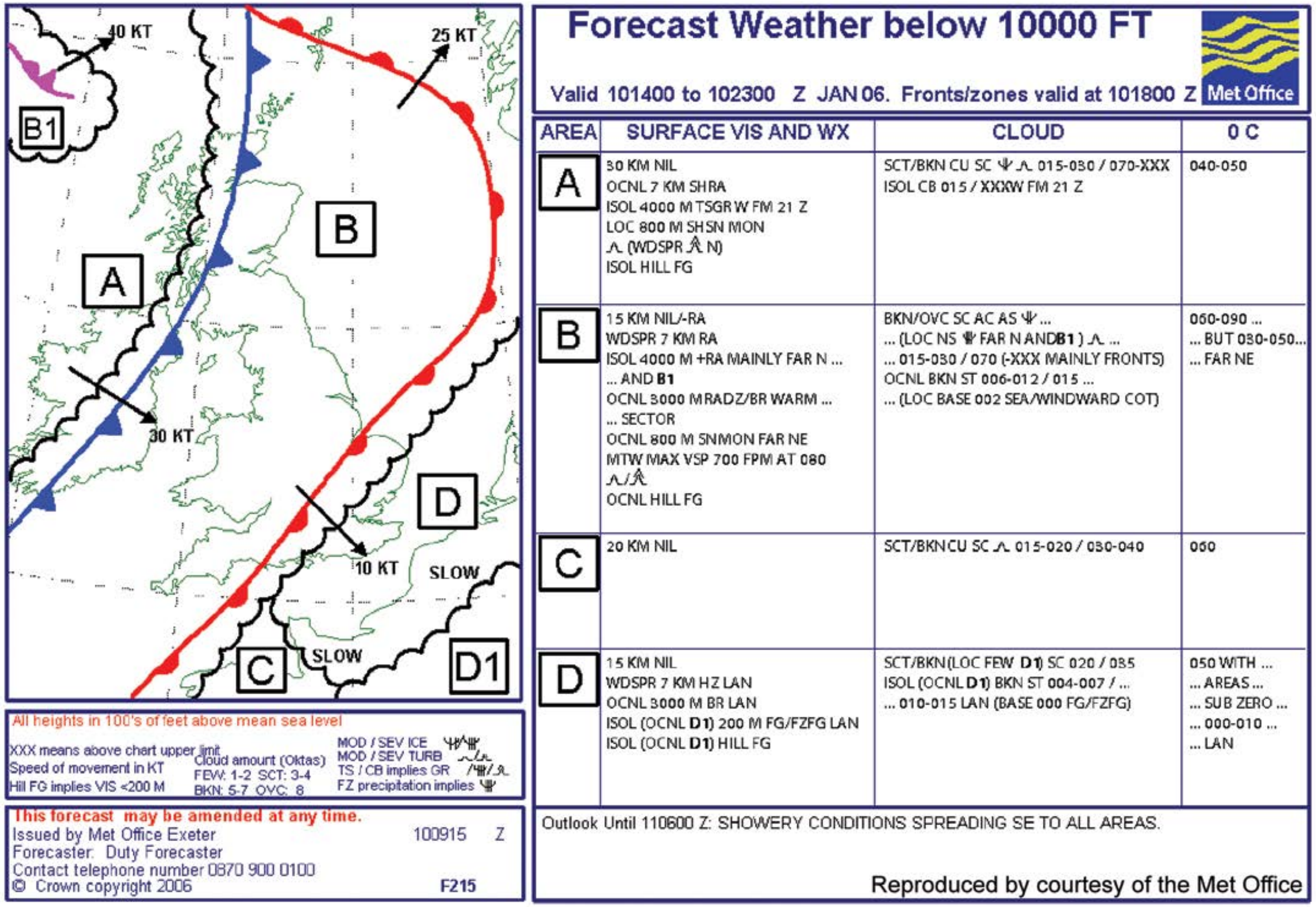

Chart 1 (Form 215).

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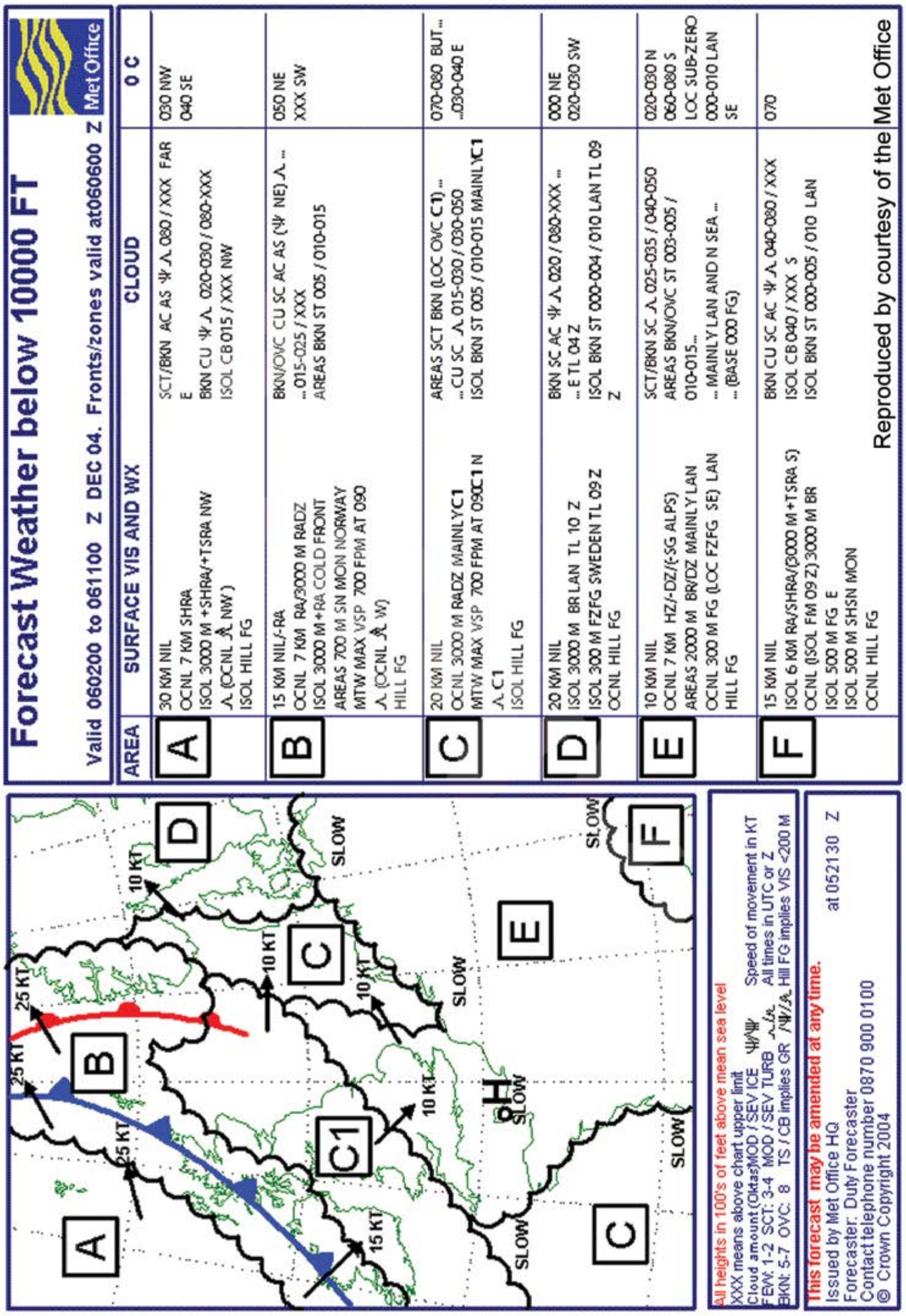

Chart 2 (Form 415).

CHAPTER 20
WORLD AREA FORECAST SIGNIFICANT WEATHER CHARTS

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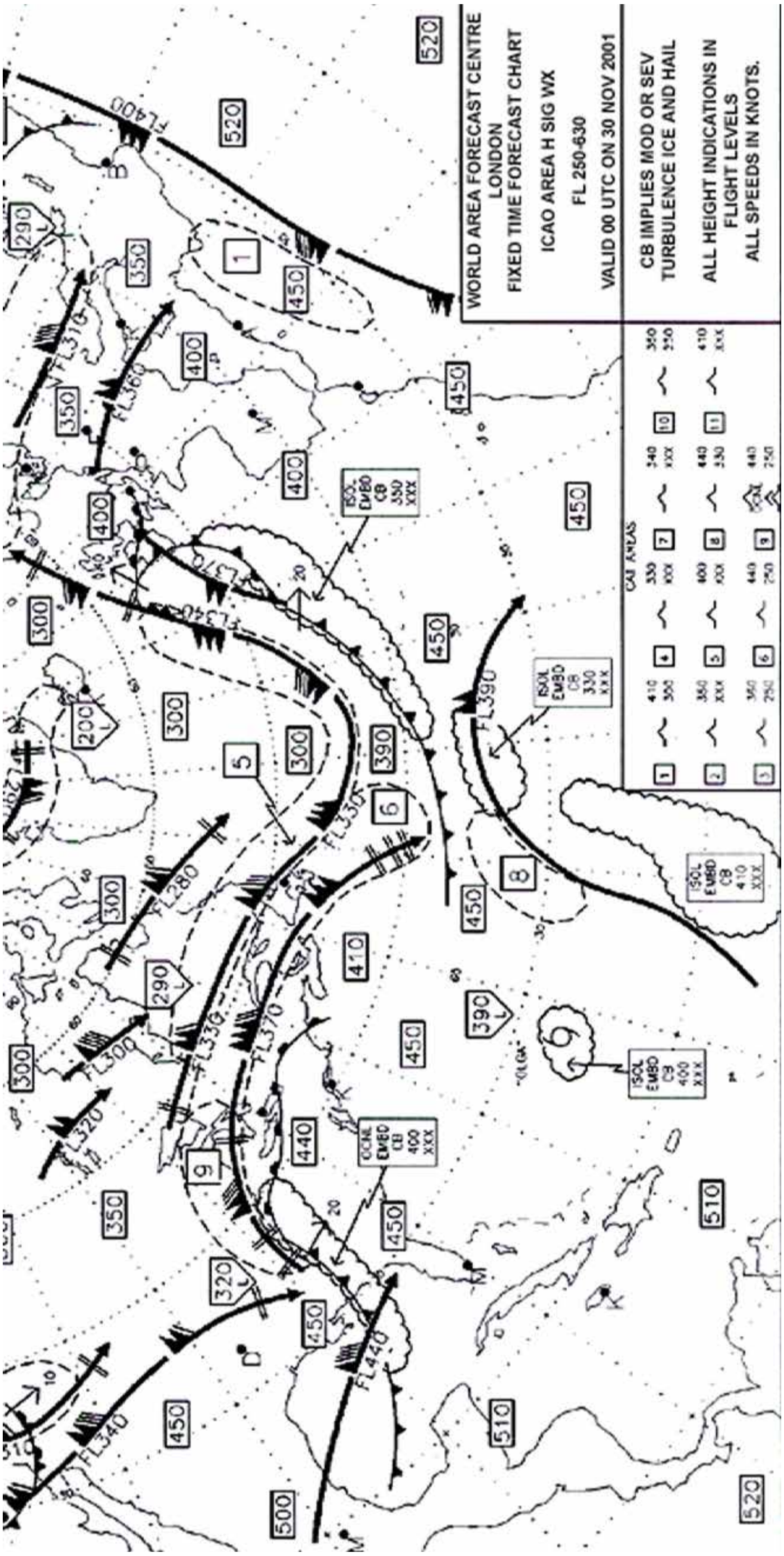

Figure 20.1 An example of the World Area Forecast Significant Weather Chart.

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INTRODUCTION.

World Area Forecast System Significant Weather (WAFS SIGWX) Charts apply to pressure altitudes between 10 000 and 63 000 feet (Flight Levels 100 - 630) to provide information about significant weather at medium and high altitudes. Significant weather phenomena include the forecast locations of embedded cumulonimbus clouds, medium and severe clear air turbulence, moderate and severe icing, jet streams, and other important meteorological occurrences.

WAFS SIGWX charts are not strictly part of the PPL syllabus, and deal with flight levels at which the general aviation pilot does not generally operate during cross-country flights, although even basic training aircraft are capable of flying at levels considerably higher than Flight Level 100. This chapter, therefore, makes only a brief study of the weather forecast charts available for medium and high altitudes, in order to introduce general aviation pilots, who may be considering moving on to professional flying, to medium level and high level weather forecasting.

HIGH LEVEL WAFS SIGWX CHARTS.

High level WAFS SIGWX charts cover the atmospheric level bounded by Flight Level 250 and Flight Level 630.

Figure 20.1 is an example of a high level WAFS SIGWX chart. The chart has a clearly defined legend which contains the following information: the name of the World Area Forecast Centre (WAFC) which produced the chart, (either London or Washington), a reminder that the forecast is for a single, fixed time; the ICAO-designated letter used to identify the area covered by the chart; the range of flight levels through which the chart is valid; the time in UTC, and the date on which the chart is valid.

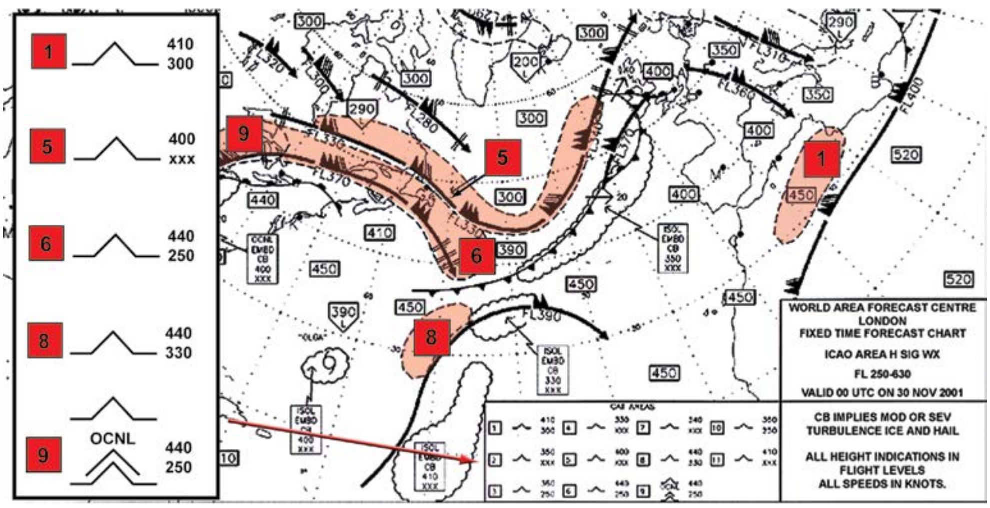

Figure 20.2 Clear Air Turbulence (CAT) Legends. This displays the degree of turbulence and forecast flight levels for specific numbered areas on the chart. The areas visible on this chart, and their corresponding numbers have been highlighted in red, for clarity.

WAFS SIGWX charts are produced, daily, every 6 hours, and are valid for 0000, 0600, 1200, and 1800 UTC. Since each chart is valid for one single fixed time only, it is the responsibility of the user to interpolate between charts to establish what weather conditions can be expected at intermediate times.

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WAFS SIGWX charts which are produced by the UK Met Office (WAFC London) have an additional legend, which highlights the flight levels between which Clear Air Turbulence can be expected.

In the legend, shown in *Figure 20.2*, each Clear Air Turbulence (CAT) symbol has a number assigned to it. This number corresponds to the number attached to an area of CAT on the chart; these areas have been highlighted in red, and are enclosed by a dashed line.

MEDIUM LEVEL WAFS SIGWX CHARTS.

The legends which are assigned to the medium level WAFS SIGWX charts are similar to those on the high level charts, except for the text line which clearly highlights that the medium level charts are valid between FL 100 and FL 450.

THUNDERSTORMS.

Thunderstorms are not explicitly displayed on the charts as such; however, thunderstorm activity is assumed whenever cumulonimbus cloud is forecast. Thus, wherever the code CB is seen on the chart, it must be assumed that thunderstorm activity is present in those areas. These areas on the chart are delineated using a scalloped line, as shown in *Figure 20.3*. However, it is important to remember that only embedded cumulonimbus clouds are displayed on WAFS charts.

On a high level WAFSSWX chart "CB" implies moderate to severe icing and turbulence.

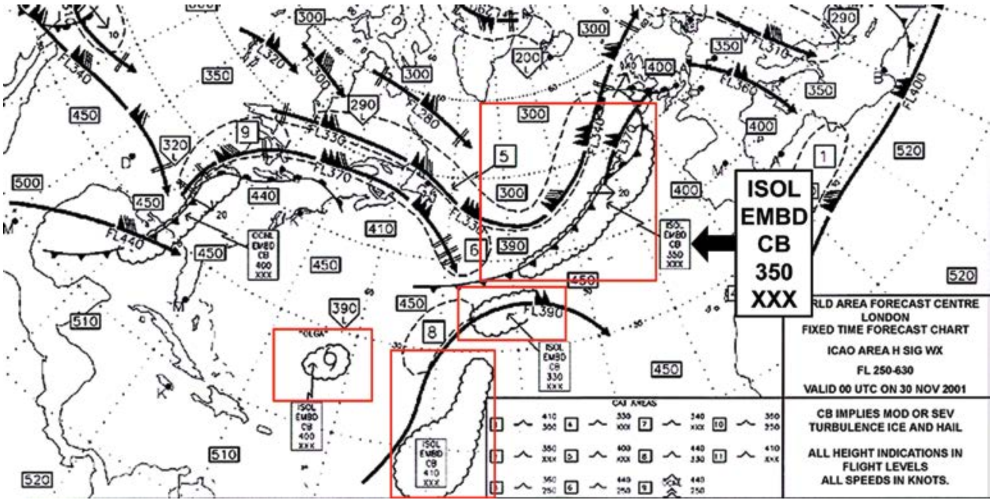

Figure 20.3 Possible Thunderstorms are indicated by the symbol CB. CB implies moderate to severe turbulence, lightning and hail. The enlarged area shows the symbols used to describe the type, and flight level, of the activity.

Included in the information about the cumulonimbus activity is an indication of the flight level at which the cumulonimbus cloud will be present. This information is included either adjacent to the chart, or within the scalloped area on the chart.

In the example shown in *Figure 20.3,* "ISOL" is used to indicate that any occurrences of cumulonimbus will be isolated within the scalloped area shown on the chart. Other abbreviations that may be used on the WAFS significant weather charts are: "OCNL," indicating that cumulonimbus may be occasionally encountered within the

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area; "WDSPD" implies that cumulonimbus are forecast to be widespread within the scalloped area on the chart; and, finally, "FRQ" is used to imply that cumulonimbus are expected to be frequent within that area.

In the boxes next to the areas denoting cumulonimbus activity, are indications of the flight levels between which cumulonimbus cloud can be expected. If any of these flight levels are outside the height range of the chart, the symbol XXX is used. In *Figure 20.4,* the top of the cumulonimbus activity is forecast for Flight level 410, but the bottom of the cumulonimbus activity is below the lowest level of the chart forecast. This is flight level 250 for the high level chart shown in *Figure 20.4*. In the example shown, the medium level WAFS SIGWX chart must be consulted, in order to discover the base of the cumulonimbus activity.

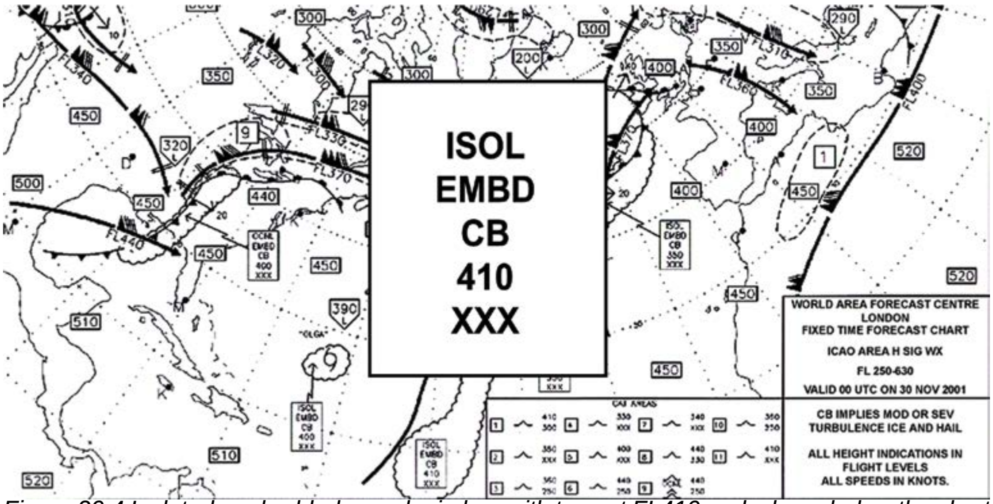

Figure 20.4 Isolated, embedded cumulonimbus with tops at FL410 and a base below the chart level.

TROPICAL CYCLONES AND HURRICANES.

Tropical cyclones are referred by a variety of names; however, if they become particularly severe, they are called hurricanes in the Atlantic Ocean , (the generic term being 'tropical revolving storm'). Hurricanes are easily recognisable on significant weather charts by the symbol highlighted in *Figure 20.5*.

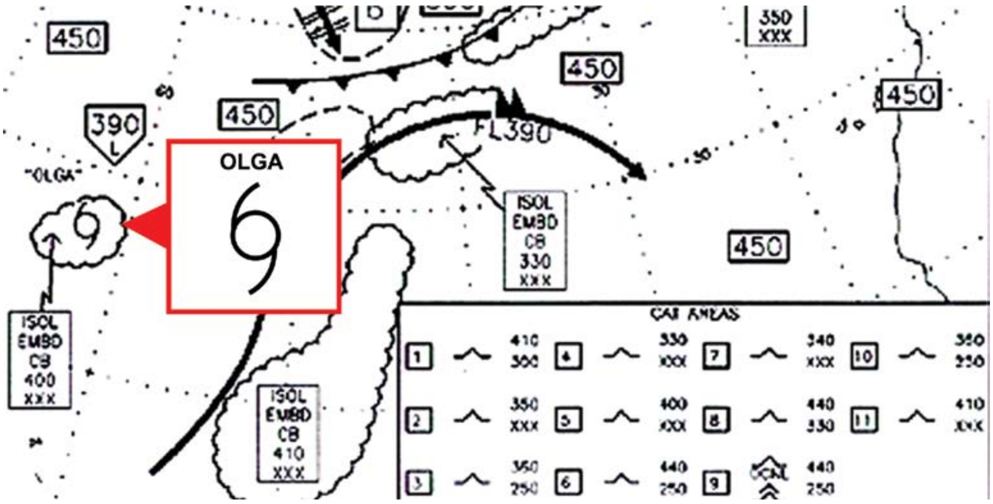

Figure 20.5 Tropical cyclones are called hurricanes in the Atlantic; they are areas of very intense cumulonimbus activity and present a major hazard to aircraft.

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The symbol is always accompanied by the World Meteorological Organisation name of the storm. Hurricanes used to be given exclusively women's names, but, for reasons that have never been revealed, are now given men's names too. In *Figure 20.5,* the hurricane has been named "Olga".

Tropical cyclones are associated with intense areas of cumulonimbus activity, and they need to be very carefully monitored.

TURBULENCE.

Moderate, or severe turbulence is displayed on the WAFS SIGWX chart using the symbols shown in *Figure 20.6.*

The symbol for turbulence, as for other weather phenomena, are the same as the symbols used on the low-level forecast charts.

Wherever cumulonimbus is forecast, moderate to severe turbulence must be assumed to be active in the area. On the medium level significant weather charts, areas of moderate and severe turbulence are also associated with other types of medium level cloud. The example from a medium - level chart in *Figure 20.7* shows turbulence around broken cumulus and altocumulus.

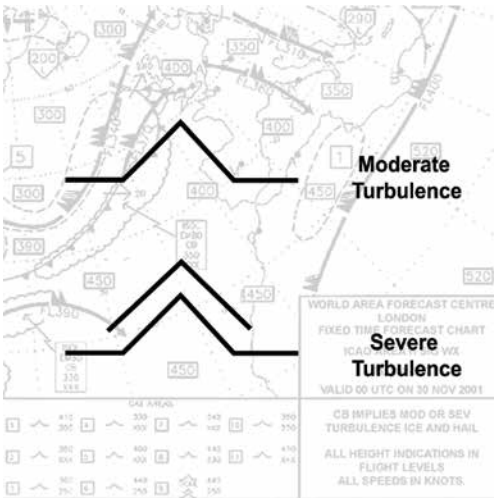

Figure 20.6 Only moderate to severe turbulence is forecast. For CB always assume moderate to severe turbulence.

The turbulence symbols are included within the "cloud" boxes assigned to every scalloped cloud area. See *Figure 20.7*.

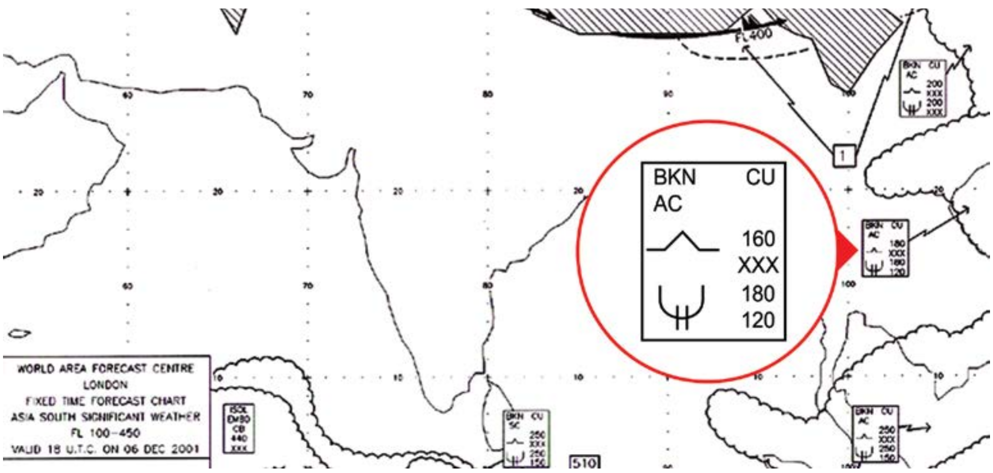

Figure 20.7 This example, on a medium level chart, shows moderate turbulence from FL160 down to a level below the chart coverage which, vertically, is FL100.

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ICING

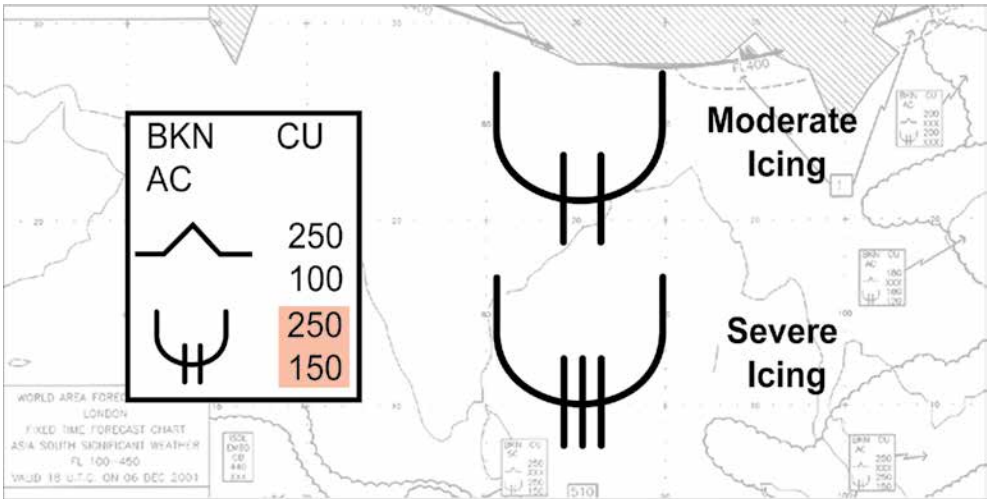

Figure 20.8 Only moderate to severe icing is forecast. For CB, always assume moderate to severe icing.

As previously described, the only cloud type shown by high level WAFS SIGWX charts, is cumulonimbus clouds. You may also recall that moderate or severe icing is also automatically assumed to be prevail in the vicinity of these clouds. However, on medium level charts, other cloud types are shown *(see Figure 20.7)*.

Moderate to severe icing is always assumed to be present in and in the vicinity of cumulonimbus.

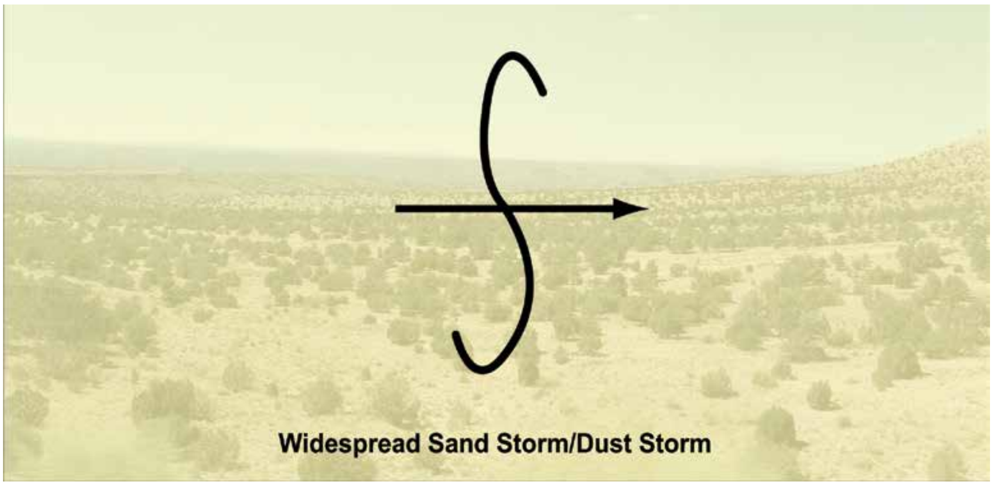

Figure 20.9 Sand and dust storms are forecast only if the dust storm or sand storm is reducing visibility within the flight levels of the chart.

SAND AND DUST STORMS.

Widespread sandstorms or dust storms are highlighted on the significant weather charts only when these phenomena are forecast to obscure visibility significantly, between the flight-levels for which the chart is valid. The symbol which is used on the chart is identical for both phenomena, and is shown in *Figure 20.9*.

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CLOUD AREAS.

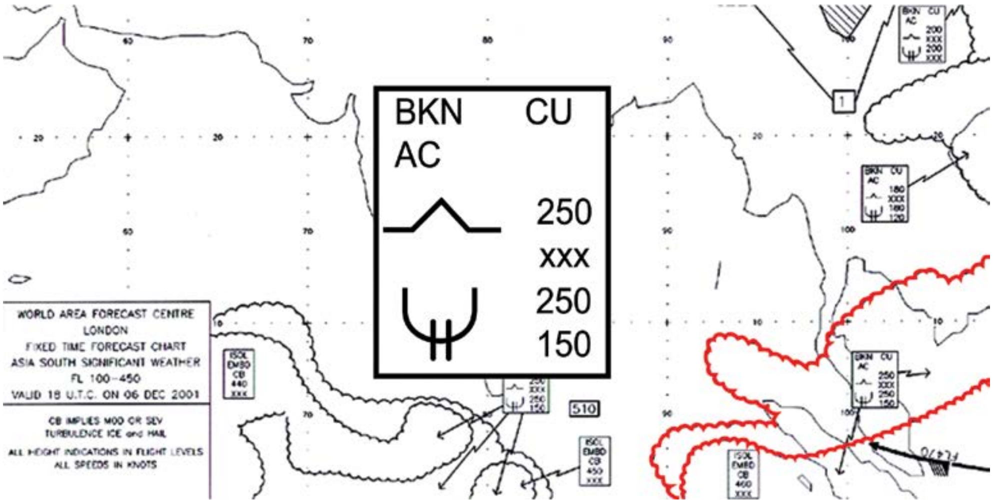

Figure 20.10 Cloud Areas - on High Level Charts only Cumulonimbus are shown. On Medium Level Charts - any cloud which could lead to significant icing or turbulence.

The only clouds which are displayed on high level charts are embedded cumulonimbus; however, on the medium level charts, rather more cloud information is displayed. Whereas high level charts show only embedded cumulous clouds, medium level charts show more detail on the types of cloud that may be encountered. Any cloud types which are likely to have a significant icing or turbulence risk are clearly highlighted. In the example in *Figure 20.10, above*, the cloud box refers to the scalloped cloud areas highlighted in red. From the symbols within the box, it can be seen that broken amounts of cumulus and altocumulus may be present; moderate turbulence can be expected between Flight Levels 250 and XXX, which is less than FL 100; moderate icing can be expected between Flight Levels 250 and 150.

FRONTAL SYSTEMS.

Significant frontal systems are highlighted on the WAFS SIGWX charts.

Standard frontal coding is used to indicate the surface positions of the fronts. The direction of travel of the front is shown by arrows, with the speed of movement of the front shown by small numbers next to the front. In *Figure 20.11,* there is a cold front moving eastwards (a) at a speed of 20 knots (b).

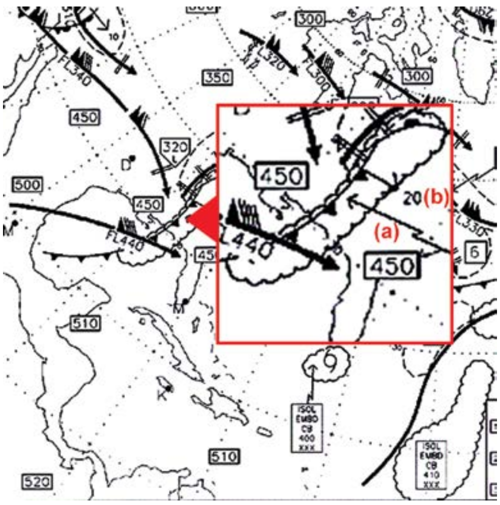

Figure 20.11 Only significant fronts are shown. Standard front coding is used to denote frontal type. Direction of movement is shown by small arrows, (a), with numbers next to them, giving speed in knots (b).

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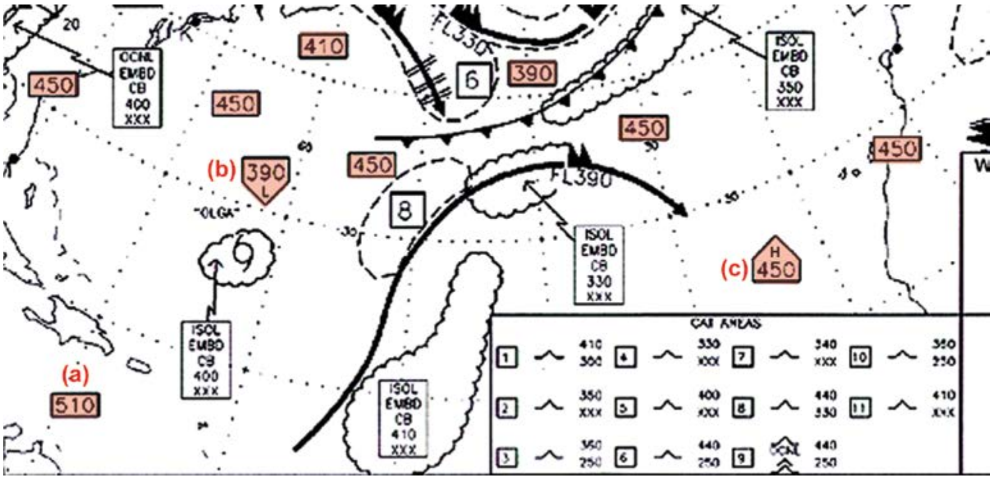

Figure 20.12 Tropopause heights are reported as flight levels inside small rectangular boxes, (a). The highest Tropopause levels are reported as 'H', (c). The lowest Tropopause levels are reported as 'L', (b).

TROPOPAUSE LEVELS

Tropopause levels are included on the high level significant weather charts. The levels shown indicate the start of the Tropopause, and are calculated by finding the coldest temperature in the Troposphere. The height of the Tropopause, therefore, is defined by the height in the atmosphere at which the temperature becomes constant, rather than declining with altitude. These Tropopause levels are indicated at a number of spot locations across the high level charts. Tropopause levels are presented as flight levels in a rectangular box. *(See Figure 20.12, **(a)**.)*

The flight level given for a jet stream on the WAFS High Level SIGWX chart is the level for the maximum wind in that jet stream.

When more than one Tropopause level is present in the atmosphere, either an **"H"** or an **"L"** is added to the Tropopause box, to indicate whether the uppermost or lowest Tropopause height is displayed. In these cases, the rectangular box is expanded to include the additional symbol, and the box looks more like an arrow head pointing up or down. In *Figure 20.12, above***,** the lowest Tropopause level is marked **(b)**, and the highest Tropopause level is marked **(c)**.

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JET STREAMS.

Jet streams are identifiable on the charts by black solid lines, which have wind “barbs”, indicating jet stream speeds at various spot points, with the flight level at which the maximum speed occurs written underneath. *(See Figure 20.13.)* The arrow head on the end of each jet stream line indicates the direction of movement of the flow. Any changes in speed along the length of the jet stream of 20 knots or more are indicated by either an additional set of wind “barbs”, or, if there is little space on the chart, two parallel lines perpendicular to the direction of flow of the Jet Stream. *(See Figure 20.13.)*

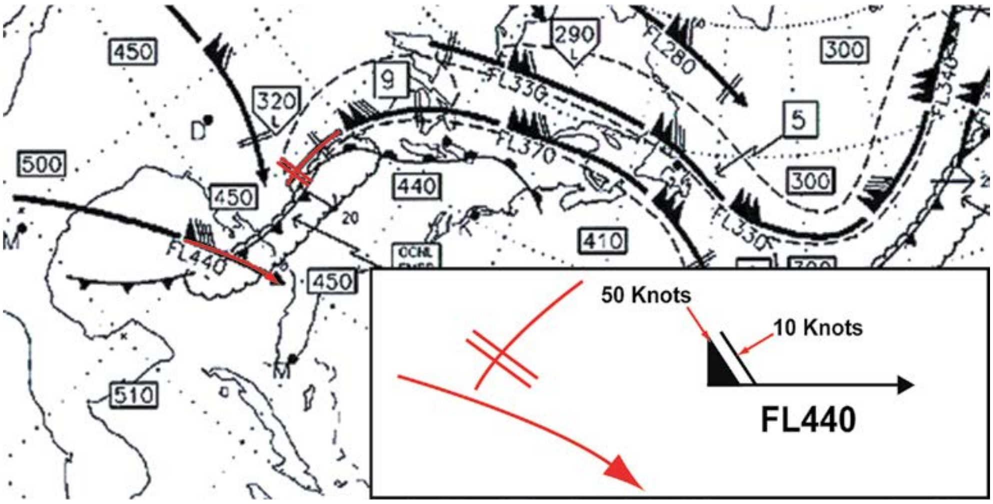

Figure 20.13 Jet Streams are indicated by solid black lines accompanied by a flight level and speed. Usually, the Jet Stream has an associated Clear Air Turbulence region indicated by a dashed line with an identifying number in it.

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Representative questions to test your theoretical knowledge of WAFS SIGWX.

1. On WAF significant weather charts, jet streams are given flight levels. To what does this flight level refer?

    a. The flight level of the mean wind in the jet stream
    b. The flight level of the maximum wind in the jet stream
    c. The highest flight level where the winds are more than 60 knots
    d. The average height of the jet stream

2. At what times are WAF significant weather charts produced?

    a. At 0000, 0600, 1200, 1800 UTC
    b. At 0000, 0600, 1200, 1800 LMT
    c. At 0000 and 1200Z
    d. At midnight and midday only

3. What is the validity time for a WAF significant weather chart?

    a. 6 hours
    b. 3 hours
    c. 30 minutes
    d. For a fixed single time only

4. When are WAF significant weather charts produced?

    a. Every 3 hours
    b. Every 6 hours
    c. Every 12 hours
    d. At midnight and midday only

5. On WAF significant weather charts what do the letters CB imply?

    a. Moderate icing and turbulence
    b. Moderate to severe icing and turbulence
    c. Moderate to severe icing and turbulence and hail
    d. Severe icing and turbulence and hail

Question	**1**	**2**	**3**	**4**	**5**
Answer					

The answers to these questions can be found at the end of the book.

CHAPTER 21
THE SIGMET

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INTRODUCTION.

The code SIGMET stands for Significant Meteorological Information. A SIGMET is an abbreviated, plain language message, which concerns the occurrence, and/or expected occurrence, of significant weather which may affect the operational safety of aircraft.

SIGMET stands for Significant Meteorological Information.

There are two classifications of basic SIGMETS: convective and non-convective. Convective SIGMETS concern the occurrence of thunderstorms, and non-convective SIGMETS warn of severe turbulence and/or icing. A SIGMET is valid for 4 hours.

A SIGMET informs pilots of actual or forecast significant weather phenomena concerning the safety of flying operations. In general, SIGMETs refer to thunderstorms, severe turbulence and icing.

SIGMETs are issued from designated meteorological watch offices each of which has a responsibility to the many Flight Information Regions around the world.

You will already have met many of the abbreviations used in the SIGMET, in Chapter 19 on Low Level Forecast Charts, but a full list of abbreviations is given in *Figure 21.1,* for your reference.

Abbreviated plain language commonly used in SIGMETs

a) at subsonic crusing levels:

thunderstorm
- obscured OBSC TS
- embedded EMBD TS
- frequent FRQ TS
- squall line SQL TS
- obscured with heavy hail OBSC TS HVYGR
- embedded with heavy hail EMBD TS HVYGR
- frequent, with heavy hail FRQ TS HVYGR
- squall line with heavy hail SQL TS HVYGR

tropical cyclone
- tropical cyclone with 10-minute mean surface wind speed of 63 km/h (34kt) or more TC (+ cyclone name)

turbulence
- severe turbulence SEV TURB

icing
- severe icing SEV ICE
- severe icing due to freezing rain SEV ICE (FZRA)

mountain wave
- severe mountain wave SEV MTW

duststorm
- heavy duststorm HVY DS

sandstorm
- heavy sandstorm HVY SS

volcanic ash
- volcanic ash VA (+ volcano name, if known)

b) at transonic levels and supersonic cruising levels:

turbulence
- moderate turbulence MOD TURB
- severe turbulence SEV TURB

cumulonimbus
- isolated cumulonimbus ISOL CB
- occasional cumulonimbus OCNL CB
- frequent cumulonimbus FRQ CB

hail
- hail GR

volcanic ash
- volcanic ash VA (+ volcano name, if known)

Figure 21.1 Abbreviations used in SIGMET messages.

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DECODING THE SIGMET.

Figure 21.2 shows an example of a SIGMET message. The first item is the location indicator of the Air Traffic Services Unit (ATSU) serving the Flight Information Region (FIR) or Control Area to which the SIGMET message refers. The ATSU which issued our example SIGMET is EGTT, (a), which is the London FIR. EGTT is followed by the code SIGMET, (b), which is the message identifier.

```
(a)  (b)    (c)       (d)           (e)
EGTT SIGMET 02 VALID 281400/281900 EGRR-
(f)             (g)                (h)   (i)        (j)
EGTT LONDON FIR SEV MTW VSP 600FPM FCST FL060/120 S OF A LINE FROM
                                   (k)  (l) (m)
N5220 W00530 TO N5300 E00300 STNR NC=
```

Figure 21.2 An example of a SIGMET.

After the identifier, the sequence number is given next, (c). In this example, the sequence number is 02, which corresponds to the number of SIGMET messages issued for the London FIR since 0001 UTC on the day of issue.

The next item is the date and time groups, (d), indicating the period of validity of the SIGMET message in UTC. In this example, the SIGMET is valid on the 28th of the month from 1400 UTC to 1900 UTC.

The first line of the SIGMET ends with the location indicator of the meteorological watch office which issued the SIGMET. Here, it is EGRR, (e), which is the UK Met Office. EGRR is followed by a hyphen which separates the SIGMET preamble from the next line of text.

At the beginning of the second line, is the name of the FIR or control area for which the SIGMET is issued; so the code EGTT is repeated, (f), but now is also decoded as the London FIR.

Next comes the name and description of the weather phenomenon which is the reason for the issuing of the SIGMET. The weather phenomenon is given in abbreviated plain language, using the abbreviations given on the previous page. In our example, the warning is of severe mountain waves, (g), with a vertical speed of 600 feet per minute.

Following the weather phenomenon, there is an indication of whether the information is observed or forecast, using the abbreviation “OBS”, or “FCST”, (h). If relevant, the time of observation in UTC will also be given.

The next group of information relates to the location and altitude of the observed or forecast phenomenon, in this instance between Flight Levels 60 and 120, (i).

Where possible, reference is made to latitude and longitude, locations or well-known geographical features. In our example SIGMET, the location of the mountain waves is given as: South of a line from a position at 52º 20’ N, 5º 30’ W to a position at 53º N, 3º E, (i). This is a line from a point on the FIR boundary in Cardigan Bay to a point in the North Sea, some miles North East of Yarmouth.

Movement or the forecast movement of the weather phenomenon is normally indicated

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by reference to one of the eight points of the compass; however, this SIGMET does not contain such a reference.

The speed of displacement of the weather phenomenon is given in kilometres per hour or knots. But if the weather phenomenon is stationary, as in this example, the code STNR, (k), is used. Finally, an indication is made of any change in intensity of the weather phenomenon, using the abbreviation INTSF for intensifying, WKN for weakening or NC for no change, as in this example, (l).

The SIGMET is ended, as with the METAR, with an equals sign (m).

COMPLETE SIGMET MESSAGE.

The complete SIGMET message in *Figure 21.2* decodes as follows:

The message is for the London FIR, EGTT; the message is a SIGMET, the second to be issued for the FIR since 0001 UTC. It is valid for the 28th of the month from 1400 UTC until 1900 UTC and was issued by the UK Met Office, EGRR. In the London FIR, severe mountain waves, whose vertical speed is 600 feet per minute, are forecast from FL60 to FL120, South of a line from 52º 20' N 5º 30' W to 53º N 3º E; the phenomenon is stationary and no change is expected.

```
EGPX SIGMET 01 VALID 280900/281300 EGRR-
EGPX SCOTTISH FIR SEV TURB FCST BLW FL070 S OF A LINE N5800 W01000
TO N5700 W00500 TO N5500 E00000 MOV NNE AT 35KT NC=
```

Figure 21.3 Sample SIGMET.

A further SIGMET is shown in *Figure 21.3, below*. This SIGMET decodes as follows:

The message is for the Scottish FIR, EGPX; it is the first SIGMET issued since 0001 UTC, and is valid for the 28th of the month from 0900 UTC to 1300 UTC, being issued by the UK Met Office, EGRR. In the Scottish FIR, severe turbulence is forecast below FL70, South of a line from 58º N, 10º W to 57º N, 5º W to 55º N, 0º E/W; it is moving North North East at 35 knots, and no change is expected.

The position line given in the SIGMET in *Figure 21.3* translates roughly as extending from a point on the Western boundary of the FIR, 90 miles West of Benbecula to a point at the South end of Loch Ness and, thence, to a point in the North Sea, 60 miles East of Newcastle.

SPECIAL SIGMETS.

There are two other specialised types of SIGMET valid for up to 6 hours. These are the VOLCANIC SIGMET, issued to notify pilots of volcanic ash, due to volcanic eruptions, and the TROPICAL CYCLONE SIGMET, used to notify pilots of hurricane or cyclone activity.

SIGMETs are valid for 4 hours, except for special SIGMETs concerning volcanic or cyclonic activity which are valid for 6 hours.

SIGMETs for volcanic ash clouds or tropical cyclones include an additional line of text. This line contains a brief outlook forecast beyond the period of validity specified earlier in the message. In a Volcanic SIGMET, the outlook will include a direction of travel for the ash cloud. For a Tropical Cyclone SIGMET, the position of the tropical cyclone centre is included.

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Representative PPL - type questions to test your theoretical knowledge of The SIGMET.

1. What do the first four letters of the SIGMET message identify?

   a. The issue number
   b. The ICAO identifier for the relevant airport
   c. The name of the Air Traffic Services Unit
   d. The validity time

2. **EGTT SIGMET 1 VALID 310730/311130 EGRR LONDON FIR ISOL CBFCST TOPS FL370 ROUTES W OF W00400 NC=**

   In the above SIGMET, what is the nature of the forecast significant weather?

   a. Hail
   b. Cumulonimbus with tops approximately at the Tropopause
   c. Trans-Atlantic routes at Flight Level 370 closed
   d. No change

3. **EGTT SIGMET 1 VALID 310730/311130 EGRR LONDON FIR ISOL CB FCST TOPS FL370 ROUTES W OF W00400 NC=**

   What is the expected change in the weather intensity indicated by this SIGMET?

   a. Weakening
   b. Strengthening
   c. Dissipating
   d. No change

4. How would a severe mountain wave be coded in a SIGMET message?

   a. + MTW
   b. SEV MTW
   c. SEV MNTW
   d. SEVERE MNTW

5. **LFFF SIGMET 1 VALID 310600/311100 LFPW- UIR FRANCE MOD TURB FCST BLW FL420 W of 04W MOVE E 30KT NC=**

   In the SIGMET message shown above, what is the hazard forecast?

   a. Moderate turbulence at 42 000 ft West of 4 degrees West and moving Eastwards
   b. Moderate turbulence below 42 000 ft West of 4 degrees West and moving from the East
   c. Turbulence at 42 000 ft West of 4 degrees West and moving at 30 kts
   d. Moderate turbulence below 42 000 ft West of 4 degrees West and moving Eastwards

Question	1	2	3	4	5
Answer					

The answers to these questions can be found at the end of the book.

CHAPTER 22
THE AIRMET

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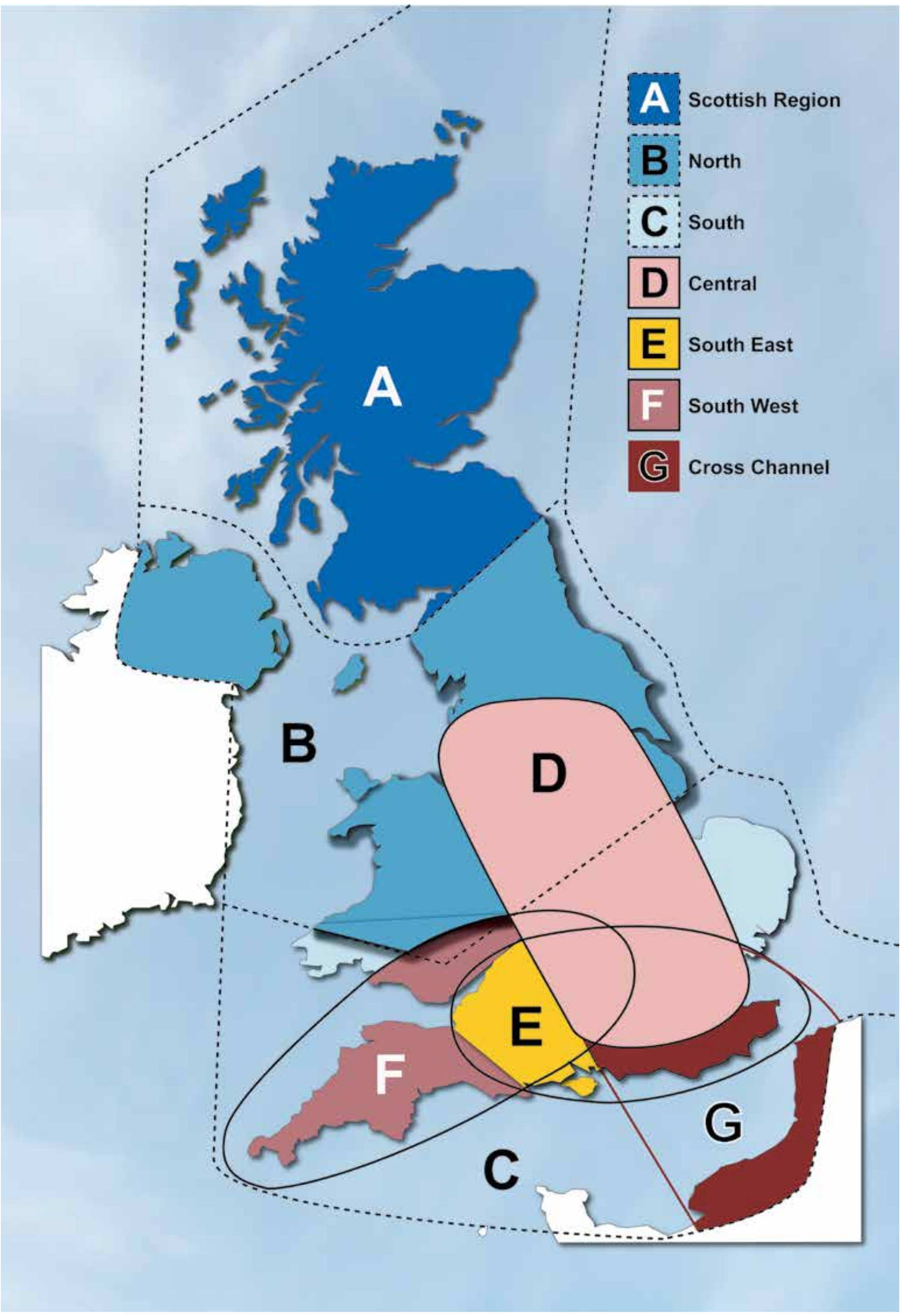

Figure 22.1 AIRMETs are forecasts of the weather up to FL100, using abbreviated plain language.

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INTRODUCTION.

AIRMET stands for Airmen's Meteorological Information. An AIRMET is a descriptive aviation forecast covering different regions, and which is updated several times a day.

The AIRMET is a descriptive forecast of the meteorological situation up to FL100, issued for different areas.

The AIRMET is a forecast designed for aircraft which normally operate up to Flight Level 100. The forecast uses abbreviated plain language, and is issued either in spoken or text form.

Together with other reports and forecasts such as METARs, TAFs, Spot Wind Charts and Low Level Forecast Charts, the AIRMET forms part of the self-briefing documentation which is generally available to the light aircraft pilot.

AIRMETs normally report or forecast meteorological conditions which, while potentially hazardous to general aviation aircraft, are less severe than weather phenomena covered in a SIGMET. AIRMETs often include moderate turbulence, icing and surface winds in excess of 10 knots.

There is an AIRMET telephone service for use by pilots who do not have access to meteorological information disseminated by fax. AIRMETs are also disseminated in text form by teleprinter to aerodrome briefing rooms. AIRMETs for the UK can be obtained, free of charge, from the Met Office website: **www.metoffice.gov.uk.**

In the United Kingdom, AIRMETs are produced for the geographical areas shown in *Figure 22.1*.

The regional AIRMETs, for Scotland, Northern England & Northern Ireland, and Southern England & Wales, are produced four times a day. The sub-regional AIRMETs, for Central, South East, and South Western areas, are produced three times a day, while the cross channel AIRMET is produced just twice a day.

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STRUCTURE OF THE AIRMET.

This example in *Figure 22.2* is from a Scottish-region AIRMET. The first line of the AIRMET gives the period of validity of the AIRMET, (a).

Scottish Region

(a) VALID FEB 18/1100Z TO 18/1900Z

(b) MET-SITUATION: UNSTABLE NW'LY AIRSTRAM WILL BE REPLACED BY WARM FRONT MOVING SE AT 40KT, EXPECTED 59N 10W TO MALLAIG TO GLASGOW TO DUMFRIES AT 1500UTC.

(c) STRONG WIND WRNG: WLY SFC WIND INCREASING W OF 04W WITH OCNL GUSTS 35 TO 45KT.

(d) WINDS:

1000FT: S OF 58N: 240/025KT BECOMING 270/040KT IN W PS3
N OF 58N: 300/015KT PS3 (d i)

3000FT: S OF 58N: 2500/035KT BECOMING 280/055KT IN W MS1
N OF 58N: 300/020KT MS3 (d ii)

6000FT: S OF 58N: 250/040KT BECOMING 280/055KT IN W MS 5
N OF 58N: 290.30K MS10 (d iii)

(e) FREEZING LEVEL: 2000FT IN S, 1500FT IN N

WEATHER CONDITIONS: 2 ZONES:

(f) ZONE1: W OF A LINE AT 1500UTC THROUGH 59N 10W, CAPE WRATH, ELGIN, ARBROATH TO PRESTON MOVING SE AT 40KT.

(g) GEN25KM IN OCNL RA, WITH 6-8/8CUAC 2000FT/14000.
OCNL 7KM IN RA OR RA SH,WITH 7-8/8UAC 1500FT/17000.
ISOL, 3500NM IN HEAVY RA, RA SH OR RA SN, WITH 3-6/8ST 800FT/1500, AND 8/8UAC 1500FT/17000.

(h) WRNG: CLD ON HILLS. MOD ICE AND MOD TURBN IN CLD. OCNL MOD TURB BLW 6000FT.

(i) ZONE2: E OF ZONE1.
(j) GEN 40KM, WITH 3-5/8CUSC2500FT/8000.
OCNL, IN N ISOL IN S, 7KM IN RA SH, WITH 5-7/8CUSC 1500FT/14000.
ISOL MAINLY IN NE, 3000M IN HAIL, TS, HEAVY RA SH OR, SLEET SH WITH 7/8CB 1000FT/17000.

(k) WRNG: CLD ON HILLS. MOD ICE AND MOD TRB IN CLD. OCNL MOD TURB BLW 6000FT

(l) OUTLOOK; UNTIL FEB 19/0100Z:

SHOWERS AND SLIGHTLY EASING WINDS RETURNING INTO N SCOTLAND.

Figure 22.2 This AIRMET is for the Scottish Region.

Next, at (b), comes a description of the meteorological situation. Mention is usually made of any fronts and their forecast movement, together with any significant air mass changes.

The AIRMET will contain a strong wind warning if there is a likelihood of the wind exceeding 20 knots.

Following the general situation, come details of any strong winds which are expected; these are included when the wind is expected to exceed 20 knots. In *Figure 22.2,* at (c), the AIRMET refers to a westerly surface wind of 20 knots or more, West of 4 degrees West, with occasional gusts of 35 to 45 knots.

Below the strong wind warning is the general wind forecast, (d), for the AIRMET region, given for different levels above mean sea-level. At the end of each wind description is a forecast of the temperature which can be expected at that flight level. PS (meaning plus) denotes temperature above zero degrees Celsius, while MS (meaning minus) denotes temperature below zero degrees Celsius.

Following the wind details, is a forecast of the freezing level, (e). Sometimes this varies in altitude across the AIRMET region, and sometimes with time. Any changes are highlighted by brief descriptive text.

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Next comes a description, (f) and (i), of the weather conditions forecast for the AIRMET region. The AIRMET region is often broken down into distinct zones; in *Figure 22.2* there are two zones. The boundaries of these zones are highlighted by explanatory text, at (f) and (i).

Within each zone, is a description of the different weather elements. These weather elements include forecasts of visibility, weather, and cloud. The different weather elements are written in the same order as they appear on the UK Low-Level Forecast Chart - Form 215.

The description of the weather in each zone is accompanied by a mention of any warnings which are applicable to the zone, (h) and (k). These warnings often cover aviation hazards such as cloud on hills, moderate or severe icing, turbulence, sub-zero layers and mountain wave activity.

At the end of the AIRMET appears the outlook for the next six hours.

AIRMETS ORIGINATING OUTSIDE THE UNITED KINGDOM.

The format of the AIRMET shown in this chapter is that of a United Kingdom AIRMET.

AIRMET formatting varies considerably from country to country. Therefore, when flying outside United Kingdom airspace, you are advised to familiarise yourself with the different AIRMET formats of the countries you plan to fly through.

CONCLUSION.

The AIRMET is an excellent briefing tool. The concise, abbreviated text makes it a simple but effective means of rapidly determining the general forecast conditions. Be aware, though, that the AIRMET is a general forecast only, useful for en-route planning, and for appreciating the general weather outlook. For detailed forecasts for particular airfields, you should consult TAFs and METARs.

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Representative PPL - type questions to test your theoretical knowledge of The AIRMET.

1. An AIRMET service:

   a. can only be obtained in textual form by fax
   b. can be obtained by telephone, telex or fax
   c. is a discrete telephone service for the sole use of private pilots from small aerodromes or private strips who do not have access to forecast charts
   d. aims to provide private pilots with simple meteorological forecast information in a graphical format

2. A Regional AIRMET is issued ________ and is valid for ________ with an outlook period of _______ .

   a. 6 times a day, 8 hours, 4 hours
   b. 4 times a day, 6 hours, 4 hours
   c. 4 times a day, 8 hours, 6 hours
   d. 6 times a day, 4 hours, 4 hours

3. A regional AIRMET is a forecast of the weather up to:

   a. FL100
   b. FL180
   c. FL010
   d. FL240

4. In an AIRMET, when are strong winds forecast?

   a. When the wind is expected to exceed 10 kts
   b. When the wind is expected to exceed 20 kts
   c. When the wind is expected to exceed 15 kts
   d. When the maximum wind is expected to exceed 25 kts

5. The usual method of weather briefing for general aviation pilots is:

   a. an individual briefing by a forecaster face to face or by phone
   b. individual briefing by a forecaster to assistant staff at weather centres and aerodromes for dissemination to individual pilots, and available every 30 minutes
   c. self briefing using facilities, information and documentation routinely available in aerodrome briefing areas, by telephone, or via the internet
   d. during flight by use of VOLMET and ATIS

Question	1	2	3	4	5
Answer					

The answers to these questions can be found at the end of the book.

CHAPTER 23
THE VOLMET

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INTRODUCTION.

The weather-briefing material and services that you have read about in this book, so far, enable a pilot to obtain information on forecast or actual weather conditions, prior to getting airborne, during flight planning. However, pilots are also able to obtain weather information when they are in the air, by tuning into appropriate frequencies on the aircraft's radio.

VOLMET is a continuous broadcast of selected aerodrome actual weather observations and forecasts.

One of these in-flight weather briefing services is the VOLMET. The first element of the code VOLMET, vol, is the French word for flight. VOLMET, therefore, is a term signifying meteorological information for aircraft in flight.

VOLMET broadcasts are ground to air transmissions on VHF and HF frequencies.

VOLMET broadcasts are ground-to-air radio transmissions of meteorological reports and forecasts made on the High Frequency (HF) and Very High Frequency (VHF) bands. These transmissions are broadcast in plain language, and give the latest weather reports and forecasts, in the form of spoken METARs, TAFs and SIGMETs. VOLMET broadcasts transmit weather information for a number of different aerodromes, sequentially. As a result, the pilot may have to wait for the forecast for the aerodrome pertinent to his flight to come around.

VOLMET OPERATION.

Figure 23.1 is an extract from the United Kingdom Aeronautical Information Publication (GEN Section), containing a list of VHF VOLMET services and their associated radio frequencies for the United Kingdom and the near continent.

GEN 3.5.7 - VOLMET SERVICES

Table 3.5.7.1 - Meteorological Radio Broadcasts (VOLMET)

Call Sign/ID	EM	Frequency MHz	Operating Hours	Stations	Contents	Remarks
1	2	3	4	5	6	7
London Volmet (Main)	A3E	135.375	H24 continuous	Amsterdam Brussels Dublin Glasgow London Gatwick London Heathrow London Stansted Manchester Paris Charles de Gaulle	(1) Half hourly reports (METAR) (2) The elements of each report broadcast in the following order: (a) Surface wind (b) Visibility (or CAVOK) (c) RVR if applicable (d) Weather (e) Cloud (or CAVOK) (f) Temperature (g) Dewpoint (h) QNH (i) Recent Weather if applicable (j) Windshear if applicable (k) TREND if applicable (l) Runway Contamination Warning if applicable (3) Non-essential words such as 'surface wind', 'visibility' etc are not spoken. (4) Except for 'SNOCLO' (see Column 7), the Runway State Group is not broadcast. (5) All broadcasts are in English.	The spoken word 'SNOCLO' will be added to the end of the aerodrome report when that aerodrome is unusable for take-offs and landings due to heavy snow on runways, or runway snow clearance.
London Volmet (South)	A3E	128.600	H24 continuous	Birmingham Bournemouth Bristol Cardiff Jersey London Luton Norwich Southampton Southend		
London Volmet (North) (Note 1)	A3E	126.600	H24 continuous	Blackpool East Midlands Isle of Man Leeds Bradford Liverpool London Gatwick Manchester Newcastle Teesside		
Scottish Volmet	A3E	125.725	H24 continuous	Aberdeen/Dyce Belfast Aldegrove Edinburgh Glasgow Inverness London Heathrow Prestwick Stornoway		

Note 1: Broadcasting Range extended to cover Southeast England and English Channel

Note 2: An HF VOLMET broadcast for North Atlantic flights (Shannon VOLMET) is operated by the Republic of Ireland

Figure 23.1 VOLMET information for the United Kingdom and near continent.

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Individual VOLMET stations, in each region, broadcast weather reports and forecasts for a group of major aerodromes in their region of responsibility.

From *Figure 23.1,* you can see that there are four UK VOLMET stations: LONDON VOLMET MAIN, LONDON VOLMET NORTH, LONDON VOLMET SOUTH and the SCOTTISH VOLMET. Next to each of these stations, is the frequency on which the VOLMET transmission is broadcast, the operating hours, and the list of aerodromes covered by the broadcast. The LONDON VOLMET MAIN broadcast, for example, is transmitted on the VHF frequency of 135.375 MHz, continuously, over a 24 hour period.

The content of each VOLMET broadcast is a set of pre-recorded weather elements. VOLMET broadcasts are updated every half hour.

You will also see from *Figure 23.1* that the LONDON VOLMET MAIN broadcast contains weather information for aerodromes in France and the Republic of Ireland, as well as in the United Kingdom. The LONDON VOLMET SOUTH broadcast contains weather information for major airfields between Birmingham, in the Midlands, and the island of Jersey, in the English Channel.

Column 6 of *Figure 23.1* details the **s**pecific weather elements which are included in the VOLMET broadcasts. You will notice that the broadcast content has the same format as that of a METAR; however, in *Figure 23.2* which contains examples of actual VOLMET broadcasts, you will notice that TAF-terminology (BECMG, TEMPO) is also used, giving the broadcast a forecast element, too.

LONDON VOLMET MAIN.

Figure 23.2 shows sample LONDON VOLMET MAIN broadcasts. Six of the major aerodromes from the broadcast are included, with associated weather information.

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The information on VOLMET broadcasts is updated every 30 minutes.

THIS IS LONDON VOLMET MAIN AMSTERDAM AT 1125. WIND 160 DEGREES 16 KNOTS. VARIABLE BETWEEN 130 AND 190 DEGREES. VISIBILITY 7 KILOMETRES. LIGHT RAIN SHOWERS. CLOUD FEW 2 THOUSAND FEET. FEW CUMULONIMBUS 2 THOUSAND 5 HUNDRED FEET. BROKEN 4 THOUSAND FEET. TEMPERATURE 14. DEWPOINT 9 QNH 1004 BECOMING VISIBILITY 10 KILOMETRES OR MORE. NIL SIGNIFICANT WEATHER.	BRUSSELS AT 1120 WIND 190 DEGREES 14 KNOTS MAXIMUM 24 KNOTS. VISIBILITY 10 KILOMETRES OR MORE. LIGHT RAIN SHOWERS. CLOUD SCATTERED 2 THOUSAND 3 HUNDRED FEET. SCATTERED 5 THOUSAND FEET. BROKEN 10 THOUSAND FEET. TEMPERATURE13. DEWPOINT 10. QNH 1006. NOSIG.
GLASGOW AT 1120. WIND 070 DEGREES 5 KNOTS. VARIABLE BETWEEN 030 AND 110 DEGREES. VISIBILITY 10 KILOMETRES OR MORE. CLOUD FEW 1 THOUSAND 8 HUNDRED FEET SCATTERED 4 THOUSAND 5 HUNDRED FEET. TEMPERATURE 14. DEWPOINT 8. QNH 997.	DUBLIN AT 1130. WIND 260 DEGREES 6 KNOTS. VARIABLE BETWEEN 240 AND 300 DEGREES. VISIBILITY 10 KILOMETRES OR MORE. CLOUD SCATTERED 2 THOUSAND 4 HUNDRED FEET. TEMPERATURE 13. DEWPOINT 6. QNH 997. NOSIG.
LONDON/GATWICK AT 1120. WIND 190 DEGREES 10 KNOTS. VARIABLE BETWEEN 150 AND 220 DEGREES. VISIBILITY 10 KILOMETRES OR MORE. SHOWERS IN VICINITY. CLOUD FEW CUMULONIMBUS 2 THOUSAND 4 HUNDRED SCATTERED 4 THOUSAND FEET. TEMPERATURE 11. DEWPOINT 9. QNH 999.	LONDON/HEATHROW AT 1120. WIND 220 DEGREES 12 KNOTS. VARIABLE BETWEEN 190 AND 250 DEGREES. VISIBILITY 10 KILOMETRES OR MORE. LIGHT RAIN SHOWERS. CLOUD FEW 2 THOUSAND FEET. BROKEN 11 THOUSAND FEET. TEMPERATURE 11. DEWPOINT 8. QNH 997. TEMPO VISIBILITY 4 THOUSAND 5 HUNDRED METRES. RAIN SHOWERS.

Figure 23.2 Example VOLMET broadcasts from LONDON VOLMET MAIN.

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VOLMET BROADCASTS IN THE HIGH FREQUENCY BAND.

The VOLMET broadcasts that we have spoken of, so far, are transmitted in the VHF band. However, VOLMETS are also broadcast, all over the world, in the High Frequency (HF) band, typically between 3 to 20 MHz. A selection of HF VOLMET is depicted in *Figure 23.3*.

ATIS	**Automatic Terminal Information Service**
VOLMET	**Routine Broadcast of Meteorological Information for Aircraft In Flight (INTL)**
VOLMET	**Routine Broadcast of Meteorological Information for Aircraft In Flight (NATL)**
WX	**Weather Broadcast**
Inactive or Planned Service	

EUR-MET Europe								
Freq (Mhz)	**Type**	**BCH +**	**Call Sign**	**State**	**Station Name**	**Latitude (N)**	**Longitude (E/W)**	**Remarks**
2.998	VOLMET							unassigned
3.413	VOLMET	00,30	EIP	IRL	Shannon	52 34 N	09 12 W	1800-0530Z
4.540	WX	15,45	MLD	GBR	Architect (Kinloss)	57 39 N	03 34 W	
4.645	ATIS	Cont	ES..	EST	Tallinn	59 25 N	24 50 E	ex-RPH 6
4.742	WX	00,30	MLP	GBR	Architect (Brize Norton)	51 45 N	01 35W	
	VOLMET	.., 35	GFG	GIB	Gibraltar	36 09 N	05 21 W	
	VOLMET	15, ..	GFW	CYP	Cyprus (Akrotiri)	34 35 N	32 58 E	Mo-Fr 0215-1815Z
5.450	VOLMET	00, 30	MPL 2	GBR	West Drayton (London)			“RAF”
5.505	VOLMET	00, 30	EIP	IRL	Shannon	52 34 N	09 12 W	
5.714	WX	00, 30	MLP	GBR	Architect (Brize Norton)	51 45 N	01 35 W	
6.580	VOLMET							unassigned

Figure 23.3 International HF VOLMET Broadcasts.

The Shannon VOLMET, shown in *Figure 23.3*, is a vital source of weather information for North Atlantic flight routes.

The types of VOLMETs listed in *Figure 23.3* contain the same information as the VOLMETs for mainland United Kingdom, although they are more likely also to contain additional weather forecast details, such as SIGMETS for en-route weather.

VOLMET transmissions are designed to be simple and easily understood, so that fast, efficient weather briefing can be obtained by pilots in flight.

During pre-flight planning, note down the VOLMET frequencies for the areas that you will be flying in, so that, en-route, you can listen to broadcasts for aerodromes in the vicinity of your destination, as well as for alternate aerodromes.

Access to VOLMET broadcasts enables the pilot to confirm that weather conditions at his destination airfield are favourable. If a diversion becomes necessary, the current suitability of the planned diversion airfield can also be rapidly determined.

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Representative PPL - type questions to test your theoretical knowledge of The VOLMET.

1. An aerodrome VOLMET report for 0450 UTC during the autumn in the United Kingdom is given as follows:

Surface wind	150/05 kts
Visibility	2000 m
Weather	Nil
Temperature	9º C
Dew point	8º C
QNH	1029 mb
Trend	NOSIG

From the information above, what type of pressure system, do you deduce, is dominating the region?

a. An anti-cyclone
b. A cyclone
c. A low pressure
d. A trough

2. A VOLMET is defined as:

a. A radio broadcast of selected aerodrome forecasts
b. A continuous telephone message of selected aerodrome METARs
c. A continuous radio broadcast of selected aerodrome actual weather observations and forecasts
d. A teleprinter message of selected aerodrome TAFs and METARs

3. VOLMETs are updated:

a. Every hour
b. 4 times a day
c. 2 times a day
d. Every half hour

4. VOLMETs are:

a. Air to ground radio transmissions in the HF and VHF bands
b. Air to ground radio transmissions in the HF and SVHF bands
c. Ground to air radio transmissions in the LF and VHF bands
d. Ground to air radio transmissions in the HF and VHF bands

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5. An aerodrome VOLMET report for 0450 UTC during the autumn in the United Kingdom is given as:

Surface wind	150/05 kts
Visibility	2000 m
Weather	Nil
Temperature	9º C
Dew point	8º C
QNH	1029 mb
Trend	NOSIG

Given that sunrise is at 0600 UTC, what might you expect during the 2 hours following this report?

a. CAVOK
b. Radiation Fog
c. Low Stratus
d. Advection Fog

Question	1	2	3	4	5
Answer					

The answers to these questions can be found at the end of the book.

CHAPTER 24
THE AUTOMATIC TERMINAL INFORMATION SERVICE

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INTRODUCTION.

The Automatic Terminal Information Service (ATIS) is a continuous broadcast of current aerodrome weather and other aerodrome information.

The Automatic Terminal Information Service (ATIS) is a continuous broadcast of current aerodrome weather and other aerodrome information.

The purpose of the ATIS is to improve controller effectiveness and to reduce congestion on busy ground, tower and approach frequencies by automatically transmitting on a discrete VHF radio frequency.

Pilots departing from or arriving at aerodromes which offer ATIS are encouraged to listen to the ATIS broadcast and to notify air traffic control, on initial contact, that they have received the ATIS broadcast, by passing the phonetic alphabet code letter by which all ATIS broadcasts are identified.

At some aerodromes there will be separate ATIS broadcasts for departure and arrival.

Pilots are encouraged to listen to ATIS broadcasts before initial contact with Air Traffic Control, either on departure from or arrival at an aerodrome.

In order to free up air traffic VHF communication frequencies, some aerodromes transmit the ATIS information on the voice channel of a VOR beacon located at the aerodrome.

Figure 24.1a, below, is an extract from the Aerodrome section of the United Kingdom Aeronautical Information Publication (UK AIP) illustrating that both an arrival and departure ATIS is available, on different frequencies, at Manchester Airport.

EGCC AD 2.18 - ATS COMMUNICATION FACILITIES

Service Designation	Callsign	Frequency MHz	Hours of Operation Winter	Summer	Remarks
1	2	3	4		5
APP	Manchester Radar	119.525†	H24	H24	ATZ hours coincident with Approach hours. †Serves Manchester and Manchester Woodford
	Manchester Radar	118.575	As directed by ATC	As directed by ATC	
	Manchester Director	121.350			
TWR	Manchester Tower	118.625 121.500‡ 119.400	H24	H24	‡Emergency Ch O/R
	Manchester Ground	121.850 121.700§ 125.375	0630-2200 2200-0630 As directed by ATC	0530-2100 2100-0530 As directed by ATC	§Departing aircraft are to make initial call on 121.700 MHz to 'Manchester Delivery' or Manchester 'ground' as appropriate.
	Manchester Delivery	121.700§	0630-2200	0530-2100	
Arrival ATIS[Ø]	Manchester Information	128.175	H24	H24	[Ø]Also available by telephone 0161-499 2324
Departure ATIS[Ø]	Manchester Departure Information	121.975	0520-2220	0420-2120	Non-ATS frequency.
FIRE	Manchester Fire	121.600	Available when Fire vehicle attending aircraft on the ground in an emergency		

Figure 24.1a Manchester Airport has separate ATIS frequencies for arrival and departure.

ATIS is generally broadcast on VHF communication frequencies but there are several airports where the ATIS is broadcast on the VOR frequency.

The purpose of ATIS is to improve controller effectiveness and to reduce congestion on busy ATC frequencies.

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Figure 24.1b is another extract from the UK AIP. This extract shows that, at Southampton Airport, the ATIS broadcast is made on the Southampton VOR frequency.

EGHI AD 2.18 - ATS COMMUNICATION FACILITIES					
Service Designation	Callsign	Frequency MHz	Hours of Operation Winter	Summer	Remarks
1	2	3	4		5
APP	Southampton Approach	128.850	As directed by ATC	As directed by ATC	ATZ hours coincident with Tower hours (but not by arrangement).
TWR	Southampton Tower	118.200	†Mon - Fri 0525-2100 Sat 0625-2000 Sun 0735-2100 and by arrangement	†Mon - Thu 0545-2030 Fri 0545-2115 Sat 0630-1915 Sun 0800-2000 and by arrangement	†Hours subject to change, consult latest NOTAM.
RAD	Southampton Ground	121.775	As directed by ATC		
	Southampton Radar	128.550	As directed by ATC		
ATIS	Southampton Information	113.350	HO	HO	Broadcast on Southampton VOR
FIRE	Southampton Fire	121.600	Available when Fire vehicle attending aircraft on the ground in an emergency		Non-ATS frequency

Figure 24.1b Southampton Airport is an example of an airfield at which the ATIS is broadcast on the VOR frequency.

An ATIS broadcast is up-dated as soon as there is any change in the weather or airfield information. Each broadcast has a distinct identifying code letter.

ATIS OPERATION.

If the current aerodrome weather conditions change, or if there is any change in other pertinent aerodrome information, the ATIS broadcast is immediately updated to reflect these changes. The updated ATIS broadcast is then given a new, sequential alphabetical code. For example, ATIS broadcast BRAVO will have replaced the previous ATIS broadcast ALPHA.

On initial contact with Air Traffic Control (ATC), a pilot is required to state the identifying letter code of the ATIS information last received, in order that ATC may know that the pilot has the most recent information.

ATIS will be broadcast in plain language and will contain some or all of the following information, if applicable.

The surface wind information given in the ATIS broadcast is referenced to Magnetic North.

- Aerodrome name.
- ATIS sequence designator or information code.
- Time of observation.
- Runway in use and status.
- Surface wind in knots and referenced to magnetic north.
- Visibility and Runway Visual Range (RVR).
- Present weather.

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- Significant cloud.
- Temperature and dew point.
- Altimeter setting.
- Transition Level.
- Type of approach expected.
- Any essential aerodrome information pertinent to flight operations.

USE OF ATIS.

On departure from an aerodrome, ATIS information should be obtained by the pilot before initial contact with Air Traffic Control. When initial contact is made with Air Traffic Control, the pilot must mention the identifying letter of the ATIS broadcast obtained, in order to confirm to the controller that the latest airfield information has been received.

Figure 24.2 On depature, ATIS information should be obtained by a pilot before initial contact is made with Air Traffic Control.

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A pilot arriving at an aerodrome should also listen to the ATIS broadcast before transmitting on the aerodrome's initial contact frequency. On hearing that a pilot has the latest ATIS information, an approach controller may omit, in his reply to the pilot, certain details contained in the ATIS broadcast. Normally, however, the aerodrome QNH will always be confirmed by the controller.

Figure 24.3 On arriving at an aerodrome, a pilot should obtain the latest ATIS information before making initial contact with Approach.

If a pilot does not acknowledge receipt of the latest ATIS broadcast on initial contact with an aerodrome controller, the controller will pass the essential aerodrome information to the pilot.

Obtaining the latest ATIS information helps ensure that radio transmissions between Air Traffic Control and the pilot are kept to a minimum. This is especially important in busy airspace where radio transmissions must be kept short to allow for effective communication between controllers and all the aircraft to which they are giving a service.

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Representative PPL - type questions to test your theoretical knowledge of ATIS.

1. When are ATIS broadcasts updated?

    a. Any time the aerodrome or weather information changes
    b. Only when the aerodrome information changes
    c. Every 30 minutes
    d. Every hour

2. To minimise VHF frequency use, the ATIS can be broadcast on the voice frequency of which navigation aid?

    a. ILS
    b. NDB
    c. VOR
    d. GPS

3. In an ATIS broadcast, what is used to identify the current report?

    a. An alphabetical code
    b. A number
    c. A validity number
    d. An issue time

4. What is the ATIS?

    a. A chart of current aerodrome and weather information
    b. A continuous broadcast of current aerodrome and weather information
    c. A continuous broadcast of weather information
    d. A printed text report of current aerodrome and weather information

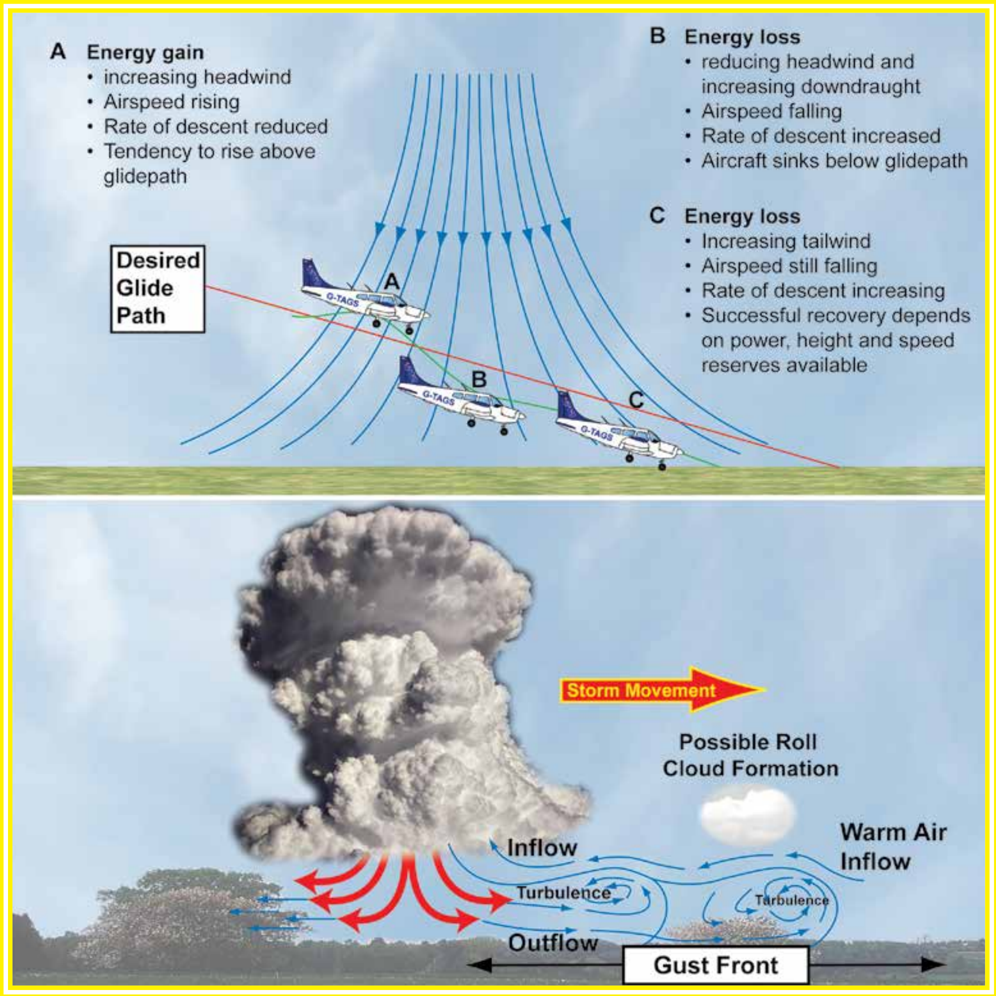
5. In what frequency band is the ATIS normally broadcast?

    a. LF
    b. HF
    c. ADF
    d. VHF

Question	1	2	3	4	5
Answer					

The answers to these questions can be found at the end of the book.

CHAPTER 25
WINDSHEAR



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WINDSHEAR.

Low altitude windshear is a major hazard to light aircraft. The effects of windshear in the take-off, approach and landing phases of flight have been responsible for numerous accidents to light aircraft.

The aim of this chapter is that the pilot should learn the definitions of windshear, where and when to expect windshear, and what actions should be taken to avoid or counter windshear.

DEFINITIONS.

Windshear may be defined as variations in wind speed and/or direction along an aircraft's flight path which may displace an aircraft abruptly from its flight path and which may require substantial control inputs to counter it.

Windshear is defined as a change in wind speed and/or direction over a relatively short distance.

Low Altitude Windshear is defined as windshear on the final approach path or along the runway, and on the take-off and initial climb-out flight paths.

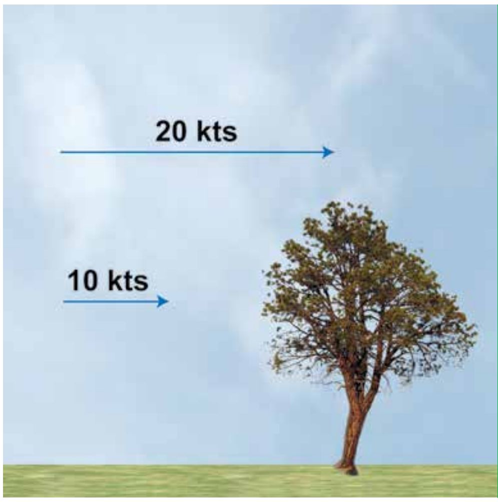

Figure 25.1 Vertical Windshear.

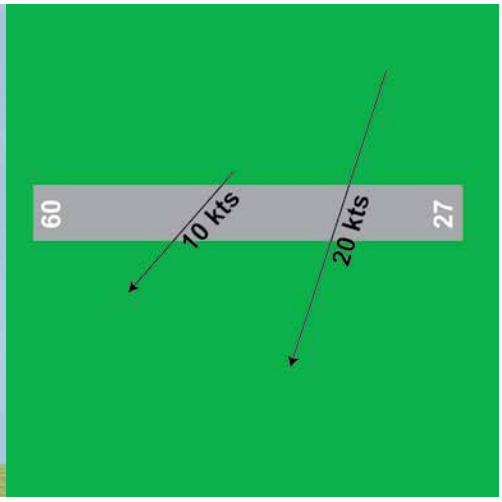

Figure 25.2 Horizontal Windshear.

Vertical Windshear is defined as a change of wind speed and/or direction with height. *(See Figure 25.1.)*

Horizontal Windshear is a change of wind speed and/or direction over a horizontal distance. *(See Figure 25.2.)*

THE EFFECTS OF WINDSHEAR.

The effect of an aircraft flying into windshear is basically that the aircraft's indicated airspeed will either decrease or increase, momentarily. Because the lift generated by an aircraft's wings is heavily dependent on its airspeed, the effect of windshear is also to increase or decrease lift sharply.

Whenever an aircraft flies into or through windshear, its airspeed will be affected. This is especially hazardous on take-off and landing.

An aircraft in flight, because it possesses mass and is flying at a given speed, will also possess a certain amount of momentum by virtue of its mass and speed. (momentum = mass × velocity). Because of the associated property of inertia, an aircraft flying at a given velocity will, therefore, tend to continue flying at that velocity, even when a force intervenes to change its velocity. In other words, it will always take a finite amount of time for an aircraft to change speed.

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So, if an aircraft is approaching to land at an indicated airspeed of 75 knots against a 30 knot headwind, its speed over the ground will be 45 knots. But, if vertical windshear is present on the approach, and the windspeed suddenly drops to 10 knots *(see Figure 25.3)*, the aircraft will be descending through decelerating air, and the aircraft's momentum will cause it to continue, momentarily, to travel at 45 knots relative to the ground. Consequently, for a very short period of time, the aircraft's airspeed will fall to 55 knots. More importantly, however, the lift generated by the aircraft's wings will suddenly decrease, too, and the aircraft will sink below the pilot's desired approach path. (Remember that the lift force acting on the aircraft varies with the square of the windspeed: **Lift =** $\frac{1}{2}\rho C_L V^2 S$) If the pilot is unprepared for this situation, height loss can be significant.

If the aircraft is close to the ground, a heavy landing or undershoot, or both, can occur. In extreme cases, such a situation may lead to a serious impact with the ground.

When vertical windshear is present on the approach, the pilot must take care not to let his airspeed decay, or the aircraft may lose height faster than planned, and undershoot the desired touch-down point.

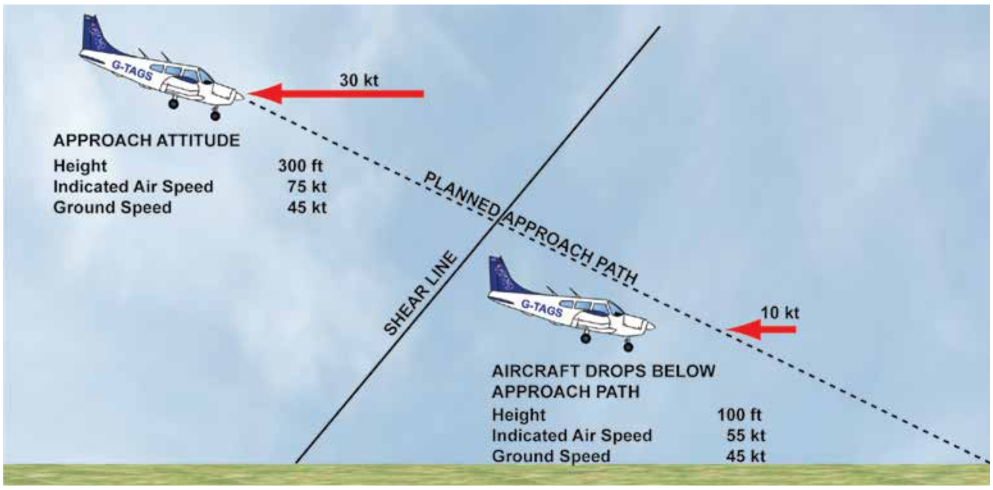

Figure 25.3 Vertical windshear on the approach and its possible effect on an aircraft approaching to land.

The pilot must, therefore, always be aware of weather and wind conditions which may give rise to windshear. He must also know the symptoms of windshear, and how to react to the effects of windshear if he has been unsuccessful in avoiding it.

The main problem facing a pilot whose aircraft encounters low-level windshear is the very fact that he may be low with little height in which to recover, if things go badly wrong. And, of course, the average light aircraft does not have a lot of power to counter the effects of windshear. Consequently, it is of supreme importance that airspeed be constantly monitored, and not allowed to decay.

Let us now look at some of the causes of windshear:-

CAUSES OF WINDSHEAR.

Thunderstorms.
Cumulonimbus thunderclouds can create conditions which will produce windshear, because of severe turbulence and precipitation associated with such clouds.

The Gust Front.
Some cumulonimbus thunder clouds have a well-defined area of cold air flowing out from downdraughts, which are called gust fronts, and which extend up to 15 nautical

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miles ahead of an approaching storm. These gust fronts are regions of great turbulence which give little or no warning of their approach. *(See Figure 25.4.)*

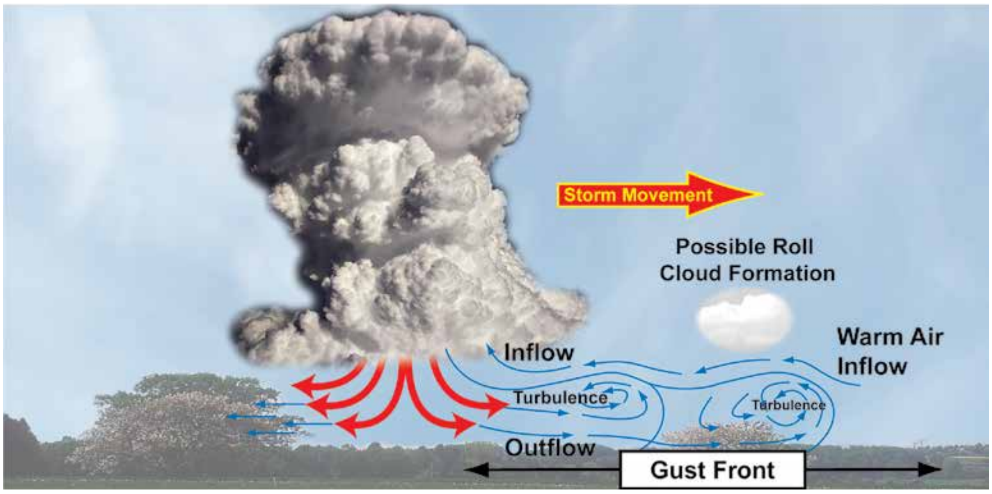

Figure 25.4 A gust front associated with a cumulonimbus thundercloud.

Microburst.

A microburst is a highly concentrated and powerful downdraught of air, typically less than 2 nautical miles across, which lasts for about 1 to 5 minutes. Microbursts are the most lethal form of windshear with downdraught speeds of 60 knots or more. There have been a number of fatal accidents to large commercial aircraft caused by microbursts on the final approach.

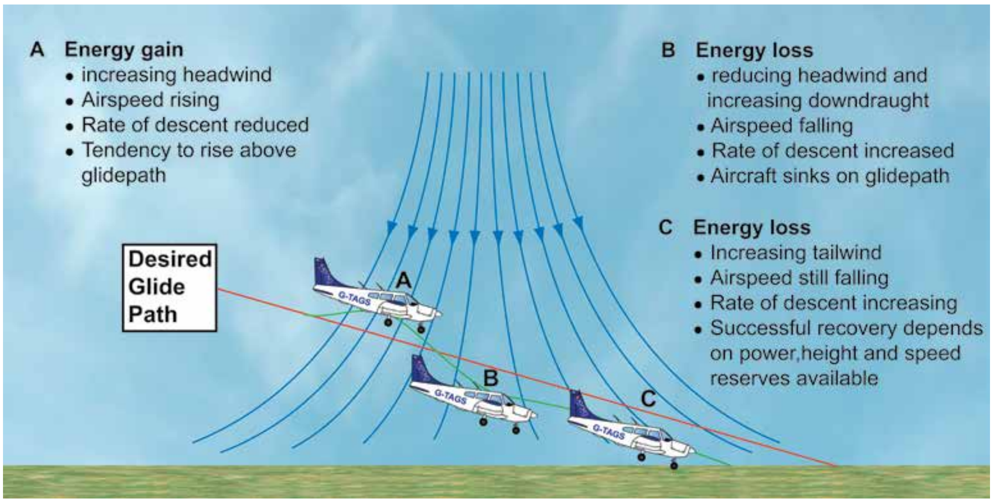

Figure 25.5 Windshear on the approach caused by a microburst.

Figure 25.5 depicts how a light aircraft on approach to land, caught in the windshear from a microburst, may be forced below the planned glide-path, because of the effects of windshear on airspeed and rate of descent.

If a pilot is caught unawares by severe windshear on the approach, an unplanned impact with the ground may result.

Frontal Passage.

Fronts vary in strength. It is, normally, only well-developed, active fronts, with narrow frontal zones and marked temperature differences, which are likely to carry the risk of windshear.

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On a weather chart, a pilot should look for fronts with sharp changes in wind direction across the front. The pilot should also note that temperature differences of 5°C or more across a front, or a front moving with a speed of 30 knots or more, may indicate a potential windshear hazard.

Inversion.

A low-level temperature inversion may develop and separate the stronger upper air-flow from slower moving air near the surface, giving rise to windshear at the inversion boundary. These inversions tend to form on clear nights.

Low-Level Turbulence.

Low-level turbulence within the friction layer can lead to windshear because of:

- Strong surface winds leading to pronounced gusts and lulls.
- Thermal turbulence caused by intense solar heating.

Topographical Windshear.

Topographical windshear is of two principal types. It may be caused by friction between the lower wind and the ground, leading to a marked decrease in wind speed as the surface is approached through the lower 1 000 feet, or so. *(See Figure 25.3.)* Topographical windshear is also caused by natural or man-made features, such as hills or buildings, which change the direction and speed of the wind blowing over them. Larger airport buildings adjacent to runways, as well as lines of trees, can create local windshear during both the final approach and initial departure.

TECHNIQUES TO COUNTERACT EFFECTS OF WINDSHEAR.

For the pilot of a light aircraft, the best way to deal with windshear is to use his knowledge and understanding of the subject to avoid severe windshear altogether, if at all possible, and consider diverting to an alternate aerodrome. However, should a pilot encounter windshear, the following actions may be considered. *(N.B. This is not a flying instructional manual, and you must, above all, deal with **windshear** in the manner recommended by your flying instructor.)*

- Increase power (to full power, if needed).
- Maintain or increase airspeed appropriately (attitude control).
- Co-ordinate pitch and power correctly.
- Be prepared to carry out a go-around or missed approach.
- If the pilot is on the ground, he should stay there until the windshear has abated.

In order to counteract windshear effect, be prepared to make pronounced control inputs.

If you wish to learn more about low-level windshear, the United Kingdom CAA currently produces an Aviation Information Circular on the subject, **AIC Number 19/2002 (pink 28)**.

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JAR-FCL PPL THEORETICAL KNOWLEDGE SYLLABUS

METEOROLOGY

The table below contains the principal topics and subtopics from the current outline syllabus for the theoretical knowledge examination in **Meteorology** for the **Private Pilot's Licence**, as published in **JAR-FCL 1**. Syllabuses may be modified, so always check the latest examination documentation from your **national civil aviation authority**, or from **JAR-FCL/EASA**.

METEOROLOGY	
The atmosphere:	composition and structure; vertical divisions.
Pressure, density and temperature:	barometric pressure, isobars; changes of pressure, density and temperature with altitude; altimetry terminology; solar and terrestrial energy radiation, temperature; diurnal variation of temperature; adiabatic process; temperature lapse rate; stability and instability; effects of radiation, advection subsidence and convergence.
Humidity and precipitation:	water vapour in the atmosphere; vapour pressure; dew point and relative humidity; condensation and vaporisation; precipitation.
Pressure and wind:	high and low pressure areas; motion of the atmosphere, pressure gradient; vertical and horizontal motion, convergence, divergence; surface and geostrophic wind; effect of wind gradient and windshear on take-off and landing; relationship between isobars and wind, Buys Ballot's law; turbulence and gustiness; local winds, föhn, land and sea breezes.
Cloud formation:	cooling by advection, radiation and adiabatic expansion; cloud types (convection clouds; orographic clouds; stratiform and cumulus clouds); flying conditions in each cloud type.
Fog, mist and haze:	radiation, advection, frontal, freezing fog; formation and dispersal; reduction of visibility due to mist, snow, smoke, dust and sand; assessment of probability of reduced visibility; hazards in flight due to low visibility, horizontal and vertical visibility.
Air masses:	description of and factors affecting the properties of airmasses; classification of airmasses, region of origin; modification of airmasses during their movement; development of low and high pressure systems; weather associated with pressure systems.

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Frontology:	formation of cold and warm fronts; boundaries between airmasses; development of a warm front; associated clouds and weather; weather in the warm sector; development of a cold front; associated clouds and weather; occlusions; associated clouds and weather; stationary fronts; associated clouds and weather.
Ice accretion:	conditions conducive to ice formation; effects of hoar frost, rime ice, clear ice; effects of icing on aeroplane performance; precautions against and avoidance of icing conditions; powerplant icing; precautions, prevention and clearance of induction and carburettor icing.
Thunderstorms:	formation – airmass, frontal, orographic; conditions required; development process; recognition of favourable conditions for formation; hazards for aeroplanes; effects of lightning and severe turbulence; avoidance of flight in the vicinity of thunderstorms.
Flight over mountainous areas:	Hazards; influence of terrain on atmospheric processes; mountain waves, windshear, turbulence, vertical movement, rotor effects, valley winds.
Climatology:	general seasonal circulation in the troposphere over Europe; local seasonal weather and winds.
Altimetry:	operational aspects of pressure settings; pressure altitude, density altitude; height, altitude, flight level; ICAO standard atmosphere; QNH, QFE, standard setting; transition altitude, layer and level.
The meteorological organisation:	aerodrome meteorological offices; aeronautical meteorological stations; forecasting service; meteorological services at aerodromes; availability of periodic weather forecasts.
Weather analysis and forecasting:	weather charts, symbols, signs; significant weather charts; prognostic charts for general aviation.
Weather information for flight planning:	reports and forecasts for departure, en-route, destination and alternate(s); interpretation of coded information METAR, TAF, GAFOR*; availability of ground reports for surface wind, windshear, visibility.
Meteorological broadcasts for aviation:	VOLMET, ATIS, SIGMET.

***GAFOR* means *General Aviation Forecast*. In Europe, *GAFOR* is used primarily in Germany and Switzerland.**

ANSWERS TO METEOROLOGY QUESTIONS

ANSWERS TO THE METEOROLOGY QUESTIONS

Chapter 1 ***The Atmosphere***

Question	1	2	3	4	5	6	7
Answer	d	c	a	c	d	a	b

Chapter 2 ***Atmospheric Pressure***

Question	1	2	3	4	5	6
Answer	a	d	a	c	a	d

Chapter 3 ***Atmospheric Density***

Question	1	2	3	4	5	6
Answer	b	b	a	c	a	d

Chapter 4 ***Temperature***

Question	1	2	3	4	5	6	7	8	9
Answer	c	d	a	c	c	a	d	b	b

Chapter 5 ***Pressure Systems***

Question	1	2	3	4	5	6	7	8	9
Answer	d	b	c	c	d	a	b	c	a

Chapter 6 ***Altimetry***

Question	1	2	3	4	5	6	7	8	9	10	11	12
Answer	d	a	a	c	b	c	b	b	a	d	b	c

Question	13
Answer	a

Chapter 7 ***Humidity***

Question	1	2	3	4	5	6	7	8	9
Answer	d	b	d	a	b	c	d	d	b

Chapter 8 ***Adiabatic Processes and Stability***

Question	1	2	3	4	5	6	7
Answer	c	b	d	c	d	a	a

ANSWERS TO THE METEOROLOGY QUESTIONS

Chapter 9 Turbulence

Question	1	2	3	4	5	6
Answer	b	d	c	c	b	a

Chapter 10 Clouds and Precipitation

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Answer	a	b	d	c	c	a	a	d	b	b	c	d	a	b

Chapter 11 Thunderstorms

Question	1	2	3	4	5	6	7	8	9	10
Answer	d	d	c	b	a	b	a	b	c	c

Chapter 12 Winds

Question	1	2	3	4	5	6	7	8
Answer	c	b	c	a	d	d	c	b

Chapter 13 Visibility and Fog

Question	1	2	3	4	5	6	7
Answer	a	b	b	c	d	c	d

Chapter 14 Icing

Question	1	2	3	4	5	6	7
Answer	c	a	d	c	d	a	b

Chapter 15 Air Masses and Fronts

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Answer	b	c	c	b	a	a	d	b	c	c	d	a	d	a	b	d

Chapter 16 The METAR

Question	1	2	3	4	5	6	7	8
Answer	b	c	d	a	d	a	a	b

Chapter 17 Terminal Aerodrome Forecasts

Question	1	2	3	4	5	6	7
Answer	b	a	b	d	d	c	d

Chapter 18 The Spot Wind Chart

Question	1	2	3	4	5	6
Answer	b	b	c	d	b	a

Chapter 19 Low Level Forecast Chart

Question	1	2	3	4	5	6	7	8
Answer	c	d	a	c	d	d	a	b

Chapter 20 World Area Forecast Significant Weather Charts

Question	1	2	3	4	5
Answer	b	a	d	b	c

Chapter 21 The SIGMET

Question	1	2	3	4	5
Answer	c	b	d	b	d

Chapter 22 The AIRMET

Question	1	2	3	4	5
Answer	b	c	a	b	c

Chapter 23 The VOLMET

Question	1	2	3	4	5
Answer	a	c	d	d	b

Chapter 24 Automatic Terminal Information Service

Question	1	2	3	4	5
Answer	a	c	a	b	d

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