PILOTS' WEATHER

ANN WELCH

A flying manual

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Pilots' Weather is a completely rewritten enlargement of *Cloud Reading for Pilots* which was published in 1943 and was reprinted several times. This new book contains the author's accumulated knowledge and experience of flying and gliding in many countries including the United States. Broadly, the contents are divided into three sections: the interpretation of weather maps and forecasts; the relation of weather found in flight to the forecast displayed on paper, and a section on weather in the air which covers frontal situations, flying through cloud, dealing with strong winds, turbulence, icing, unexpected wave formations and many other problems which arise from weather peculiarities.

The book is fully illustrated with diagrams, weather maps and photographs intended to be informative and useful to active pilots, particularly those who do not have sophisticated navigational aids. There are also first-hand accounts by many pilots of weather problems encountered in flight.

Colour photo – Ann Welch

By the same author

THE STORY OF GLIDING
NEW SOARING PILOT
(With Frank Irving and Lorne Welch)

All drawings and photographs are by the Author except for the NASA satellite pictures.

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To John Neilan:
test pilot and gliding pioneer,
through forty years of
British weather

Foreword

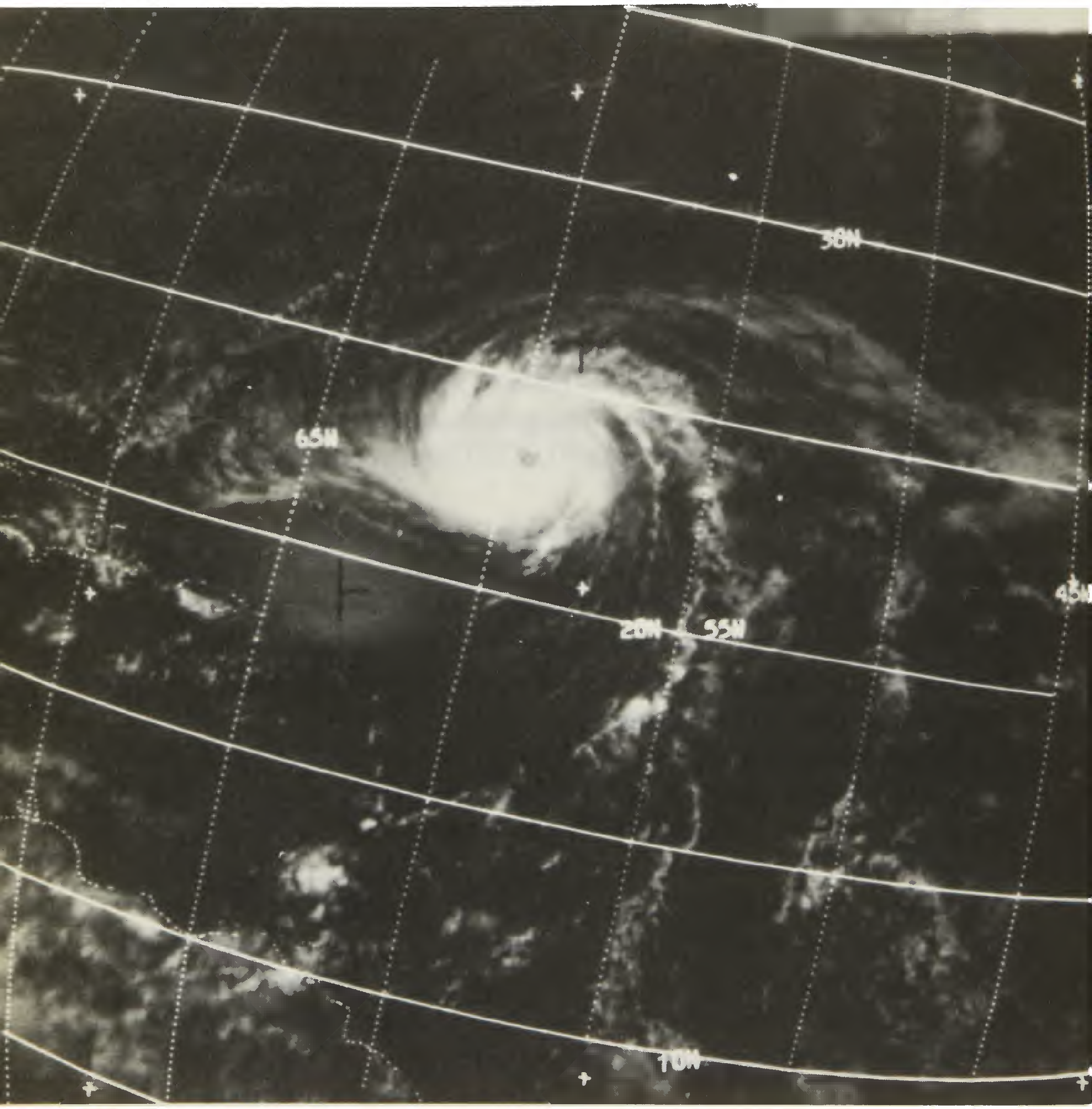
I am not a professional meteorologist, having learnt about weather from the ground up – the hard way. I have, however, worked a great deal with meteorologists both at the receiving end as a pilot, and as a task setter in World and National Gliding Championships, and I am very grateful for the help that they have always given me, in particular Professor C. E. Wallington now Director of the Institute of Marine Studies at the University of New South Wales.

For help with the preparation of this book I am sincerely indebted to Tom Bradbury of the Meteorological Office, Charles V. Lindsay of the US Weather Bureau, and John Ward, Secretary of the General Aviation Safety Committee and Editor of its Flight Safety Bulletin. The satellite photographs are from the National Environmental Satellite Service of the US Oceanic and Atmospheric Administration.

A great deal of generous assistance has come from the Editor of and contributors to *Pilot*, the official journal of the AOPA Foundation which does so much for the safety and the encouragement of the private pilot all over the world; also from the Editors of *Weather*, *Sailplane and Gliding*, *Soaring*, *Swiss Aero Revue*; and from John Simpson, expert on sea breezes.

The passages with rules round them throughout the book are specific examples of what the weather can do and why the pilot must never take it for granted. Those in the pilots' own words are acknowledged at the foot of each extract. I am also grateful to the following contributors to the magazines mentioned above on whose work I have based other passages: *Weather* – W. A. L. Marshall, R. F. Williams, C. M. Stevenson, N. Rutter, J. A. Taylor, D. Storr, Carl S. Benson, J. Gentilli; *Aero Revue* – Jiri Forchgott; *Sailplane and Gliding* – Adam Zientik; *Volo a Vela* – Plinio Rovesti.

A.W.



Hurricane Debbie over the Caribbean. Venezuela is marked by dotted lines at the foot of the photograph, with Santo Domingo at left centre. Taken from Satellite Essa, 19 August 1969 at 1806 hrs.

Introduction—At home in the air

The air is not our natural habitat as it is that of the albatross or the eagle, so we cannot expect to have the instinctive knowledge possessed by birds. We know our way around the land all right, but here we mostly get by without any real concern for the weather. We more often than not take a coat or, when it is needed, an umbrella, and remember times of the radio and TV weather forecasts; but since our lives are spent largely indoors the majestic life of the sky frequently passes unnoticed. When we go on holiday, particularly if we sail, fly, or ski, and certainly if we camp, the weather becomes much more important and we realise how little we really know about it – but even if we judge it wrong this rarely means more than getting a bit wet or cold.

When starting to fly, however, we expect the freedom of an unfamiliar and three-dimensional element. All our lives we have been *in* the air on the ground, so there seems no reason to believe that being *up* in it could be all that different. The instructor quite quickly teaches us basic pilotage skills in weather that he knows to be suitable, but thereafter it is possible to continue to fly without gaining any real understanding of our new element. Several factors contribute to this situation. For a start theoretical meteorology seems far removed from our simple needs. When flying in increasingly dirty weather and wondering what to do about it, we are not in the least concerned about the rotation of the earth or the coriolis force, but simply whether there is going to be a big enough gap between cloud and ground just for us. Since there can be no rule book which will give the answer to this or any other weather problem met with in the air, we have to work out what to do for ourselves; even if told on the radio of a clear weather alternate airfield, it is still we alone that have to get there.

Another reason is that it is easy to lose interest after we have made a vain effort to get to grips with the subject. The weather that one is supposed to know about as a pilot always seems to be made more complicated than necessary. This is not only because some erudite questions about its structure and behaviour are still not fully answered, but because it is too often surrounded by a mumbo jumbo of geostrophic forces, tephigrams, and spidery whorls on synoptic charts, instead of being treated as the everyday matter that it really is. So we tend to learn about the weather in unrelated bits and the subject as a whole becomes difficult to understand. At school it was all Horse Latitudes and Tropics of Capricorn; the private pilot does fronts, the glider pilot concentrates on thermals, and the yachtsman lives with Viking, Fisher, Dogger and Sole. So we give up. After all, there is probably a nice forecaster not too far away, and if he gets it wrong, it's not our fault.

This is a pity. In real life everyone's weather problems are, in fact, much the same whether we farm, fish or fly; we are concerned that we do not get caught out by weather that is unsuited to what we want to do. This is particularly so with flying whether it be in aeroplanes, gliders or even balloons. It certainly makes us free of this new element, and it brings rewards that are inconceivable to those who have never taken themselves into the air; but being right inside the weather is not the same as seeing and feeling it pass by. The air is too powerful; its movements and behaviour are on a scale that totally dwarfs our activities, and in the face of some of them, like hurricanes, we are powerless. So both for our enjoyment and continued existence we need to find out more about the air, and not just hope to pick up snippets of knowledge as we go along. We do not have to regard weather as a textbook subject because it is present all the time. From the clouds that form and grow in their infinite variety, and change and decay, we can learn most of what we need to know. Their language can be learnt by keeping our eyes open, and noting, and comparing what we see with what others have seen and experienced, and with what the forecasters say. As weather behaviour becomes familiar we find more that is interesting or unusual, and if we don't see it for a day, it is almost like missing an instalment. When we go to a different part of the world we meet new people – and new weather. Quite soon we find that the sky can be read, and that we are getting better value from forecasts, or that we can make our own. We develop the instincts and cunning that enable us to know how to thread our way safely through or between the excesses of the weather jungle. This book has one aim; to enable any pilot, or would-be pilot, to reach this stage as quickly and painlessly as possible.

Ann Welch

Part 1 Weather analysed

1 Why we get weather

The basic causes of weather are simple, and we can base our future learning about the whole subject on just two fundamental rules.

(1) *When air at a certain pressure is warmed its density decreases, it becomes buoyant in relation to the surrounding air, and rises. Conversely the density of cooled air increases, and it sinks.*

(2) *When air is cooled enough some of the invisible water vapour that it carries condenses and creates cloud. When cloud is warmed it evaporates back into invisible water vapour.*

In practice we see the result of this second rule in a car. The condensation on the inside of the windscreen is just a thin film of cloud; when we put on the heater the condensation evaporates.

These two rules apply equally over those millions of square miles around the hot Equator, in every spell of rotten weather, and in the weakest little upcurrent that a glider pilot leaves in disgust. Obviously there will be different reasons for the air to go up or down, clouds will come in all sizes, and the terrain over which air moves will contribute its share of modifications, but these are details. They are fascinating and necessary to know but secondary to the main theme, *that whenever air is cooled sufficiently cloud will form*; and our weather is just clouds arranged in different ways. So we are concerned in this book with why clouds develop, what form they will take, what they will look like, and when they will go away.

The sky is thin

Because of the huge difference in warmth received from the sun at the Equator and at the Poles, and because the earth goes on spinning, it is obvious that the air in which all these clouds will form is being constantly churned around. This turmoil, with its ever changing temperatures, densities and pressures, and the humidity which the air possesses, is confined within a remarkably shallow layer. From the surface upwards the air thins out imperceptibly as height increases, but the depth with which we are concerned is about 50,000 ft, or a mere 10 miles thick. This is horizontally equivalent

Luck is useful too . . .

. . . Altitude 11,000 ft. The sun's rays on top of the perfectly solid creamy cloud beneath me made it very difficult to judge the distance between the plane and the cloud deck. All of a sudden, I found the clouds billowing up around the plane, rising more rapidly than the plane would climb. Within a matter of seconds, I was entirely involved in a sort of white wool, which 5 minutes later was black – but black, like a darkroom. I could barely make out the instrument panel.

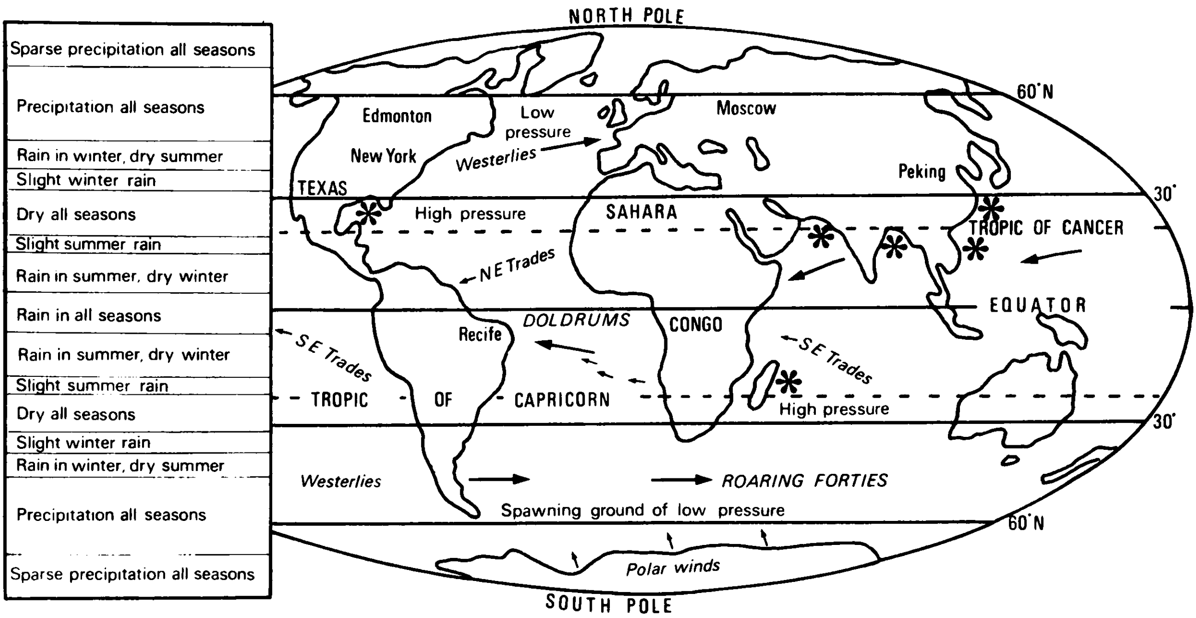
There was turbulence within the cloud, so violent that, at times, I noted the plane climbing 2000 fpm, and a moment later plunging downwards at the rate of a thousand or more. There was no sense of control whatever in the plane, the same as if ailerons, rudder, and elevator had been disconnected. The compass spun one way and then the other. It was like being a peanut in a mixmaster. . . . all of a sudden out of the mist off my right wing, a fir tree whipped by. Five minutes later a cliff was momentarily visible close by my left wing. I had lost a great deal of altitude, had climbed up little by little, only to lower again, but by that time I knew with a certainty what was coming. A few seconds later, with a little cone-shaped tip of a mountain at my very nose, I was prepared. I cut the switch and the gas, and ploughed into the mountaintop. The altimeter marked 11,800 ft.

The plane ploughed forward into the ground, stopping within 7 or 10 ft. Pine saplings, which cut slots in the wings, broke the roll forward . . . the cabin was flooded with gasoline, and a mass of gasoline vapour rose over the hot motor. . . . I hopped out in one curve, like a fish out of a tank. . . . In a matter of moments I was sopping wet, the cold was something terrible, and I climbed back into the cabin still dripping with gasoline, to think it over.

William Spratling, on a flight from Iguala to Mexico City which he had previously made 2000 times.

—*AOPA Pilot*

to just 7 minutes driving on a motorway; a jet fighter could go straight upwards through it within 5 minutes of take-off. In light aeroplanes and gliders we mostly use little more than the bottom tenth of this air – which holds the worst of the weather. Passenger jets usually have two-thirds of the atmosphere below them and nine-tenths of the cloud, so the lucky people are above most of it most of the time. It is, of course, the meagre depth of our atmosphere that determines the scale of weather – the size of depressions or the height of storms. If the atmosphere were deeper there would probably be larger areas of bad weather further apart, and if it were



1.1 World weather

In the northern summer there is a seasonal shift of weather belts to the north, and in the southern summer to the south. The asterisks show hurricane, typhoon, and cyclone trouble spots.

thinner, they would be smaller but closer together. In a transatlantic jet we may fly over a single depression for 600 miles, but nowhere is it more than 6 miles thick, or deep. This is not the impression that one retains from most diagrams of atmospheric circulations, which too often give a ludicrously exaggerated vertical scale; if the earth's diameter were the height of this page, the atmosphere would be as thick as only 5 sheets.

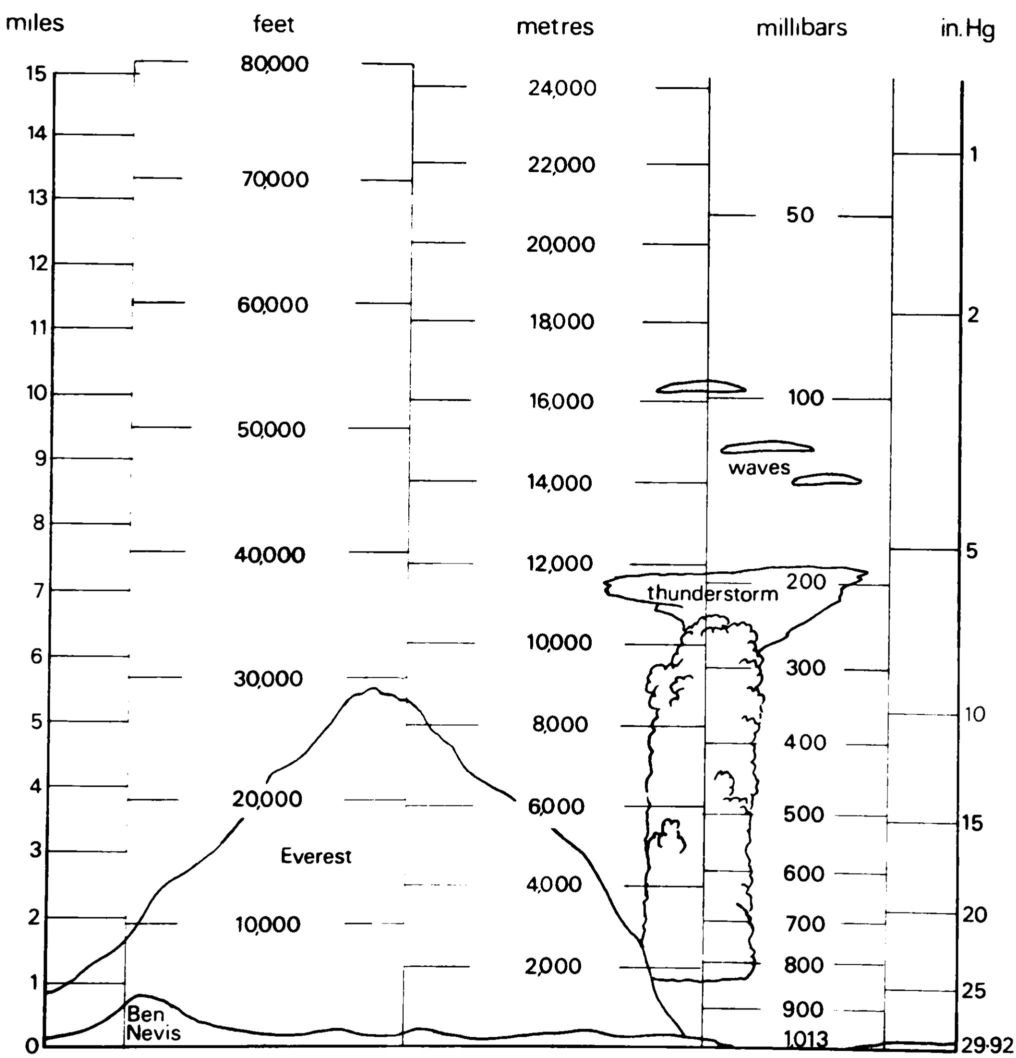
This skinny covering of air is all that effectively shields the earth from the many billion horse-power of heat energy that it intercepts from the sun; heat that is absorbed by the ground, or reflected from the clouds, and which is the starting point of all the interrelated processes that determine our weather. We now need, therefore, to look at its ingredients in a little more detail, even at the price of some dull workaday pages. If we do not have clear in our minds a few essential points about the structure of the atmosphere it will be less easy to achieve any real understanding of how and why weather changes take place, and the flying-orientated parts of this book will be of less use.

Density and pressure

We must start by being clear about the difference between density and pressure. The *density* of the air is the closeness together of air particles, and is expressed in mass per unit volume. For example, at 15°C a cubic metre, at sea level, contains 1226 grammes of air.

The *pressure* is the weight of all the air above any given unit area of the earth's surface. The total weight of air above any square foot of surface is about 15 lb. As we go higher there is less air above, and so the pressure is less. On top of Mt Everest, almost 30,000 ft, the pressure is only about one-third that at sea level – about 5 lb sq ft.

Although pressure is strictly a force per unit area, it is sometimes expressed in inches of mercury (the height of a column of mercury



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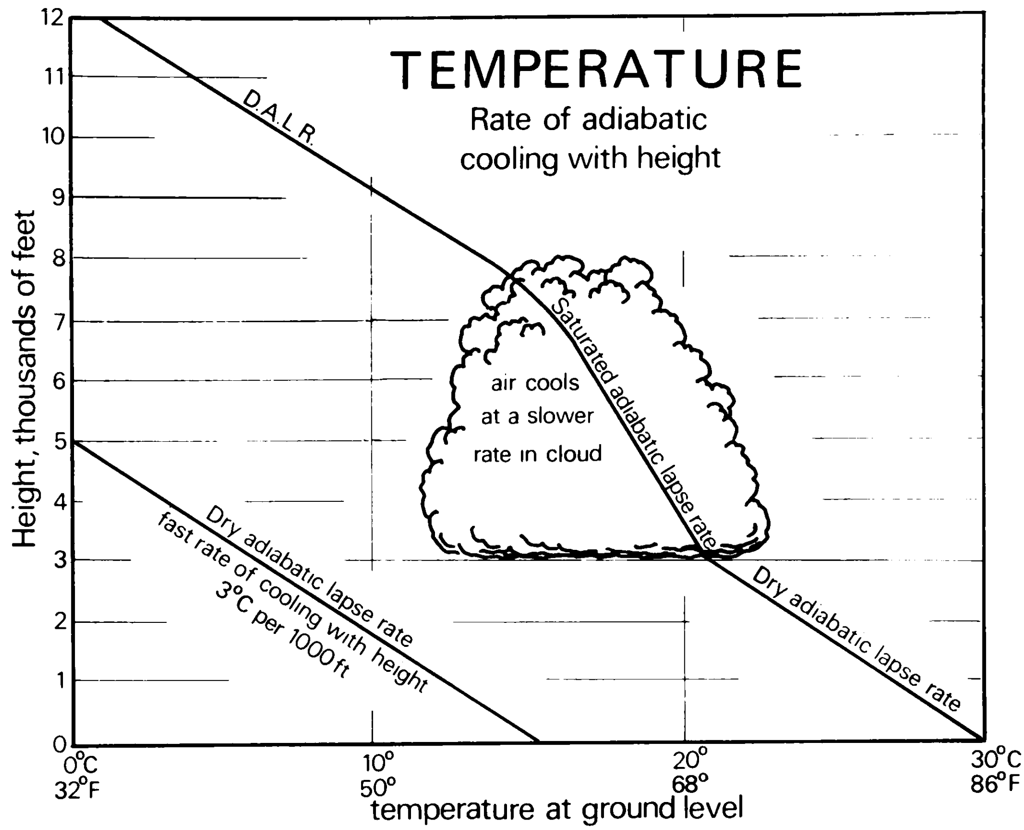


1.3

which produces the same pressure). In aviation it is more usual to use an international unit of pressure called a *millibar*, or *mb* for short. The distribution of pressure in the atmosphere is the basis on which weather forecasts are made and presented.

Pressure and temperature

We notice changes of temperature because we feel hot or cold, but unless we do something less usual, like blow up a bicycle tyre, we may forget that the temperature of the air alters whenever its pressure changes. As pressure is increased the temperature will increase – as with the hot cycle pump, and as pressure is reduced so the temperature will lower – a cause of carburetter icing. Alterations of temperature caused by changes in pressure are termed *adiabatic*. The word simply means that a parcel of air can be subjected to changes of pressure without it gaining or losing heat from, or to, outside sources.

To summarise this density, pressure and temperature interrelationship; if our parcel of air at the surface is warmed, then its pressure will initially remain unaltered, but due to the higher temperature its density will be slightly less than that of the surrounding air. It becomes buoyant and so rises. As it rises its pressure will decrease – because there is now a lessening amount of air above it – and its temperature will likewise decrease because the change of temperature will be very nearly adiabatic. The amount by which it cools as its height increases is called the *adiabatic lapse rate*. If air is dry – that is, without cloud – the rate is 3°C per 1000 ft. If, however, the air is saturated as it is in cloud, the adiabatic lapse rate is lower, only 1·5°C per 1000 ft. This is because heat is given out by the processes of condensation, and it is known as the *saturated adiabatic lapse rate* (Fig. 1.3).

Many of the world's airfields are situated several thousand feet above sea level. The lower pressure at altitude adversely affects take off performance – due to the reduced engine power available combined with the need to reach a higher *true* airspeed to get off. If the air is very hot this will make matters worse as it is equivalent to increasing the effective altitude. (*See* Appendix 4, 'Density Altitude'.)

Heat

The heat of the sun, which is not reflected back into space by cloud or dust, or radiated away, reaches the earth and warms it. This warming will be uneven because different types of surface absorb heat at varying rates, and because of the periodic effect of night and day, and the seasonal inclination of the earth to the sun. In turn the warmed surface will warm the air in contact with it, also of course unevenly.

Wind

Wind is simply air moving from where the pressure is higher to where it is lower, just as air in a blown-up balloon wants to escape until the pressure inside equals that outside. Because temperature and pressure changes are related, it should not be forgotten that the cause of a wind may not be only a simple pressure change, but could also be due to air moving from a cooler to a warmer place. Within a large area of substantially uniform pressure, with consequently little incentive for air to move on a big scale, there will be winds created by local temperature differences, as between cool sea and warm land. There will, of course, be some small pressure difference between the two, but not enough to effectively modify the big pressure pattern. This is one reason why the wind often drops in the evening and at night – winds produced as a result of heating during the day cease, and the overall pressure change, or gradient, is insufficient to cause the air to move with any force. Lack of heating is also the reason that a fine winter day is often less windy than an equivalent fine summer day.

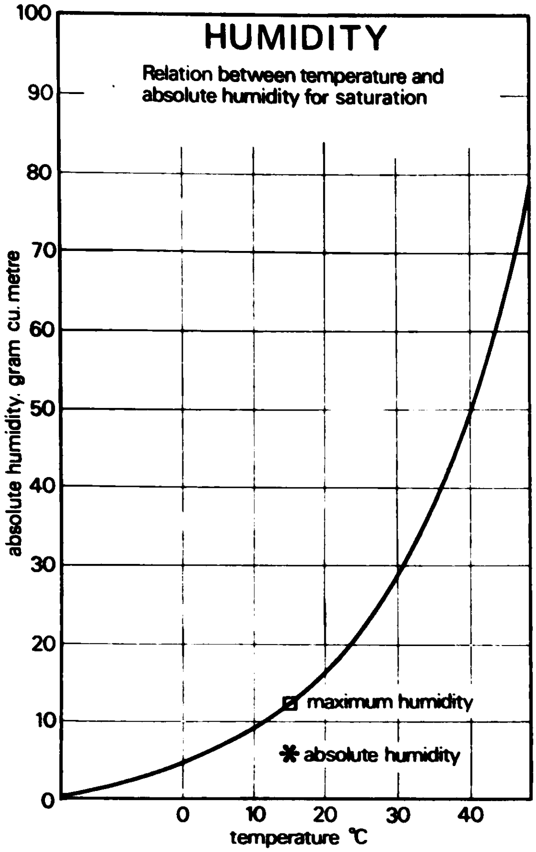
Winds do not blow *directly* from higher pressure to lower because they are deflected by the rotation of the earth. When blowing away from the fast-spinning equator they 'get ahead of themselves' as the speed of rotation slows towards the Poles. This curves the wind progressively – to the right in the Northern Hemisphere and to the left in the Southern.

Humidity

Air is never dry except in a laboratory. The atmosphere carries as invisible water vapour a fantastic quantity of moisture – a single thunderstorm alone can deposit some 10,000 tons of it in 5–10 minutes. As we saw in our two Rules, the amount of moisture that the air can carry depends on the temperature; *the warmer the air, the more moisture it can carry, and the cooler the air, the less.* So when air cools there comes a time when it is saturated and can no longer support all the water vapour that it holds. Any further cooling will result in some of the moisture condensing on to tiny nuclei in the air as droplets of water which remain suspended as cloud. They are minute, but in certain circumstances they will be able to grow bigger, and then will fall as rain.

The process of condensation liberates heat into the air; known as the *latent heat of condensation.* If sufficient moisture is present, condensation will continue taking place in the rising air, and cloud will go on forming.

When saturated air, or cloud, subsides or moves into warmer regions, so that the cloud droplets evaporate, work is needed to make this change. The energy required is taken out in the form of heat, and the temperature of the air is consequently lowered. The loss of heat due to evaporation is most apparent when we have to stand about in wet clothes, particularly if a wind is increasing the rate of evaporation. Humidity is the term for the dampness of the air. The amount of moisture that the air contains at any given moment is called the *absolute* humidity – or just the humidity, whereas the amount that it holds in relation to the maximum that



1.4 ***Example.*** If at 15°C a cubic metre of air actually holds 6.5 grammes of water vapour the ***absolute humidity*** is 6.5 g/cu m (point *). As air at 15°C could carry 13 g/cu m (point □) the ***relative humidity*** of the sample is 50%.

it could contain for that temperature is called the *relative* humidity. For example, if a cubic metre of air at 15°C and 1013·2 mb pressure held 6·5 grammes of water vapour the absolute humidity would be 6·5 g/cu m. But at this pressure and temperature a cubic metre of air is able to hold 13 grammes of invisible water vapour, so if it actually holds only 6·5 grammes, the relative humidity is 50% (Fig. 1.4).

Dew point

If air is gradually cooled down, the time will come when it becomes saturated and some of the water vapour starts to condense; the temperature at which this occurs is known as the *dew point*.

A beautiful day . . .

The trip was to take 1 hour 10 minutes. I checked the weather Friday evening and was told a front moving in from the SW would be no problem. Saturday morning it was the same story. The weather people said it was all okay for the trip; so we were in the air by 0700, expecting

—continued

to be at our destination in slightly more than an hour. As we climbed out, heading south, I commented on what a beautiful day it was.

But 20 minutes south of Atlanta we ran into rain, light turbulence and low visibility. I called weather; the report was the same as before. They saw no reason for me to turn back and were optimistic. We continued, but within another 10 minutes conditions had deteriorated to the point that I elected to return. Atlanta, which an hour earlier had been covered only by a low, very thin, broken layer, was now socked in. I couldn't find a hole through which I could let down. I heard on the radio of 1000-ft ceilings, snow, and freezing rain – no place for a VFR pilot like myself. Atlanta radar, because of the weather, could not pick me up and advised my landing somewhere else.

The Mooney still had plenty of gas so we turned NE, thinking to outrun the edges of the front, and be on the ground in less than half an hour. But I was almost in serious trouble. A thousand feet below was the top of the cloud cover. Several thousand feet above was another cloud cover, and between the two, in the leading edge of the front, were scattered patches leading me to think they might meet soon, with me sandwiched between. I had no reference to the ground and could see nothing but the white glare of clouds. I kept a close eye on the altimeter and hoped the cloud deck below was not slanted.

In about 15 minutes we had left behind the white-out and were flying at 7500 ft in clear air atop an overcast stretching to the horizon. The Great Smokey Mountains could be seen over 100 miles away. I was on the radio almost constantly now, checking the weather and hearing the same story, ice, low overcast, snow. Where had it all come from? I proceeded on into South Carolina, but had now flown off my chart. Greer Radio told me the entire south-east was socked in. Then he came back to say I might be able to get into Bristol, up on the Virginia border. By now I had been in the air over 2 hours. I turned back to the NW on a course that would take me directly across the ominous 8000 ft-plus peaks of the Smokies. Greer Radio was now calling every few minutes. I knew the one thing that would mean the end of the ball game would be for me to lose my cool. I made a conscious effort to remain calm so my non-pilot friend would not be alarmed. But I need have had no worry. He was looking at the mountains, wondering aloud at their beauty and occasionally asking, 'What happens when we run out of gas?' or 'Is your insurance paid up?'.

As we crossed the mountains it was apparent that they had acted as a barrier in holding back the low ceilings accompanying the front. The valley beyond – where we were to land – was clear. But already clouds were beginning to wisp through the passes and wind down the north side of the ridges.

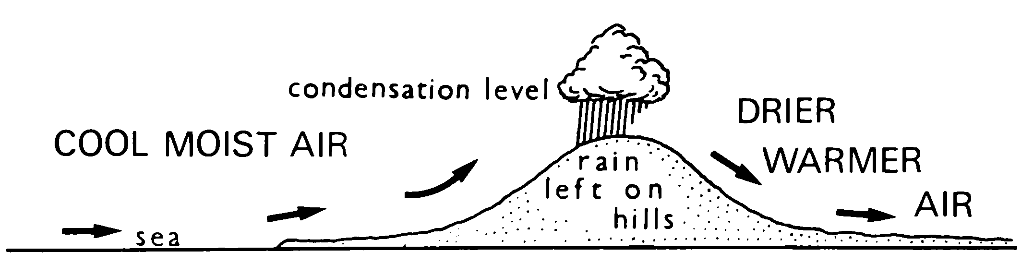
—Extract from account by Robert Coram. *AOPA Pilot*

The effect of land and sea

When trying to work out what the continually changing temperature, pressure, and humidity is doing to the weather, the source of the air and the sort of surface over which it has subsequently moved has to be taken into account. Oceans, land masses, and mountain ranges all modify the characteristics of air that flows over them – the Himalayas, after all, stick up through most of the atmosphere.

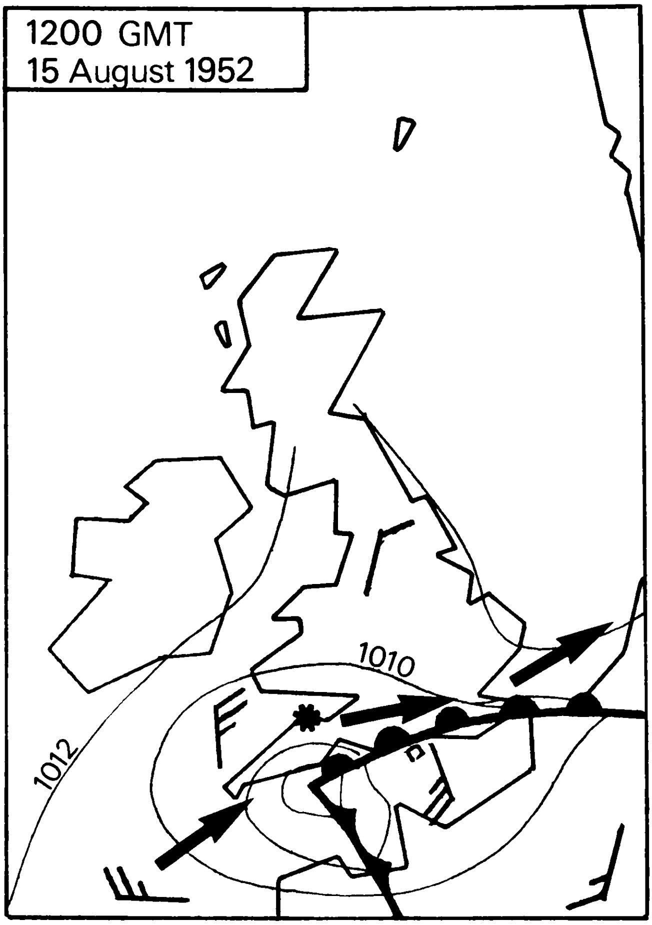
Air is affected by the type of surface over which it travels, the time that it spends over that surface, and the amount of heating or cooling that is imparted to it.

If air moves over the sea for any length of time it will pick up moisture; if the sea is cold it may cool the air sufficiently to cause cloud or fog. When air arrives over land after a long sea crossing it will be moist, so if it is forced to rise up over high ground it will expand and cool. The extent of this cooling will determine how much cloud will be produced over the hills. So if we are flying towards high land in bad weather we should expect more and lower cloud. If the hills are high enough the air will be substantially cooled as it passes over them, and rain as well as cloud will result. The rain will be left on the mountain, so that the air moving on beyond the high ground will be drier. When cool air moves over a large warm land mass it will become heated and its *relative* humidity will decrease, although unless rain falls its *absolute* humidity will stay the same (Fig. 1.5).



1.5

To anyone with an orderly mind the involved behaviour of the air must seem chaotic, with little prospect of ever discovering what state it will achieve next. Fortunately, the physical laws which govern the activities of air are exact, and exacting; so in any given set of circumstances, the air *will* behave in a certain way. This is why we are able to recognise and give names to weather patterns and systems, and forecast what they will bring.



1.6

The Lynmouth disaster

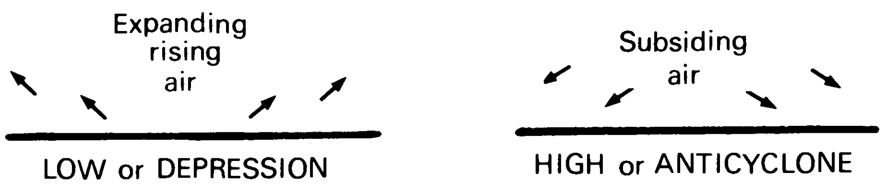
Looking at this weather map the pilot in a hurry would be excused if he thought that the bad weather would be just along the south coast and up from Cherbourg. But the most disastrous rain and floods occurred in North Devon, marked with a star. The Lynmouth floods of 1952 were caused by a small depression to the SW of England bringing unstable thundery air up from France. This air drifted up across the Channel, across southern England, swinging round to become a northerly wind blowing towards the N coast of Devon. There had been a lot of rain in the area over preceding days and on 15 August, but the critical fall occurred during the late afternoon, continuing until midnight. The situation at this time was not dissimilar to the Welsh floods (page 71) in that the rain-filled and unstable wet air was accelerated towards the coast during the afternoon as a result of thunderstorm convection lifting air massively over the land. At Lynmouth the land it hit was even higher, up to 1500 ft above sea level within four miles, giving a powerful orographic effect. The rain continued for 12 hours, 7 inches falling between 1700 hrs and midnight. The disaster was not caused directly by this rain, but resulted from its effect on the already boggy and saturated moors. The underlying rock of Exmoor prevents water soaking away so when the really heavy rain of August 15 arrived there was nowhere it could go but down the face of the hills; something like half a million tons of water per square mile did just this.

2 Outlining weather systems

The effect of the interplay of temperature, pressure, and humidity gives us all the weather we have, from the small and local patch of sea fog lying across our destination airfield for just a few hours to weather in the grand manner which may afflict us for weeks. In some parts of the world, such as the subtropics, where variations in temperature are neither particularly great nor sudden the weather is both stable and predictable. But where large masses of air of widely different temperature continually come in contact the weather that results will be both unstable and difficult to time. Needless to say, the British Isles and the Atlantic lie in such a zone, and the situation is further complicated by Britain being a rocky island at a 'cold' latitude lying in a relatively warm sea.

When such huge masses of air of different temperature come together they create the big pressure system well-known as the *Depression*, or *Low*. It has these names because the pressure within the system is lower than average, and it produces characteristic and sometimes formidable weather. The greater the temperature difference between the two air masses the more vigorous the depression will be, and the smaller the difference, the milder or weaker the depression that will develop. An agglomeration of air of higher pressure, and more uniform temperature, is known as an *Anticyclone* or *High*, and it gives more settled weather.

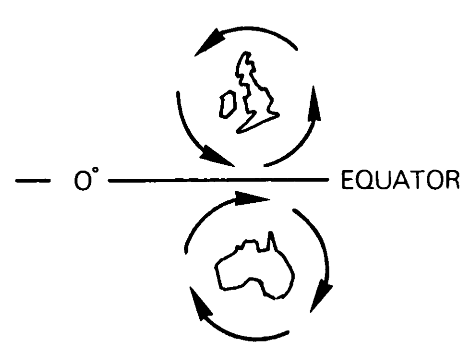
Before investigating the habits of Lows and Highs there is a semantic confusion which should be cleared up in order to make it easier to visualise what is actually taking place within these all-pervading and impressive air mass systems. To a pilot, thinking in three dimensions, the words Low and depression have a 'downward' sense, and High, even if not anticyclone, has an 'upward' meaning. As a result it may be difficult to visualise *a Low or depression as a region in which air is substantially ascending – that is why it has so much cloud; and a High as a region in which air is substantially subsiding,* which is why it develops relatively insignificant cloud or none at all. Lows and Highs were named at a time when low pressure and the storms to which it gave birth were of concern primarily to the seaman, and high pressure more often than not gave blessed relief. The barometer would fall as the Low approached, and rise as a High developed. But in flying we are concerned not only with the weather that is approaching, but with what the air is doing underneath us, and at high levels. Because it produces cloud we are just as concerned with the vertical movement of air as with the horizontal; when pressure is falling, it is doing so because air is expanding and going up. On its way up condensation takes place when the air cools sufficiently, and cloud, and perhaps rain, are produced. We can even draw a simplified diagram to get the picture quite clear in our minds (Fig. 2.1).



2.1

The depression

A depression may develop anywhere, but the ones that we know and regard as typical in Europe, are most prolific between latitudes 50°–60° (in both hemispheres) (Fig. 1.1). This is the natural meeting place of the masses of cool air moving away from the polar regions, and those of warm air that have risen above the tropics and are moving towards the poles. On meeting, the warm air will stay above, or flow up over, the cold; in doing so it will expand, lower in pressure, be cooled, and produce vast quantities of cloud. The denser polar air stays underneath, moving in towards the area of lessening pressure created by the warm air upflow, and initiating the characteristic circular motion around the system. Because of the W–E rotation of the earth, in the Northern Hemisphere the direction of flow around a Low is anticlockwise; in the Southern Hemisphere it is clockwise (Fig. 2.2).



2.2

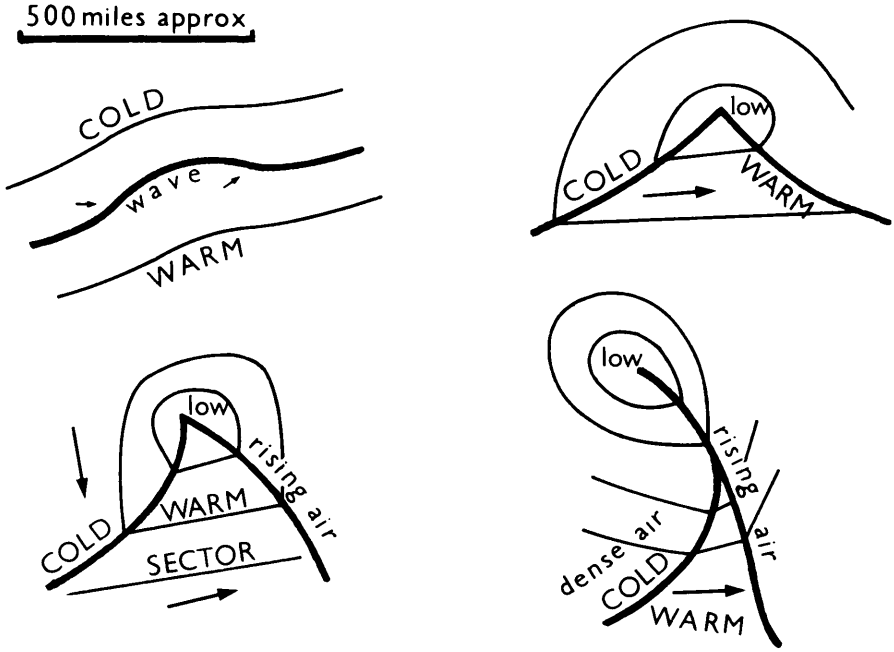
A depression may be deep or shallow. It is deep if there is a steep pressure fall towards the centre – indicating that there is rapid expansion and rising of the air. This will produce strong winds, and a lot of cloud and rain. A shallow depression has a more gradual pressure fall, or gradient, towards the centre because the ascending movement is only gentle. There will be plenty of cloud, but less strong winds, and maybe not so much rain. When the pressure in the Low ceases to fall, the system will start to 'fill', weaken, and die away.

A very large depression may be as much as 2000 miles across, and a small one as little as 50 miles, but both can be equally fierce. Depressions may form one after another and follow a similar track, so that the weather remains unsettled for a week or more. Sometimes, in Britain the rain goes through on succeeding nights and the days are relatively clear, but too often the opposite seems to happen; it rains and blows all day, and the nights are starlit and calm. Typhoons and hurricanes are small extra-ferocious depressions with an unusually large pressure fall at the centre (page 232).

Fronts

Where the ex-tropical air and the ex-polar air come into contact there must obviously be a discontinuity of temperature and pressure over a large interface area. The actual temperature difference will depend on a lot of things, including how long the two lots of air have been on their journey, and whether it is summer or winter. Where the warm air is expanding, floating up, and producing cloud over the cooler air ahead of it, the discontinuity is known as the *warm front*. The *cold front* is where cold higher pressure air is advancing under warmer air, and creating cloud mainly by pushing it up. The fronts are drawn on weather maps as lines, but these show only where the change in temperature and pressure between the two lots of air lies at ground level. Above the ground frontal cloud and weather covers a much greater area, with maybe 100 miles or more of poor flying conditions ahead of the warm front. This region is mostly filled with superimposed layers of cloud, usually thick, and often running one into the other (Fig. 2.3).

Although the complete depression is moving along, the fronts do not necessarily move at the same speed as the whole system. The higher pressure cold front usually travels faster than the warm front



2.3

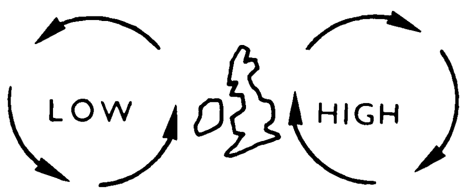
because it is being pulled towards the low pressure ahead. Gradually the cold front catches up with the warm, starting to do so where the two fronts are closest together at the centre. The overlapping fronts are said to be *occluding*. Eventually the *occlusion* may extend most of the way along the front line.

2.4 The occlusion weather will be of cold frontal or warm frontal type depending on the relative temperatures of the two lots of cold air.

The anticyclone

An anticyclone is a stable, slow moving, often vast, mass of air whose pressure is higher than 'average'. Unlike the Low, which is born in areas of the world where there is considerable variation in temperature, and humidity, such as the North Atlantic, the anticyclone will generally develop where there are more uniform conditions. The air in a High is relatively homogeneous, without fronts, and is generally, and gently, subsiding. Air sinks into it from above, and leaves as a divergent flow nearer the surface. Although the rate of subsidence is very gradual, it is enough to have a strong stabilising influence on the air through its compressive and warming effect.

The air circulates around an anticyclone in the opposite direction to a Low (Fig. 2.5). In the Northern Hemisphere the circulation is clockwise, and in the Southern Hemisphere, anticlockwise.



2.5

The areas of the world where anticyclones are most common are over the Poles and in the Horse Latitudes, or sub-tropics. The cold area anticyclones, including those over Siberia in winter, develop because cold dense air sinks and in the lower levels there are huge quantities of it doing so. The high-pressure belts of the sub-tropics exist as a result of the massive uplifting of tropical air over the equatorial regions. It is replenished by air on either side of these regions subsiding and moving in towards the equator. These belts of high pressure, which are around latitude 30° in both hemispheres, produce large and long-lasting anticyclones, including of course, the well-known Azores High.

Anticyclonic conditions will also develop more locally as a pressure balance mechanism, usually between two adjacent depressions. Such a small region of marked pressure rise is called a *ridge* (page 37). An anticyclone will start to decline when air ceases to sink into it at high levels. The central pressure drops and the whole circulation weakens. Decline also may occur if the system drifts over a quite different surface, such as from cold land to relatively warm sea.

The big picture

Because we constantly hear about depressions and anticyclones in forecasts, it is easy to get the idea that the weather is made up entirely of these two systems. The depression, in particular, features largely in our European lives because we are at the receiving end of one of the most active spawning grounds of the Low in the world – the North Atlantic. But since we may fly elsewhere and find quite a different situation, and since Europe does have other weather as well, we should always keep an open mind and consider whatever we find from first principles. That is, that *the atmosphere is a thin layer of damp and dirty air in a state of continuous movement, and that any change in temperature will alter the pressure, which in turn will alter the cloudiness.*

We need to remember that even more than our own cash accounts, the big pressure picture has to balance. There are times when pressure may be fairly uniform from Newfoundland to Kiev, but if deeper and deeper depressions start growing in the Atlantic, pressure will begin to get higher elsewhere. We should look out for it.

In the next chapters we will return to the big pressure systems to see how they appear on weather maps, and what they look like in the air. *But whatever weather situation is presented to us, our concern is primarily to consider how it* is *changing, and how it* will *change. If we ever leave a met office without having done our best to get answers to these questions, then we have not got a forecast.*

The Tynemouth balloon race

The flow around an anticyclone is well illustrated by the garden fête balloon race of the Tynemouth Priory Round Table on 16 May 1964. Nine-inch balloons filled with hydrogen were used with name and address labels hopefully attached. The race looked like being a failure when the balloons drifted in a monotonous stream straight out into the North Sea, borne on a light SW flow in a mainly cloudy airstream. But to everyone's surprise, that evening at 2045 hrs a balloon was found in Germany 400 miles away, having averaged a speed of 40 knots. By the next day there had been a succession of landings right down into Italy. It is even possible that some foundered in the Mediterranean.

The weather map (A) showing the surface plot for the day of the race is marked with some known landing places, but it does not give the whole answer. The clue is discovered in the upper air chart (B), which indicates a strong northerly flow, although it presupposes that the tiny balloons rose to 30,000 ft or more, into a temperature of −40°C without bursting. Some similar balloons were quickly tested. They took about 2 hours to rise into the strong upper flow where the wind blew at 60–70 knots; they then burst, but took several hours to descend, all the time drifting on across Europe.

On this occasion the upper winds were strong, and over the Alps and Mediterranean quite different in direction to the low level winds. A flight across the Alps from S to N, for example, would have started and ended with light easterly winds, but a strong head wind would have been encountered at the height needed to cross the mountains with safe clearance.

—*continued*

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Ann Welch has held a private pilot's licence since 1934 and during the war ferried aeroplanes without radio in all weathers. She started gliding in 1937, founding Surrey Gliding Club and becoming an instructor in the following year. She was Manager of the British Team at the World Gliding Championships between 1948 and 1968. This took her to Switzerland, Sweden, Spain, France, Poland, Germany, Argentina, USA, and Yugoslavia. In 1965 she was World Championship Director. In 1961 she gained the British National Women's Goal Record of 325 miles.

As well as her life as a gliding instructor, writer, lecturer, sailor, and grandmother, she is the Vice President of the Gliding Commission of the Federation Aeronautique Internationale.

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Ann Welch *photo - Christian Gad*

Clouds over the Isle of Man